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Performance Evaluation of Paraffin Wax as Phase Change Material in a Horizontal Cylindrical Thermal Energy Storage Unit

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ABSTRACT

Fossil fuels like coal, oil, and natural gas currently dominate global energy production but release significant amounts of CO_2 and other greenhouse gases, contributing to global warming and climate change. To address these environmental concerns, alternative methods of energy production and storage must be explored. This study investigates the thermal performance of latent heat thermal energy storage (LHTES) using phase-change materials (PCMs) in a horizontal cylinder. The experimental setup consists of a copper tube, 650 mm in length, with an inner diameter of 25 mm and a thickness of 2 mm, enclosed by a 600 mm acrylic tube with a diameter of 45 mm and thickness of 5 mm, and insulated to minimize heat loss. The temperature distribution was monitored along the axial direction during charging and discharging processes. These findings suggest that the proposed method can enhance the efficiency and performance of thermal energy storage systems, making them more suitable for practical applications in renewable energy storage.

1. Introduction

The decomposed plants and many more organisms under the earth crust has taken many years to become carbon rich and today called as fossil fuels. These are non-renewable energy sources and vanishing rapidly. These fossil fuels include oil, coal and natural gas mainly produces 80 % of energy required to run the world. Releasing CO_2 and green house are the major output of fossil fuel burning which result in global warming and climate change and hence required to take over alternate method of energy production. In the modern world energy storage based on thermal through the phase change material has become a hot topic because large amounts of energy can be stored and released by it. The PCM melts, solidifies, or evaporates by accepting or releasing the

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heat. Depending on the phase change, heat is either absorbed or emitted either solid to liquid or liquid to solid [1-3]. The PCM has found application in sensible or latent heat storage systems, but later ones are more effective because of the application of phase changes around a constant temperature. In the case of a thermal energy stored in a latent heat storage system and released is a sudden change of phase energy storing materials. There are basically ample amounts of latent heat energy storing materials amongst them. Organic materials, including paraffin and non-paraffin compounds, are used in building, heating, and cooling applications [4]. The metallic alloys and salt composition are belonging to the category of inorganic phase change materials with a high tendency towards the corrosion. Applications for building heating and cooling also utilize eutectic mixtures of any organic-organic, organic-inorganic, or inorganic-inorganic composition. Fadl *et al.,* [5] examined experimentally the thermal performance of portable thermal energy storage systems. Their results show that for the Heat Transfer Fluid (HTF) inlet temperature has a higher impact on charging time during the charging process as well as flow rate. They also describe the effect of average power factor on the method for charging as well as heat exchange fluid inlet temperature. According to Al-Hinti *et al.,* [6] the performance of water-phase change substances storage that can be employed with traditional solar water heating systems is being experimentally investigated. The result shows that forced circulation of water for short periods of time has the least impact on the system performance. They also analyzed the retrieval effect, and the PCM storage performance in open-loop operating conditions, which are designed to simulate daily use patterns.

1.1 Literature Survey

The Phase Change materials is a hot topic now a days in research industry due to its irregular characteristics of solar energy stored in day time and use it in night-time. The various researchers used the various combinations from solar water heating systems certain phase transition materials from them has been discussed below.

Jesumathy *et al.,* [7] conducted experimental research on the heat transmission attributes a double pipe filled with paraffin horizontal the storage of latent heat. According to their predictions, lowering the heat transfer medium input temperature may cause in a decrease in discharging time due to improved heat transfer rate, while raising it may result in a reduction in charging time. In a horizontal thermal energy storage using a shell tube system, Das *et al.,* [8] examined the improved melting behaviour of phase change nano composite materials. According to their predictions, the performance of the thermal energy storage system would improve as a result of the addition of nano composite material to the materials. Kothari *et al.,* [9] performed an experimental examination of the rate of heat transfer in phase transition material in a cylinder-shaped latent heat storage system. The results highlight how effectively the system performs when charging and discharging phenomena occur at different flow rates as well as at different HTF inlet temperatures. Beeswax-expanded graphite composite was studied by Dinker *et al.,* [10-12] for its potential as a thermal energy storage material. The researchers examined the paraffin wax various properties using techniques like differential scanning calorimetry (DSC), Thermal gravimetric analysis (TGA), scanning electron microscopy (SEM), and X-ray diffraction (XRD) of PCM to assess the system performance.

The latent heat energy of a helical coil thermal performance was experimentally analysed by Jayakumar *et al.,* [13] for utilising renewable energy. They observed at a variety of charging and discharging performance parameters for the energy storage system based on latent heat. In a novel-new tube-in-shell device, Akgün *et al.,* [14] examined storage of thermal energy capabilities of paraffin. Three different types of paraffin wax were used to anticipate the results, and the material thermal and physical characteristics were checked, as well as the results of melting and solidification variables on system performance, using DSC testing. Mehta *et al.,* [15] conducted a thermal performance analysis evaluation of a shell and tube latent heat storage system using the latent heat storage unit major aspect orientation. Demonstrated the performance of solidification and melting. They provide a solid-liquid interface description, a liquid fraction profile, and solidification and melting performance parameters. Rathod and Banerjee [16] use of longitudinal fins to enhance the latent heat storage system's thermal efficiency units was investigated. They revealed the outcome of increasing the material thermal conductivity, which enhances system performance. Al-Abidi *et al.,* [17] by adding fins, an experimental study of phase-change materials in a heat exchanger as they are being charged and discharged in triplex tubes was carried out. In the storage thermal unit, they examined the paraffin wax discharging process under various temperature gradients and rate of mass flow in both angular and radial directions. Abdulateef *et al.,* [18] examined the triplex tube heat exchanger's melting of phase-change material was studied experimentally and computationally. by including longitudinal and triangular fins with a variety of melting ranges of temperature as well as a variety of flow rates to validate the effect on system performance. In addition to analysing the DSC evaluation of phase-change materials and its impact on the melting time during the solidification and wax paraffin melting. Avci and Yazici [19] studied the experimental characteristics of paraffin for thermal energy storage in a horizontal tube-in-shell storage unit. For the objective of studying the latent heat storage in the case of low temperature solar heating applications, Kumar and Krishna [20] investigated and analysed via means of differential scanning calorimetry of various phase transition materials. They examined the thermo physical characteristics of several types of phase change materials and how those properties affected the parameters that controlled the solidification and melting processes.

