Hindawi
International Journal of Photoenergy
Volume 2022, Article ID 7065940, 9 pages
https://doi.org/10.1155/2022/7065940

Research Article

Experimental Analysis of the Thermal Performance of a Latent Heat Energy of Helical Coil for the Application of Solar Energy

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Received 13 December 2021; Revised 26 December 2021; Accepted 27 December 2021; Published 25 January 2022

Academic Editor: V. Mohanavel

The latent thermal power storage system has more characteristics than the sensitive storage system. The heating system is a process of releasing and absorbing heat energy using phase transfer material (PCM) and it provides more efficient energy than sensible heat storage. This also consist of high energy storage and high density. It provides high heat transfer in low volume and thereby enhances heat transfer. This enhances the capacity and efficiency of the EFU while extending the service life. The coil tube is designed for latent thermal energy storage to implement and enhance thermal performance during the loading and unloading process. The offloading time, however, was not affected by the flows. Higher throughput has also been shown to improve the effectiveness of recovery. The direction of flow of the HTF did not affect the total time of loading and recharging but affected the temperature changes of the PCM in the energy storage element. It is intended to predict the ability to store maximum energy as higher energy efficiency during the phase shift process. Parameters such as the mean temperature of the PCM, the growth of the melting front, the energy efficiency, and the number of generations of entropy are studied.

1. Introduction

Renewable energies, such as wind and solar, are plentiful, but intermittent, and there is often a mismatch between market forces. It is critical to building effective energy loading devices that can store electricity harvested during periods of the highest production and afford it during times of high mandate to fully practice this renewable energy. In the domestic sector, conventional solar thermal water heaters are used; in addition, they have lower capacity and efficiency, particularly during periods of low sunlight. The use of phase switching materials (PCM) to conserve thermal energy is an option [1]. Because of the high energy density of PCM, thermal heat storage solutions using PCM have proven more productive than thermal energy storage methods. For various renewable energies, thermal systems, and energy efficiency of buildings, phase change-based storage solutions (PCM) with acceptable storage behavior and temperature gradient are attractive solutions. These heat transfer, storage (LHS) devices can meet constant thermal energy demand, eliminating problems caused by changes in power generation. The success of LHS systems is influenced by the heat capacity of PCMs and the heat transport suitable interventions in storage technologies. The thermal efficiency of most LHS technologies is degraded by the huge, microscopic heated surface and low thermal expansion of PCM [2].

When the heated coolant (HTF), such as everything from a solar panel, passes through the PCM tank, it adds heat to the energy storage unit. In latent thermal exchangers, water is usually used as HTF. Recent research has suggested the use of liquid nanomaterials, which have superior thermal conductivity and a higher heat transfer rate than the basic liquid [3]. In their solid shape, liquid metals are good melting temperatures and are extremely tough. Due to its high melting and boiling points, inorganic MCPs are often used in high concentration applications. Previous research has demonstrated that inorganic MCCs have significant disadvantages, such as undercooling and degradation of containment materials. Because of its availability, high heat source of fusion, chemical resistance, and tolerance with a broad variety of materials with no degradation in the enclosure medium, wax is a good choice [4]. Despite this, paraffin has high thermal conductivity, resulting in slow heat transmission and extended charging or discharging durations. Different heat transfer augmentation approaches have been used to overcome this problem.

As a result, the solution has poor melt and crystallization, as well as considerable temperature differences. As a result, before commencement, the creation of effective storage systems as well as rigorous heat study is critical. Building heat pumps, solar thermal technologies, absorbing coolers, electronic element heat dissipation, battery heat dissipation, and photovoltaic thermal systems has all successfully used PCM-based energy storage devices [5]. Furthermore, the helical coil significantly improved heat transmission performance and reduced the overall freezing time of the storage system, according to the findings. The temp according to the findings, the helical coil considerably increased thermal transfer efficiency and decreased the overall melting time of the storage solution. Numerically and experimentally, the temperature distribution and thermal characteristics of paraffin in an indistinguishable and nonequidistant helical-coil storage facility were examined. Creature supply and thermal properties of paraffin in an indistinguishable and nonequidistant helical-coil storage facility were evaluated numerically and experimentally. The simulation demonstrated consistent temperature, and the nonequidistant alpha helix device outperformed the equal one in terms of results.