Alkilani *et al.,* [21] fabricated and investigated experimentally utilising PCM in the form of capsules for the application of solar air heating. The outcomes depicted the charging duration may be reduced by adding aluminium to paraffin wax, and the system effectiveness also improved by mixing wax along with aluminium powder. Regarding a solar collector, Koca *et al.,* [22] conducted an energy method. An examination of a latent heat storage based on phase-change materials system in accordance with the second law of thermodynamics. They determined that 45% and 2.2%, respectively, are the average energy and exergy efficiencies. According to their analysis, which was conducted using the first rule of thermodynamics, this may be useful for system efficiency evaluation throughout the charging cycle. The thermal enactment of a shell and a multi-tube storage of latent heat that is oriented horizontally, that was conceived, constructed, and experimentally was examined by Fadl and Eames [23]. According to the results of the experimental research, the time required for both decreasing charging and discharging considerably as the volume flow rate of HTF increased. They also examined how Stefan number and Reynold number affected the melting properties. In present the population growth rate is around 2% approximately whereas some countries having exceed to it. More population required more energy as well living standard is also an incentive for energy requirement. By keeping all in mind it is expected that the energy demand is increasing at least by 2 to 3 times before 2050 as suggested by Padmaraju *et al.,* [24]. The materials for phase change find their feet in Heating Ventilation & Air conditioning Systems. The most significant application of PCM is space heating or cooling [25]. The PCM is of great mean to change the phase due to energy interaction and find application in recent thermal energy storage system. Basically, there is mainly two thermal energy storage systems one sensible heat storage system and latent heat storage system by Bayomy *et al.,* [25]. The Sensible Heat Storage System (SHSS) uses single phase material and stored the heat simply by rising material temperature. It uses either solid material like packed bed or liquid material to store the energy.

Whereas Latent Heat Storage System (LHSS) uses materials which change phase transitions from solid to gas, liquid to gas, or solid to gas. The solid to liquid phase change material having upper hand over remaining because of either solid to gas or liquid to gas need more volume for energy store. The PCM use in Solid-liquid is melt and solidifies on phase transformation. In the solid heat transfer due to conduction where in the liquid phase due to convection presented by Sivasamy *et al.,* [26].

Sensible heat storage systems performance analysis for thermal applications was executed by Dinçer and Rosen [27]. The author deductions relate to the economics of SHS systems, the selection criteria for SHS systems, and the availability of SHS techniques for solar thermal applications, the key considerations when assessing SHS systems, their feasibility, and their effects on the environment, and the standards for SHS feasibility studies are all covered in detail. Energy-saving options are also discussed. Using stratification, the PCM- module will increase hot water heat stores are done by Mehling *et al.,* [28]. Solar energy sources and the recycling of surplus heat frequently use hot water heat tanks with stratification. The system might store more data and correct for the top layer heat loss by placing a PCM module on the water tank apex. The study given here comprises the system numerical modeling utilizing a direct finite-difference technique, as well as experimental results. Various cylindrical PCM modules were used in investigations and simulations. The energy density increased by 20% to 45% on average. And the water at the top of the store was maintained heated for 3/16 for an additional 50% to 200% of the time. with just 1/16 of the volume of the store being PCM. Myristic acid thermal characteristics as a phase-change material for use in energy storage was investigated by Sarı and Kaygusuz [29]. They also presented the rates of heat transfer were measured. When the latent heat-storing substance, myristic acid, was melted and hardened in the case where it was placed in a single vertical pipe and a cylindrical heat storage container mounted vertically was introduced as the heat exchanger into the container. According to the experimental findings, the melting front advances axially from the PCM tube apex towards at the base as well as radially inward. It was shown that the melting procedure is significantly influenced heat transfer by convection in the liquid phase by Sarı and Kaygusuz [30]. In the investigated range, the rate of flow and entrance temperature of the heat transfer fluid going to the PCM tube had negligible effects pertaining to phase change processes.

Thermal and heat transport properties of a system utilising lauric acid to store latent heat. The results of the experiments demonstrated that the PCM solidifies and melts uniformly. The melting method was mostly natural convection is in the control of the liquid phase because of effects of buoyancy, but the method of solidification was managed through the conduction of heat and retarded by passing thermal resistance through the layer of solidification by Sarı and Kaygusuz [31].

With the addition of a stearic acid material for a change of phase in a thermal energy storage technique. According to the experimental findings, the PCM has superior radial melting stability than axial melting stability presented by Sarı and Kaygusuz [32]. Additionally, the relationship between the change in inlet water temperature and the PCM solidification and melting properties is investigated. The author hypothesised that when the heat exchanger tube is horizontal as opposed to vertical, the PCM exhibits more effective and continuous phase change characteristics. In this study, the typical heat storage efficiency (or heat exchanger efficacy) is 50.3% which is lower than what we had anticipated for the container (PCM tube). Utilising a concentric short helical heat transmission tube, an experimental investigation was conducted to increase the vertical phase-change material melting cylindrical latent heat storage investigated by Punniakodi and Senthil [33]. Even though numerous research has been conducted to lessen the impact of PCM low thermal conductivity; it is still difficult to guarantee long-term benefit through such improvement techniques. The current study recommends an HTT design to enhance melting. The suggested approach has a straightforward design but is also advantageous for long-term usage that works well. SWH and air heaters to meet home and commercial thermal needs are prospective uses for the TES setups that are currently being shown. Analysis of the model for freezing outside of a circular tube with angular coolant temperature variation by ignoring heat capacity and axial conduction, approximation closed-form equations have been developed for a material to freeze outside of a coolant carrying tube. In the radial plane, Logarithmic temperature distribution is presented in research paper by Shamsundar [34]. F distribution, solid percentage along the axis, along the radial plane, and axial temperature distribution are all identical. For large Biot numbers, the interface is a truncated cone, and the axial temperature distribution is parabolic.

In a recent study, Al-Mahmodi *et al.,* [35] explore the enhancement of thermal energy storage through paraffin-based PCM nanocomposites with copper nanoparticles. Their findings reveal that adding Cu nanoparticles significantly improves thermal conductivity (up to 39%), specific heat, and thermal diffusivity, making the PCM more efficient for solar thermal systems. The nanocomposite showed durability over 150 heating cycles and is proposed for applications in energy-saving building materials due to its thermal stability and reliability.

In this paper, a test facility for the proposed work has been constructed to explore the solidification and melting phenomenon of PCM. This research introduces a systematic evaluation of paraffin wax as a PCM in a horizontal cylindrical thermal energy storage unit, utilizing water as the HTF. The motivation for this research stems from the increasing demand for efficient thermal energy storage solutions in renewable energy systems, particularly in solar thermal applications. The primary objective of this study is to analyse the effects of HTF temperatures (70°C, 75°C, and 80°C) and flow rates (2 LPM, 4 LPM, and 6 LPM) on the thermal performance of paraffin wax as a PCM.

2. Methodology

The Phase Change Material having tendency to store energy by melting at the constant temperature which is novel one no other material having characteristic like PCM. Whereas selection of PCM for particular application required to take extra care of properties of other substance used in as system. The ample quantity of PCM mixtures is available in a category of single component system, congruent mixture, eutectic mixture and peritectics mixture.

A test setup that includes a heat-storing container, a cold-water bath, a hot-water bath, and a circulation pump, and a k-type thermocouple with the necessary piping arrangement was used to determine how well LHTESS performed. Two cylinder-shaped pipes in a concentric pattern make up the heat-storing container. The tube is 740 mm long, with a thickness of 1.5 mm and an inner diameter of 20 mm. Due to their high thermal conductivity, copper tubes are chosen. The outside diameter of the shell is made of with a 40 mm internal diameter, thickness 3 mm, and length 510 mm. Another benefit of Low thermal conductivity is one advantage of polycarbonate, making it ideal for visualising the charging and discharging of paraffin wax. Before usage, every k-type thermocouple was accurately corrected to within ± 0.25 ^{0}C. In order to determine a measuring, the temperature of heat transfer tube entrance and exit, two thermocouples are positioned at those points. Figure 1 show three thermocouples attached to the copper tube edge to measure the HTF in the copper tube and three thermocouples measuring the temperature of paraffin wax. In order to retain a constant isothermal temperature, a 2 kW electrical heater with a thermostat was provided. For water circulation, a hot water pump with a ¼ hp power rating is employed. The rate of flow is measured using a rotametre, with a measurement uncertainty ± 0.03 kg/sec. The test part is maintained horizontally and filled with solid paraffin wax.