Because no type of substance can meet the requirements for all of the key qualities, no solitary PCM could be used for all applications. Consequently, selecting an ECHP for a given purpose requires careful consideration. Since it produces high heat, is noncorrosive, chemically stable, and nontoxic, beeswax was investigated as a PCM. Despite this, the thermal resistance of wax remains the major obstacle to its application as a PCM in latent thermal energy storage (LHTS) [6]. As a result, several recent studies have focused on optimizing the heat exchange process in the PCM by employing various approaches. The addition of fines to the pipe shell and storage to improve thermal efficiency and the addition of microphones to the PCM to improve thermal conductance are examples of these strategies. According to the literature, a traditional SAH is observed as a poor potential heater in practice due to significant heat losses and low heat storage capabilities. As a result, numerous modifications have been introduced to advance the quality and construction of solar thermal systems. Two strategies have been discovered to be far superior to others, including the use of rough surfaces, surface or stretched geometries, and the employment of a high-quality thermal power storage (TES) substance.

Various LHTES designs and expansion techniques, such as adding blades and nanomaterials. It was suggested that metallic foam be added to the primary material (MCF) to improve the efficiency of the LHTES. Due to the comparatively high thermal performance, which may be exploited as an annulus around two concentric circular tubes, dual-energy packing has effectively acquired high thermal efficiency among the various LHTES unit designs [7]. Furthermore, the power storage needs can be easily met by building and possibly installing a single unit or perhaps an array. Helical tubing is a design that can be used in the LHTS to improve thermal efficiency while loading and unloading. This project has several advantages over traditional designs, including ease of design and implementation, a high heat transfer surface in a slight capacity, and increased fluid mix across the tube due to secondary vortices created by the helical flow, which improves thermal performance [8].

During the melting process, the thermal performance of the innovative conical-shaped helical coiled LHSU design is studied and compared to that of a spherical coil with almost the same heat transfer under the same operating temperatures.

2. Related Works

To investigate the feasibility of storing solar energy in thermal energy storage (TES) tank employing different heat transfer fluids (HTF), the TES container is combined with a flat plate solar absorber and is meant to provide hot water for an average of four family people in India: a method on the performance of latent heat and solar thermal energy storage system [9]. The TES tank serves as a heat storage unit, with phase change materials (PCM) encased in metal tubes and stacked in three beds, all surrounded by heat storage material (SHS), which is water. The TES tank is filled when solar power is produced by passing variables HTF through the flat-plate solar collection. The HTF uses a helical copper coil heating element in the TES tank to transmit heat from the solar concentrator to the TES tank. The heat is stored as a mix of thermal energy, heat in the water, and PCM in the TES tank. The performance metrics of several HTFs, including such recharge time and immediate heat stored, are investigated.

The method of performance evaluation approach based on the solar heat storage system using phase change material is proposed by [10]. In comparison to thermal storage, latent heat storage with exchanger provides an alternate strategy with higher energy storage density and reduced area demand

Table 1: Specification of LHTS units.

Equipment			Unit
Helical (coiled) LHTS unit	Shell	Building material	Acrylic
		Measurement	49.5 cm
		Inner thickness	17.6 cm
		Shell thickness	0.6 cm
		Lagging	Glass wool of 4 cm thickness
	Coil	Construction material	Copper
		Number of turns	46 cm
		Pipe diameter	12.6 cm
		Height	17
		Diameter	4 cm
		Pitch length	0.954 cm
		Pipe length	0.08 cm
		Pipe thickness	700 cm

and has seen widespread use in recent years. To determine whether a system design is practical, a measuring performance approach is required. With one example of conventional solar latent storage systems, the suggested method was used to analyze five design instances with various mass transit efficiency of heat transferring fluid and solar collecting regions. A three-dimensional numerical model was also created and verified by experiment to replicate the transient thermal decomposition inside the latent heat storage unit. The analysis was used to predict the temporal connection between both the storing unit's intake and outlet temperatures. The proposed technique is able for performance assessment of solar thermal energy storage systems and aid relevant professionals in optimizing the system design, according to the findings of five designed examples.

The research presented a thermal performance assessment of an integrated solar water heater. This incorporates the phase change material-carrying helical tubes [11]. The goal of this study was to increase the performance of solar water heaters. There is a template SAH-A as well as a revised model SAH-B with wax as a reduced power backup system. The model SAH-B can also be transformed into a version SAH-C, and it has a unique wax and a particulate charcoal dioxide mixture. The use of a copper helical tube as a heat storage container for the abovementioned active materials has been investigated. According to the key factors of the present employment, the model SAH-C is an economical and excellent architecture for house heating, hardwood conditioning, drying activities, and other processes. The total cost of the greatest SAH-C model is only 68 dollars.