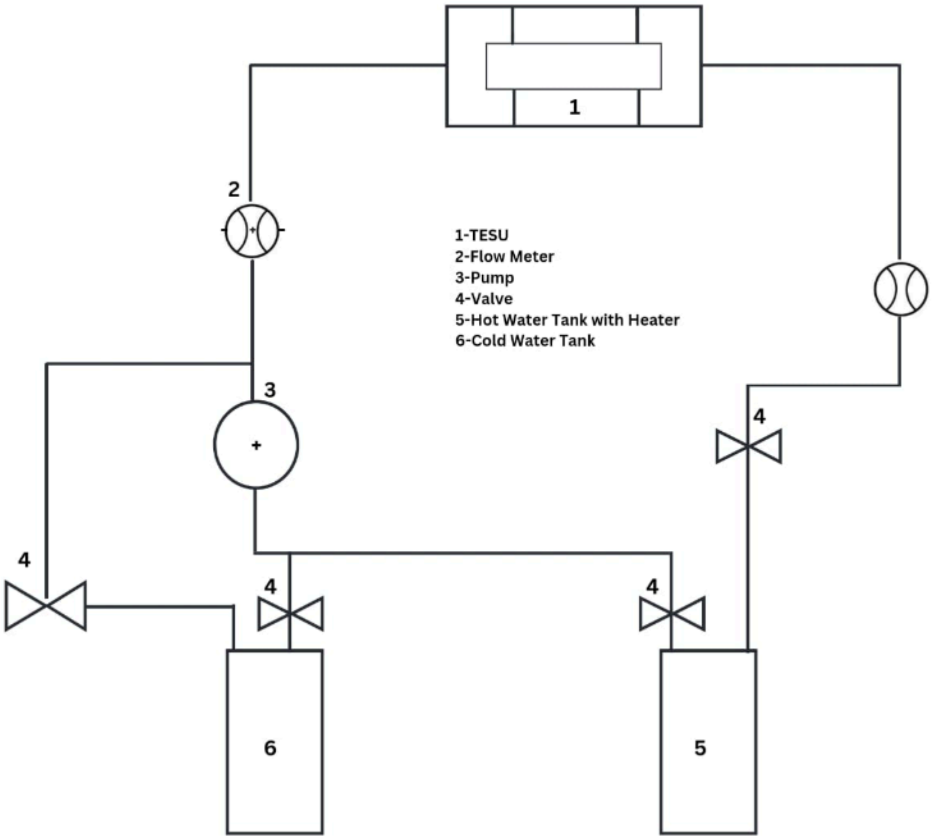

Fig. 1. Experimental set up thermal energy storage unit

Thermocouples TC7 and TC8 are installed at the inlet and outlet of the thermal storage unit to measure the inlet and exit temperatures of the heat transfer fluid. Thermocouples TC1, TC2, and TC3 are positioned to measure the PCM temperature during charging and discharging, as shown in Figure 2.

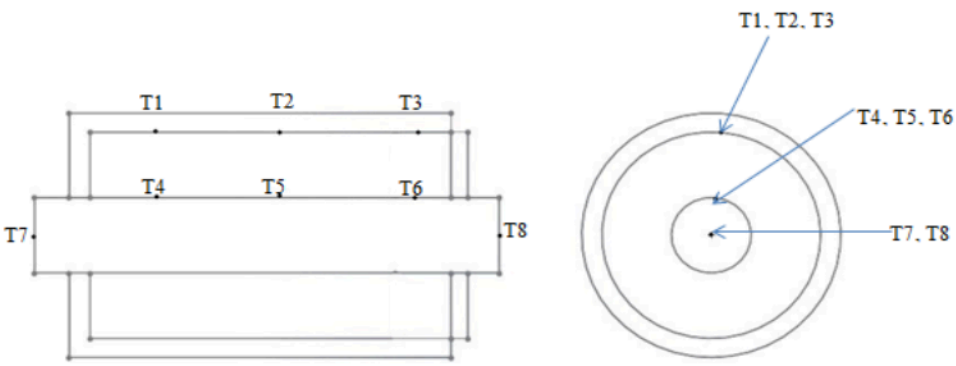

Fig. 2. Position of various thermocouples inside thermal energy storage unit

The thermo physical characteristics of paraffin wax which is obtained from Differential Scanning Calorimetry (DSC) test of paraffin wax is depicted in Table 1. The thermo physical characteristics of water is summarised in Table 2.

Table 1
Thermo physical properties of paraffin wax

Property	Value
Melting temperature range (°C)	58-60
Enthalpy of phase change (kJ/kg)	210
Density (kg/m^3)	960 (s), 870 (l)
Thermal conductivity (W/m K)	0.24 (s), 0.21 (l)
Specific heat (kJ/kg K)	2.3 (s), 2.1 (l)
Volumetric expansion (%)	10
Dynamic viscosity (N-S/m^2)	0.205
Operating maximum temperature (°C)	130
Polycarbonate thermal conductivity (W/m K)	0.22

Table 2
Thermophysical characteristics of water [36]

Property	Value
Latent heat of fusion	333.5 kJ/kg
Boiling temperature	100 °C
Specific heat	4.189 kJ/kg·K
Density	999.93 kg/m^3

At the starting with an adjustable rate of flow 2 lit/min, 4 lit/min, and 6 lit/min, hot water is pumped through the heat transfer tube in order to start the charging process. Every five minutes during the charging procedure, temperature deviations in the axial direction were recorded. A heat transfer tube was used to circulate cold water at varying flow rates of 2 lit/min, 4 lit/min, and 6 lit/min after the melting phase was completed in order to begin the solidification process. At different intake heat transfer fluid temperatures and rate of mass flow in the laminar range, the procedures for phase-change material charging and discharging were followed. Test Procedure has given below.

i. During the experimentation PCM paraffin wax is filled within the polycarbonate tube depending upon the availability of volume available.
ii. Then the system is heated at constant temperature of 70 ^{0}C, 75 ^{0}C and 80 ^{0}C.
iii. In case of melting phenomenon, the hot water as heat transfer fluid along with constant rate of mass flow passed inside the HTF pipe.
iv. A solidification period was induced by introducing cold heat transfer fluid by a temperature and mass flow rate remain constants within the range of solidification into the pipe carrying heat transfer fluid.
v. The input and exit temperatures of the fluid used for the transfer of heat passing through the tube, as well as the temperature distribution within the phase change material, were monitored and noted.
vi. The set of reading of temperature obtained at one five-minute interval time during experimentation.

The numerous ways that storage of thermal energy is categorized and discussed in subsequent section.

Storage of Sensible Heat: Sensible heat storage (SHS) is a technique for energy storage by altering a storage medium temperature. The quantity of storage media, the quantity of temperature fluctuation, and the medium specific heat all influence the extent to which heat is stored is indicated by Eq. (1).

$$Q_{ch=}\ m_{cp(T_{in}-T_{out})} \quad (1)$$

where m rate of mass flow C_p specific heat and T_i, T_o HTF at inlet and at exit temperature, respectively.

Storage of Latent Heat: The concept of latent heat storage (LHS) is focused on the heat that is absorbed or released during a storage material transition from either from gas to liquid, or both solid and liquid. Eq. (2) represents the LHS system's storage capacity when using PCM media.

$$Q_{W=}\ m\left[C_{sp}(T_m - T_i) + L + C_{lp}\left(T_f - T_m\right)\right] \quad (2)$$

where T_m, T_i, and T_f are the temperatures at which PCM melts, starts to melt, and final to melt respectively, the mass of PCM is m and L is PCM latent heat and solid PCM C_{sp} specific heat, PCM liquid specific heat C_{lp}.

3. Results

In the process of PCM melting, the transient changes of heat transfer fluid and phase change materials for three distinct HTF rate of flow are described. In-depth research is done on the PCM temperature profile during melting of wax paraffin in an enclosed tube.

3.1 Effect of Operational Parameters on Thermal Energy Storage System

3.1.1 Temperature profile during melting process

The experimental analysis is carried out in accordance with the following parameter, effect of rate of flow of HTF during charging and discharging on heat transfer tube PCM inlet and outlet temperature Phase change material and heat transfer tube**.** Figure 3 shows how the HTF flow rate affects the temperature at which paraffin wax melts at various stream rates. According to the graph, as the HTF flow rate rises at different locations throughout the test section, the temperature at which melting occurs also rises due to alteration of temperature between the intake and the outflow temperatures.

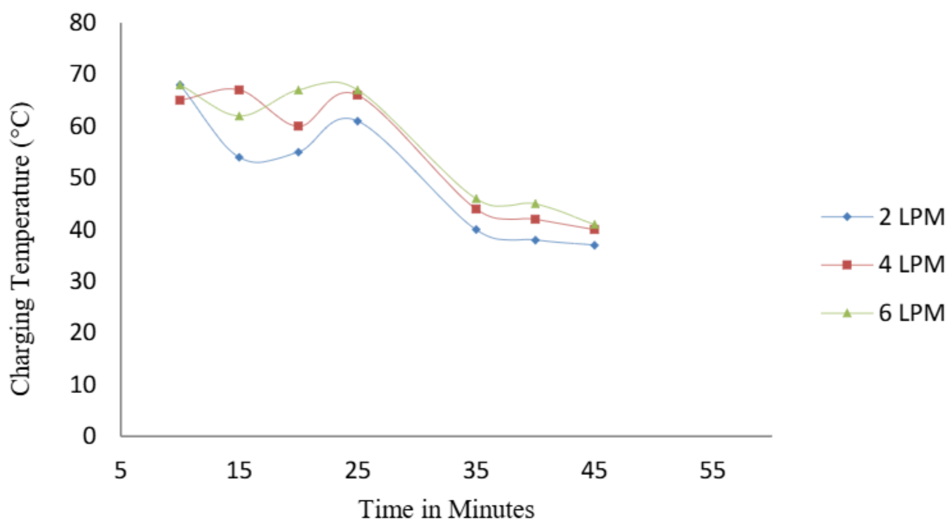

Fig. 3. Effects of charging process flow rate and inlet HTF temperature

From the experimentation, it is evident that melting time decreases as the charging temperature rises. As seen in Figure 3, influence of melting temperature during charging. Furthermore, the correlation of PCM temperature and melting time in minutes at various PCM tube locations alongside the tank axial ways is shown in Figure 3 for volume flow rates of 2, 4, and 6 litres per minute. As the PCM achieves its transition phase temperature of 58 °C, It's a temperature variation of the PCM at the various places increases uniformly till it reaches that temperature value. When heating liquid PCM, an isothermal phase change process is observed, and its amplitude increases quickly. Latent heat is a type of heat storage through the melting of PCM.

3.1.2 Effect HTF rate of flow during charging process

It is obvious from Figure 4 shows the result of paraffin wax temperature changes at several thermocouple locations. Convection is more prominent than conduction in the present scenario, so melting of PCM occurs at flow rates of 2, 4, and 6 litres per minute of the test section, and its temperature is monitored by the thermocouple T_4, T_5, T_6. For the reason that as temperature increases, the primary reason of heat transfer is due to convention among wax paraffin and heat transfer fluid. In the present study, the rise in PCM temperature in conjunction with the hot water tank temperature HTF, which increases steadily in line by means of the temperature heat transfer fluid inlet provided from the constant temperature bath. Consequently, a rise in rate of fluid flow may results in increase the PCM melting. Consequently, a rise in rate of flow of fluid cause a rise in the coefficient of surface heat transfer between phase change materials and the rate of flow has an impact on the time required for PCM in the tube to melt because it is a heat transfer fluid inside the tube.