The usage of double-tube helical tubes as a single-performing phase change (PCM) material for low-temperature thermal energy storage (LHTES) systems is proposed in this work. The study effectively verified a three-dimensional mathematical method that tackles convective dynamics during PCM melting. The frozen trend of PCM in longitudinal and lateral linear double-pipe LHTES apparatus of the same surface area will be analyzed and compared with a new similar LHTES equipment to analyze the unique LHTES design. After that, the double-pipe spherical vault's thermal efficiency was put to the test in a variety of settings. The usage of a double piping helical coil tube energy storage device is offered as a method for improving PCM dissolving in energy storage systems [12]. With the double helical-coiled tube, the optimal coil pitch for PCM melting is 2 OD. According to the study, the ignition temperature and the radiation parameter (Re) of the heat transmission medium have a significant impact on the PCM crystallization process. The ideal coil pitch for PCM melting in a double-pipe helical-coiled tube is 2 OD. According to the findings, the combustion temperature and the heat transmission medium's radiation parameter have a substantial impact on the PCM crystallization process.

The method for the design and experimental analysis of a helical coil phase in which the phase change hears the exchange for thermal energy storage is expressed in the proposed system of [13]. Heat transfer power supply replaces traditional perceptual power storage technologies. At a practically precise temperature, a phase change material (PCM) with a high heat of fusion can collect and release a significant amount of thermal energy. This increases the energy-storage device's efficiency and scalability while also extending its service life. This study designs, fabricates, and tests a prototype PCM exchanger with a helical coil tube for heat storage performance under various operating conditions. Even though the PCM is wax, the heat transmission is a mixture of propylene glycol (EG) and alcohol (HTF).

3. Materials and Methods

3.1. Apparatus and Materials. The experimental analysis is carried out by using custom-built coiled LHTS units. To a 16-turn coil, a 7 m copper piper was wounded in it and with a 12.5 cm centerline diameter. To an acrylic shell of a diameter of 17.6 cm, the coil is embedded. The side of the shell is filled with 12 kilograms of P56-58 wax. In the container, a 4 cm thick coating of wool beaker with a laminate surface was used to insulate the shells outside the surface. Table 1: illustrates the specification of LHTS units [14]. This depicts the challenges being faced that were created, and the

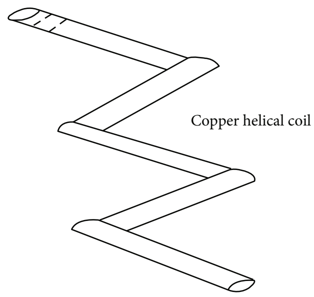

Figure 1: Copper helical coil.

following Figure 1 shows the copper helical coil. The heat transmission properties during the crystallization processes were evaluated using this setup. The LHTS was installed vertically, LHTS unit (coil and shell), 22 K-type heat temperature is linked to a information acquisition system and PC, and a 500 L electrical heating water tank, a compressor, ball joints, and an LZM calibrated flow meter (0.07 L/min uncertainties) were all included in the challenges being faced [15]. For both the crystallization procedures, tap water was utilized as the HTF, while P56-58 wax was employed as the PCM. The following Figure 1 represents the copper helical coil.

4. Experimental Setup Procedure

A TES tank with insulated spherical chaplets encased in PCM, a solar flat plate collector, a flow meter, and a rotating pump. The experimental set-up is seen via the lens of a camera. The carbon steel TES tank, which has a width of 455 meters and a thickness of 580 mm, has a volume of 95 L and can give hot water to a family of 58 people [2]. Glass wool, 50 millimeters thick, is used to protect the storage facility. The spherical container is composed of aluminum with a wall nominal thickness and a 45-millimeter internal diameter. Regarding the situation with porosity $\varepsilon = 0.49$, the overall number of carpets in the TES tank is 180. Three layers of spherical couplets are evenly packed, each held by wire mesh. When the PCM containers occupy 50% of the whole volume of the holding tank, with SHS substance occupying the remaining volume, the following Figure 2: thermal energy storage system shows the schematic diagram, and their specification is mentioned below.

4.1. Thermal Energy Storage Specification. The thermal energy storing tank was constructed based on the calculation and appropriate composition. From the copper tubes, the heat exchanger of the helical copper coil is constructed, and by using bull hose pipes, the solar collector is connected to the tank [8]. The TES tank was filled with glass wool and then covered with aluminum cladding after the leak performance test, and then the leak is arrested.

4.2. Selection of Phase Change Material. PCM Selection depends on the following parameters:

(i) Thermal assets

(ii) Physical assets

(iii) Kinetic assets

(iv) Chemical assets

Thermal assets are as follows:

(i) For a particular operation, a suitable melting point is selected

(ii) High latent melting heat per unit volume

(iii) To improve heat transfer, the thermal conductivity is high due to solid, and liquid phases are chosen

(iv) For additional sensible heat storage, higher specific heat is selected

Physical assets are as follows:

(i) Small container blocks with higher density were selected

(ii) During the phase transition, small volume is noted

(iii) To reduce the containment problems, low vapor pressure is used

Kinetic assets are as follows:

(i) During freezing no supercooling or little cooling

(ii) High nucleation and growth rates

(iii) Efficient heat transmission

Chemical assets are as follows:

(i) After a certain number of freeze/melt cycles, there is no degradation

4.3. Phase Change Material Selection. Based on the above characteristic, the wax is used as the PCM. Testing with a differential scanning calorimeter has confirmed the freezing point and thermal heat of reaction of the wax (DSC). This wax grade was chosen for the purpose, which is to supplying warm water for home use [16]. During the manufacturing of petroleum products, wax is extracted from crude oil. The oil extracted and refining level of such waxes is used to classify them. The wax offered is fully purified and includes less than 0.5 percent oil. Various characterization methods were designed to estimate the thermophysical parameters of the P56-58 wax utilized in the studies. The precision of the heat conductivity measurement was less than 5%.

The above Figure 3: DSC curve depicts the heat transfer of wax in the solid form at temperatures ranging from 25 to 45 degrees Celsius [17]. When the temperature is raised from 25-35 degrees Celsius, the heat transfer drops linearly. The curve result of the wax used in the studies may be seen here. The melting maximum temperature of the wax is between 48.3 and 62°C, with a melting energy of 114.5 kJ/kg.

By using a digital viscometer, the recommended thickness of the crude wax is measured. The liquid wax sample is then placed in a glass pipette that has been immersed in swirling boiling liquid to prevent overheating consistently

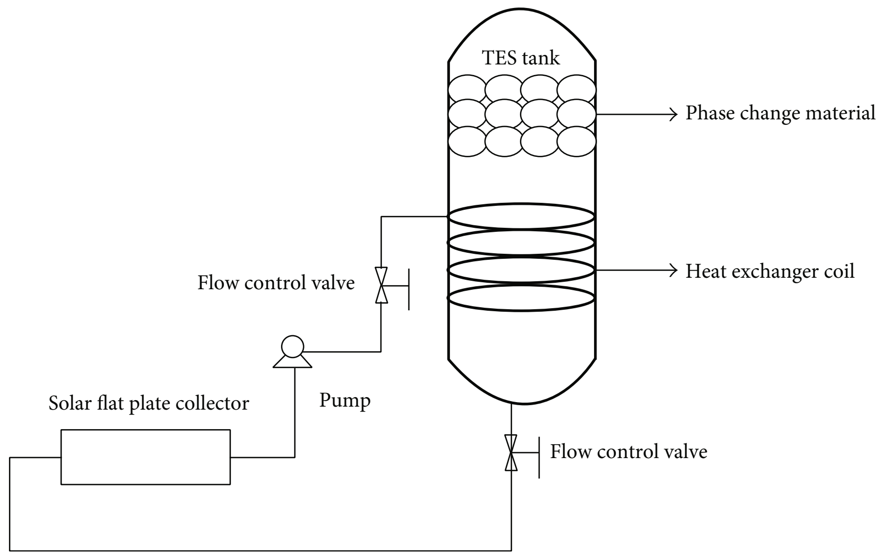

Figure 2: Thermal energy storage.

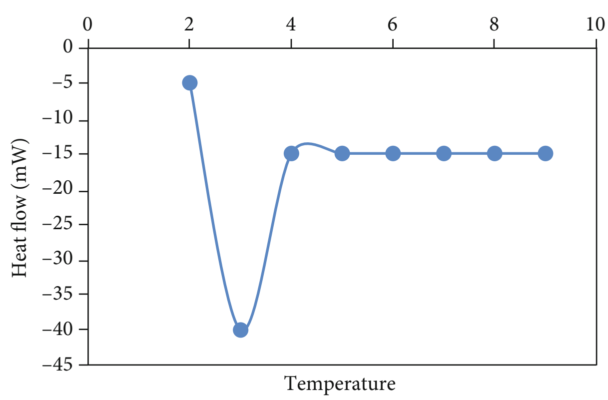

Figure 3: DSC curve.

throughout the investigation. The measurement was performed at a temperature of 53°C to 62°C at a speed of 100 revolutions per minute.

4.4. Experimental Procedure and Operating Conditions. The experimental procedure is used to investigate the temperature and flow rate of heat transfer fluid, and this affects the thermal behavior of the PCM; this is measured using the multiple heat transfer fluid. Each behavior is investigated using the phase change material and LHTS. To simulate the real-world operation of a household solar water heating system, where degrees can exceed 80°C, and to reduce water evaporation, three freezing temperatures were chosen: 65°C, 70°C, and 75°C. The crystallization method was performed out with tap water at 30°C. Multiple HTF flow rates were examined both for melting and solidification processes. For all of the testing runs, the PCM temperature was set to 30°C. Experiments were conducted in the setup depicted [18]. During the chilling phase, excess heat from the hot water was fed into the base of the Latent Heat thermal storage unit (i.e., charging). When all of the temperature measurements were above the high melting point of the phase

Table 2: Parameter of uncertainty.