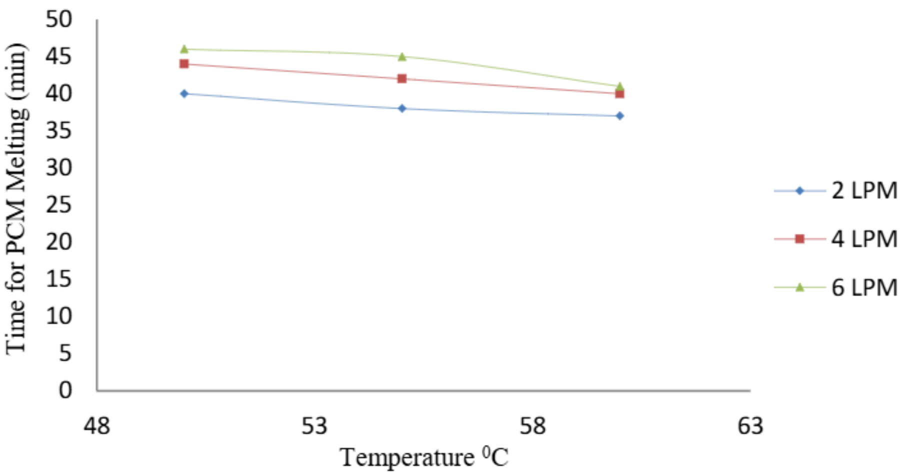

Fig. 4. The implications of HTF flow rate on paraffin wax profile temperature at various thermocouple positions (T_4, T_5, T_6)

The information displayed in Figure 5 demonstrates how the rate of flow HTF affects the temperature profile of the TESU at different thermocouple locations. More of the test section HTF temperature is found on the left and right sides. The transfer of heat via conduction through a copper tube is the primary cause of the rising temperature. Due to the conduction behaviour of heat transfer, the melting phenomenon takes place more quickly as the temperature rises throughout the length of the test segment. For an HTF rate of flow of 2 litres per minute, Figure 5 depicts the deviation in HTF and PCM temperatures at the top layer. It has been noted that the temperature increase in water is greater than in the PCM. This is because water can absorb more heat energy more quickly than phase change materials, and it contributes heat to the phase change materials.

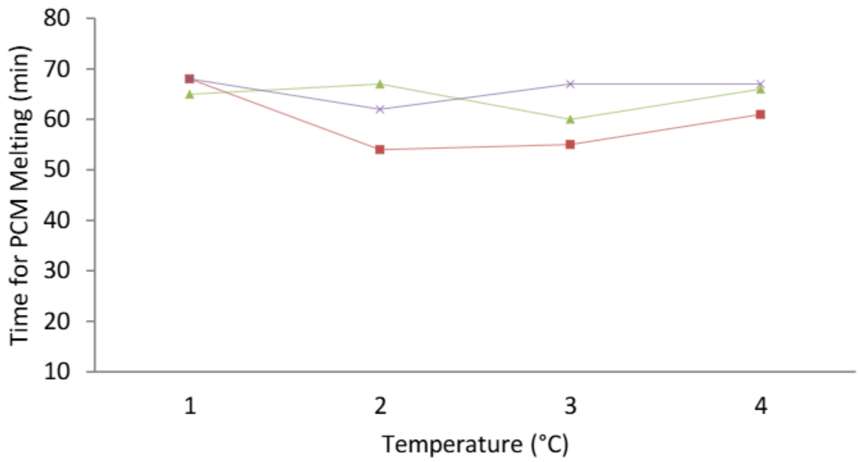

Fig. 5. The effect of HTF rate of flow on temperature profile of TESU at various position of thermocouple T_1, T_2, T_3

The result of the water temperature on the HTF fluid inlet and output is shown in Figure 6. During the experimental investigation, the exit temperature of HTF was advanced than the PCM temperature of paraffin wax and lower than the inlet temperature of HTF.

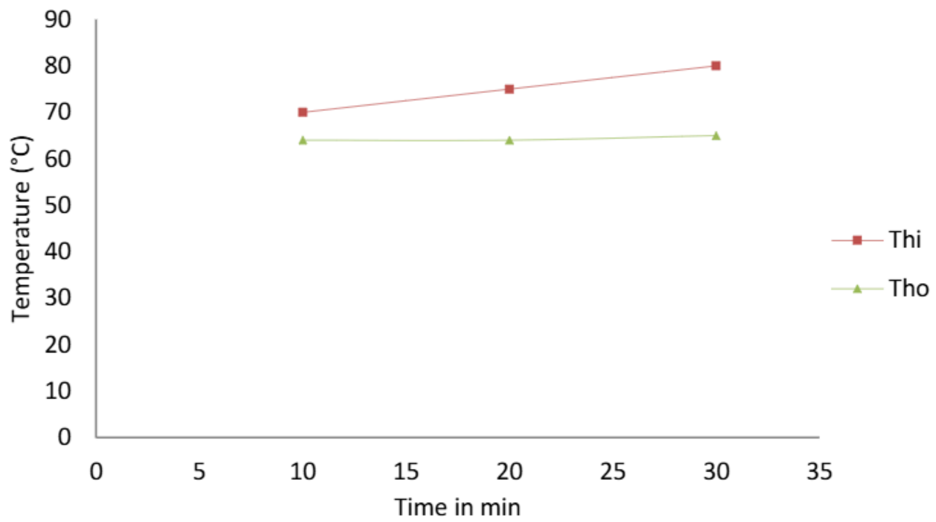

Fig. 6. An effect of inlet and outlet charging HTF temperature Period of PCM

Influence of intake and HTF outlet temperatures on the water discharging time is shown in Figure 7. To maintain equilibrium, the water's entrance temperature must be higher than its final temperature.