Specification	Unit	Uncertainty (%)
Thermocouples	°C	±1.7
National Instrument cdaq-9175	°C	±0.080
Water volumetric flow rate	L/min	±0.26
Melting process effectiveness	*	±1.8
Solidification process effectiveness	*	±3.5

change material at the end of the recharge procedure, it was reasonable to conclude that solid PCM had already been totally changed to a liquid condition. The wax crystallization process was initiated by releasing the valves and allowing cool water to permeate the LHTS unit from the top. A digital camera was configured to detention a snapshot every single 10 minutes while the dielectric was modified to make concealing and revealing the coil LHTS unit easier during image collection. Every minute, the temperature and pressure of the crystallization operations were measured [19].

4.5. Uncertainty Analysis. In most cases, the precision of experimental results is determined by the measurement tools and techniques used. The following formula was used to analyze the uncertainty caused by several independent variables:

$$\sigma_M = \left[\left(\left(\frac{\partial M}{\partial A_1}\sigma_1\right)^2 + \left(\frac{\partial M}{\partial A_2}\sigma_2\right)^2 + \cdots \cdots \left(\frac{\partial M}{\partial A_n}\sigma_n\right)^2\right)\right]^{1/2}. \quad (1)$$

M stands for the dependent variables, which seem to be a purpose of a large number of independent variables () and is the uncertainty [20]. For this study, Eq. (1) was used to quantify the uncertainty in the efficacy of the solidification and melting process $(A_1, A_2, \cdots..A_n)$ as a purpose of time

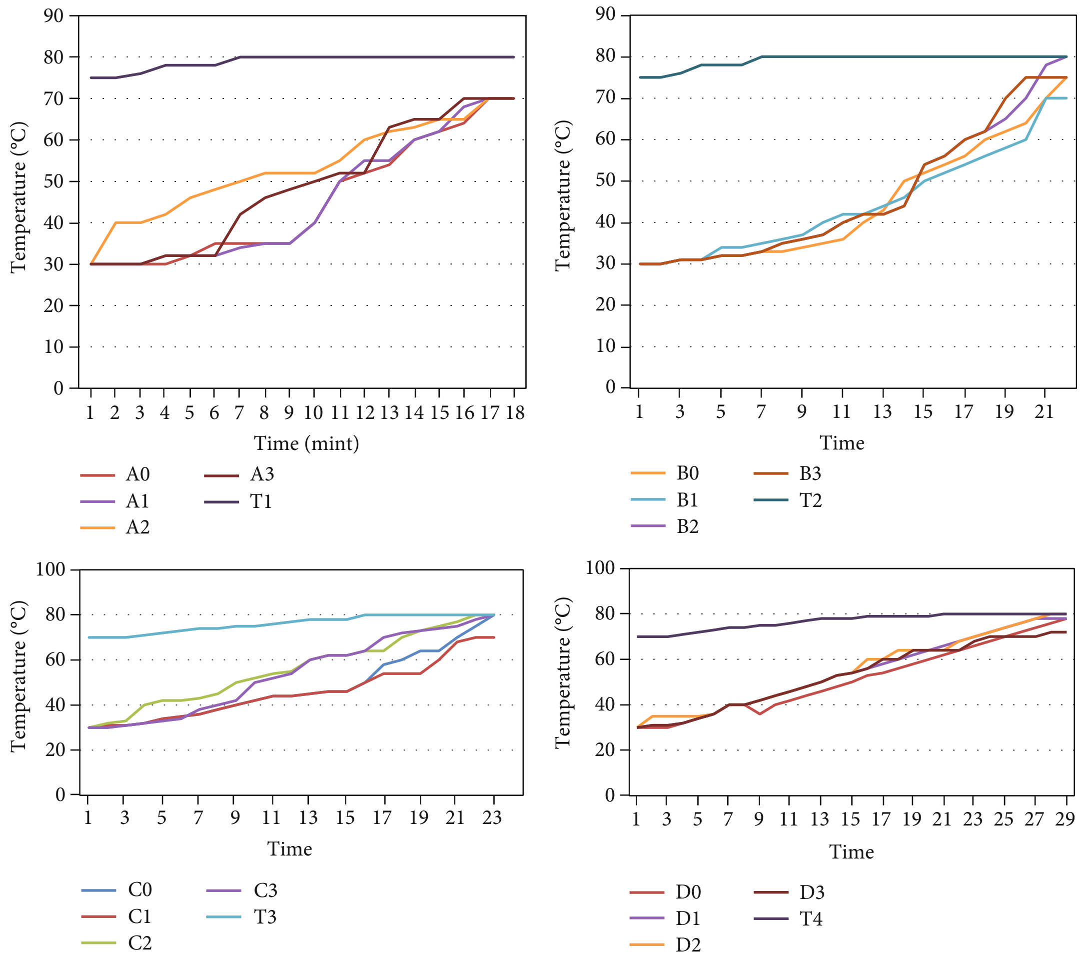

Figure 4: Phase change material temperature variation with time throughout melting time process based on different radial and axial locations along with the vertical latent heat thermal storage.