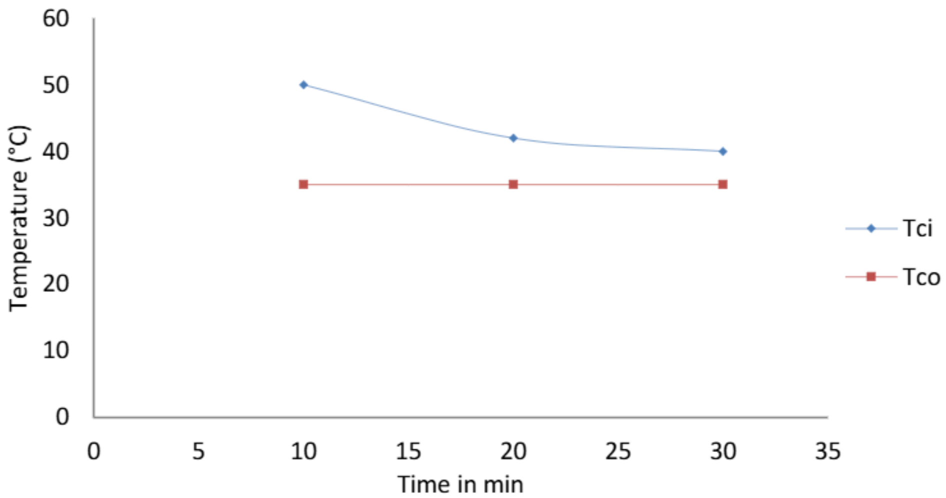

Fig. 7. An Effect of inlet and outlet HTF temperature discharging Period of PCM

In this experiment, the PCM temperature rises accordance with the temperature of the heat transfer fluid within the hot water tank, which increases gradually rises in accordance with the inflow HTF temperature provided from the tank with a constant temperature. The surface heat transfer coefficient between PCM and HTF tubes increases causing an increase in fluid flow rate, and this has an impact on the duration that PCM takes to melt in tubes. Due to the materials and the working fluid's thermal conductivity, Figure 8 demonstrates the typical temperature of a copper tube is significantly greater than the paraffin wax average temperature.

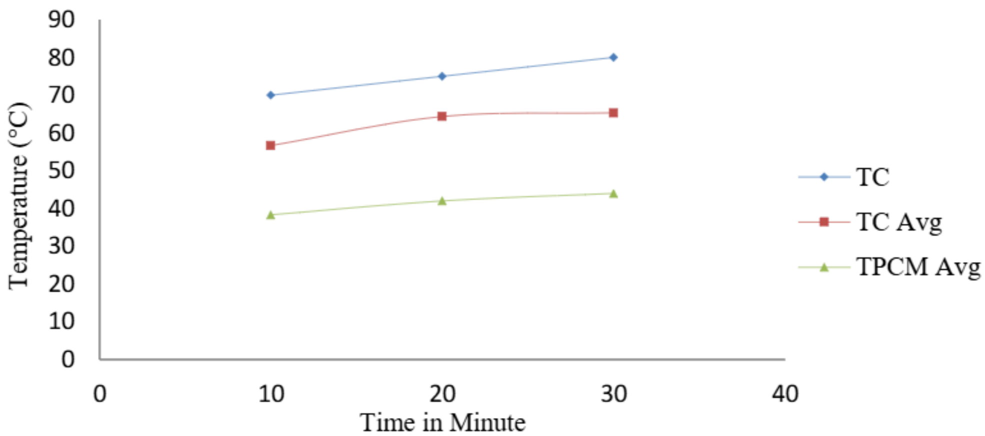

Fig. 8. Effect of average temperature of copper and PCM during charging process

3.1.3 Temperature profile during solidification process

The effect of temperature profile during the HTF discharge procedure is depicted in Figure 9. The process of discharging occurs in the same direction as the process of charging. By pumping cold HTF into the test portion, the discharging process is taken place. The temperature of the cold HTF is almost ambient or 25 ^{0}C. The difference in temperature between phase change materials and heat transfer fluid is quite considerable at the beginning of the solidification process. When there is a significant temperature differential, the liquid phase change material temperature is sharply reduced to begin the discharging process. After a specific amount of time, the temperature is nearly equal to cylinder surface HTF temperature. As a result, the discharge procedure takes extremely little time.