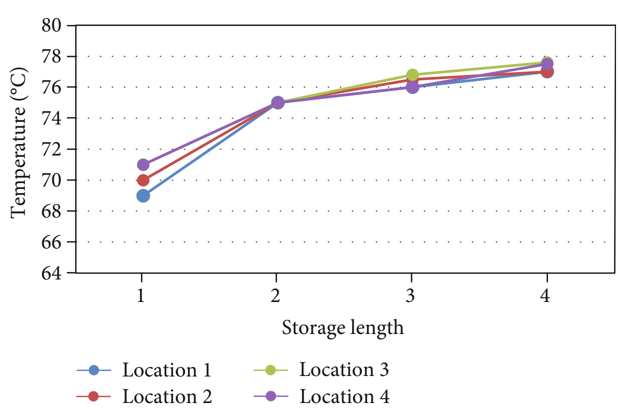

Figure 5: Local temperature.

and temperature (T), with the findings provided in Table 2: parameter of uncertainty.

$$\sigma_M = \left[\left(\left(\frac{\partial \varepsilon}{\partial T_{in}}\sigma_{Tin}\right)^2 + \left(\frac{\partial \varepsilon}{\partial T_{out}}\sigma_{out}\right)^2 + \cdots \cdots \left(\frac{\partial M}{\partial T_m}\sigma_{Tm}\right)^2\right)\right]^{1/2}, \quad (2)$$

where ε, T_{in}, T_{out}, and T_m denote the effectiveness, inlet temperature of heat transfer fluid and outlet temperature of heat transfer fluid, and finally the melting temperature of phase change material.

4.6. Melting Process. The temperatures of the PCM rise as the elevation of storing rises from the base to the tip, which is shown in the following seen graph. This has an outcome in organizations on the length of the localized crystallization process, shortening it [21]. In practice, the melted PCM rises from the bottom of the container under the force acting, generating a PCM liquid layer at the top. As a result, convection predominates at this layer compared to other regions of the store that are controlled by convection and conduction. As a result, near the top of the container, the PCM temperature rises noticeably with time, while the melting front consistently moves slowly lower, and the model provided the local PCM temperature. The time it took to complete PCM freezing at different rotational points along the storage varied between 185 minutes, 155 minutes, 125 minutes, and 90 minutes for positions L, M, N, and P correspondingly. The temperature of phase change material is visibly greater first from the centre outward, which is consistent with this

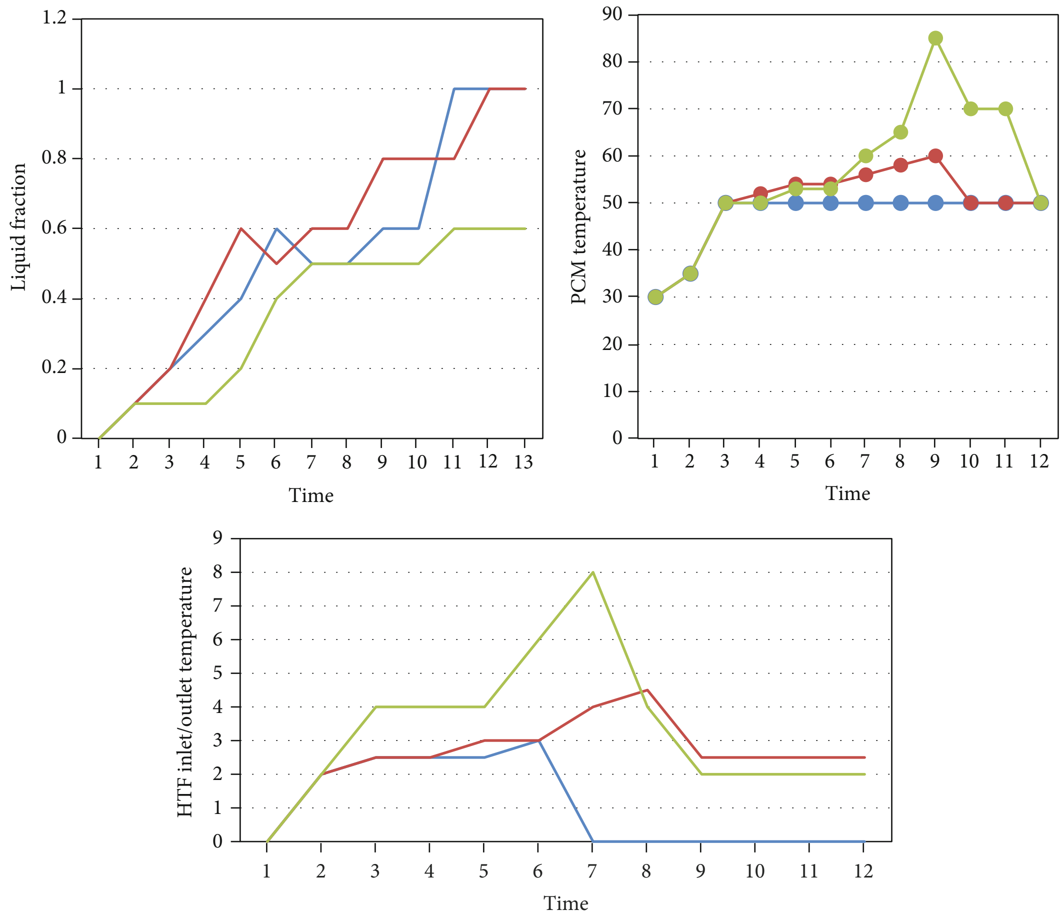

FIGURE 6: Mass flow rate evaluation of heat transfer fluid.

pattern [22]. The maximum PCM temperature was found near the helical surface (heat transmission surface) and the holding shell, resulting in the formation of radial dissolving fronts. Unexpectedly, when other places have fully melted, the observed temperatures of the PCM for the locations closest to the storing centre significantly increase. The high convection that accompanied the radial and axial two meltdown fronts may cause effect on the temperature. The coil turn at axial locations M, N, and P is closer to radial location 2 than site 3, resulting in inconsistencies in the observed PCM degrees at radial locations 2 and 3, as illustrated in subfigures M, N, and P.

4.7. Solidification Process. The feasibility of energy storage must be investigated during the charging and discharging periods. Using a steady HTF temperature (30) and various flow rates (1 L/min, 3 L/min, and 5 L/min), the discharging (solidification) phase is explored immediately after the conclusion of the blistering phase in this study. Throughout this section of the studies, the very same arrangement and several temperature sensors were used. Along with the storage, the temperatures of the PCM began to drop [21]. At the start of the solidifying process, the PCM temperatures along the radial and axial locations both dropped sharply and equally. As a result, the entire operation is governed by convective during this brief period. Following that, temperature variations become largely dependent on the thermocouple's radial position, indicating the creation of PCM solidifies. Along with the storage, the temperatures of the PCM began to drop [23]. At the start of the solidification process, the PCM temperature along the radial and axial locations both dropped sharply and equally. As a result, the entire operation is governed by convective during this brief period. Following that, temperature variations become largely dependent on the thermocouple's radial position, indicating the creation of PCM solidifies.

5. Result and Discussion

The experimental findings of the PCM crystallization process in a vertical helical type LHTS unit under various operating conditions are reported in this section. Figure 4: variation of temperature of PCM displays the value of PCM during the melting process at each radial distance (0, 1, 2, 3) and axial position (L, M, N, and P) all along the column at a consistent HTF rate of flow (3 L/min) and beginning temperature 80°C. Generally, the heating temperature of the PCM changes to increase throughout the melting process at all points along the storing elevation, with different behaviors according to the position. In all circumstances, the temperature goes up immediately at the start of the crystallization process and then gradually rises again until the

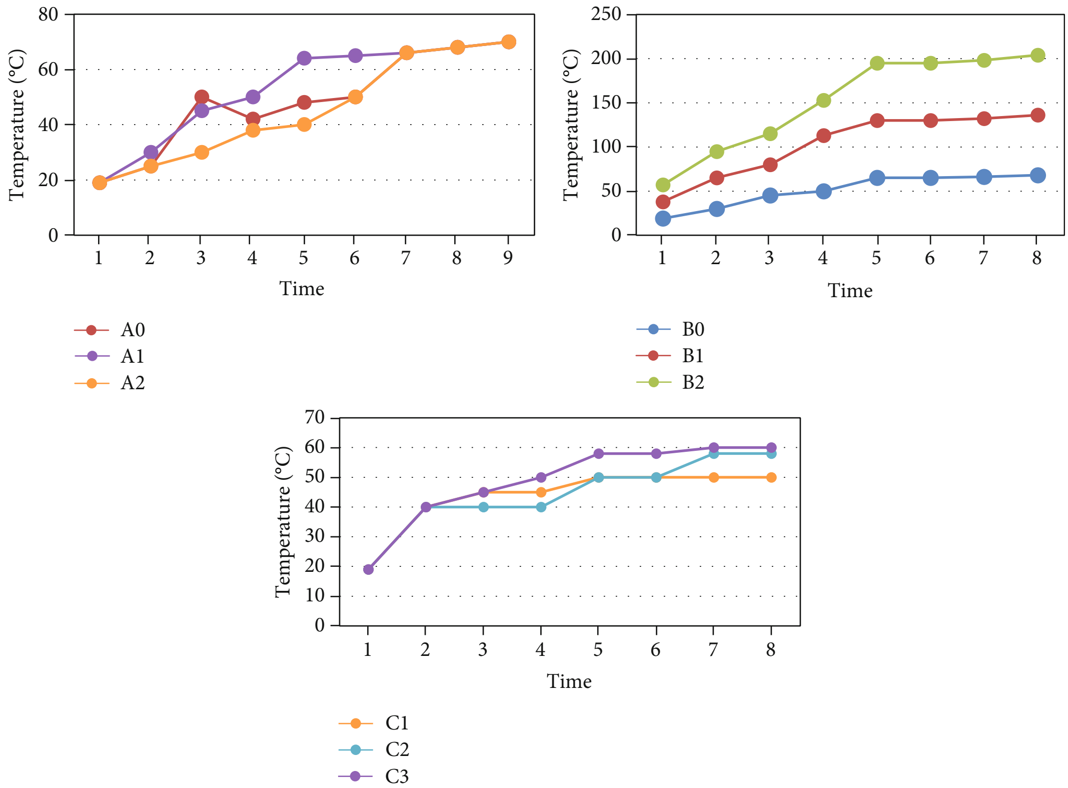

Figure 7: Temperature profile of helical coil latent heat storage.

phase is terminated. The degree of melting PCM, on the other hand, largely depends on the radius for a particular axial site. The greater the longitudinal position, the higher the temperature of PCM, according to consistent.

The following Figure 5: local temperature of PCM shows the temperature of a system of the PCM at the termination of the melting process about the storing elevation for just a temperature difference of 80°C and a rate of flow of 3 L/min. From the base of the container towards the high, it is evident that the heating of the PCM rises with elevation. This temperature rise, though, is large at the base and then increases slightly.

Moreover, the difference in temperature at different points all along storage elevation appears to be more pronounced at the bottom of the warehouse and afterward fades because as store length increased. The PCM local weather's action, on the other hand, is uniform throughout all radial sites.

5.1. Mass Flow Rate Evaluation of Heat Transfer Fluid. For each case, the entire charging process can be loosely broken down into four categories: For instance, in case 1 (mf = 0.028 kg/s), throughout the first stage (10 : 0012 : 00), when the cooling process did not take place and the PCM stored the power in the reasonable form, the liquid fraction remained zero, and the PCM heating rate increased rapidly from 30°C to 47.6°C, resulting in a low rate of heat transfer between both the HTF and PCM. The temperatures in the HTF intake rapidly climbed from 30°C to about 52.7°C (Figure 6: mass flow rate evaluation of heat transfer fluid). The temperature differential between the HTF input and output temperature grew from 0°C to 3.1°C when solar energy and ambient temperature were increased.

5.2. Comparison of Melting Behavior. Different calculated temperatures of the PCM during charging are monitored by a series of sensor thermocouples. Figure 7 shows only the outcomes found at a heat transfer fluid inlet temperature of 75°C for brevity. The charging period increased all of the temperature curves.

The curves' overall behavior entails a relatively straightforward rise in temperature at the beginning of the procedure. This observation indicates that the PCM was solid and heated by dispersion at the temperature needed to conduct, despite the PCM's weak heat capacity. The depending on the temperature fluctuations decreases as the freezing process begins once the temperature at that area approaches the PCM freezing maximum temperature of 48°C.

6. Conclusion

Experimentally, the thermal efficiency of helically coiled latent heat thermal energy storage was examined. The processes of melting and solidification were both explored. In both procedures, wax was used as a PCM, and tap water at various flow rates was employed, whereas three different HTF temperatures were used just in the melting phase. Only one HTF starting temperature is employed in the solidification process. The research defines the different processes involved in the solar energy application and their performance during the investigation process. To evaluate the melting behavior of conical and helical coil LHSUs, they were tested concurrently. In addition, the influence of HTF inlet temperature was investigated. Temperature curves, heat outlines, and photos acquired to track its melting front while recharging has been used to evaluate their thermal efficiency.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this article.

Acknowledgments

The authors would like to express their gratitude towards Saveetha School of Engineering, Saveetha Institute of Medical and Technical Sciences (formerly known as Saveetha University) for providing the necessary infrastructure to carry out this work successfully. The authors are thankful to the Researchers Supporting Project (RSP-2021/129), King Saud University, Riyadh, Saudi Arabia.

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