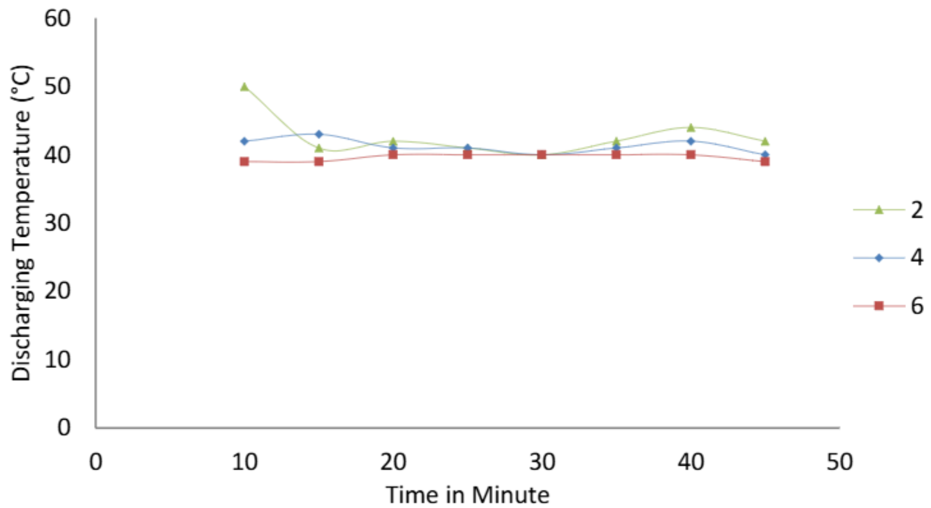

Fig. 9. Temperature profile during discharging process at various HTF flow rate

3.1.4 Effect of melting of paraffin wax on non-dimensional number (Re, St)

The result of rate mass flow on the rate of melting when charging is in progress was extensively examined. When the heat transfer fluid temperature is 70 °C, 75 °C, and 80 °C, the mass flow rate of HTF may vary between 2, 4, and 6 litres per minute. Figure 10 demonstrates the impact of the charging process's melting temperature because the charging interval is reduced by some amount as the inlet HTF temperature rises. The Reynolds number Re for the case of HTF can be evaluated from Eq. (3).

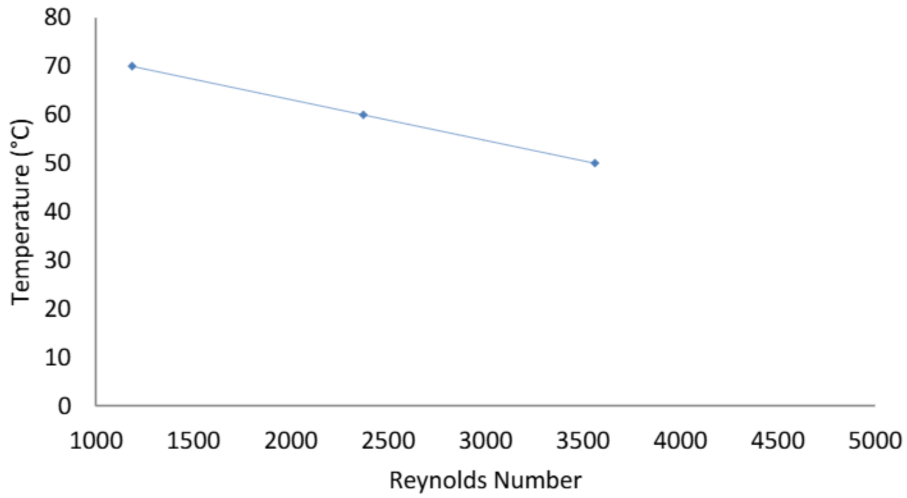

Fig. 10. Reynolds number effect on PCM temperature

$$R_e = \frac{\rho V d_i}{\mu} \tag{3}$$

where d_i, μ and V are the HTF's inner tube diameter, dynamic viscosity, and mass flow rate, respectively.

The influence of the Reynolds number (Re) on the charging and discharging processes at varying flow rates is presented in Table 3.

Table 3
Effect of Re during charging and discharging process

Process	Charging Process			Discharging Process			
Sr.no	Inlet Temp. of HTF ^{0}C	Mass flow rate LPM	Re	Sr.no	Inlet Temp of HTF ^{0}C	Mass flow rate LPM	Re
1	70	2	1186	1	25	2	1186
2	75	4	2372	2	30	4	2372
3	80	6	3561	3	35	6	3561

When temperature gradient among the PCM and the source of the heat is high, the heat distribution becomes faster, which causes the PCM to melt more quickly, as shown in Figure 11 and Figure 12, and the Stefan number, the non-dimensionless number that shows the proportion of sensible to latent heat, will increase. The Stefan number is the ratio of sensible to latent heat which can be evaluated from Eq. (4).

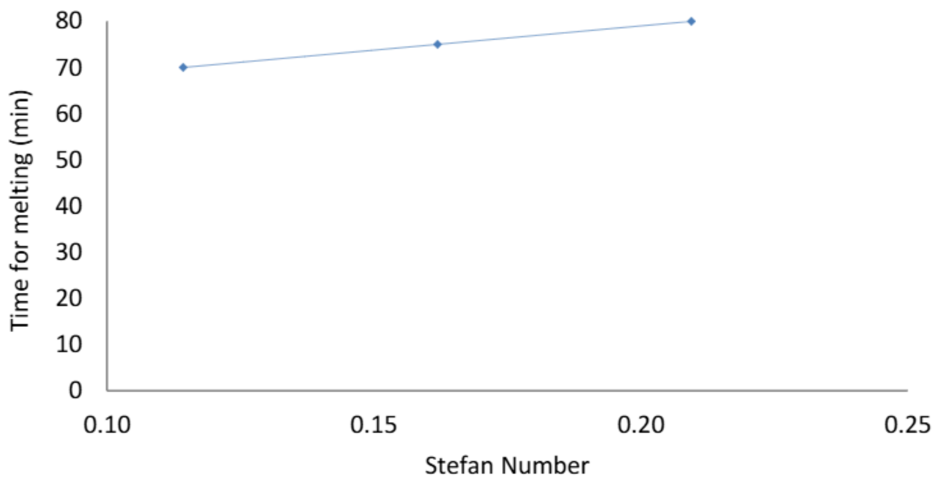

Fig. 11. Influence of the Stefan number on melting time during charging process

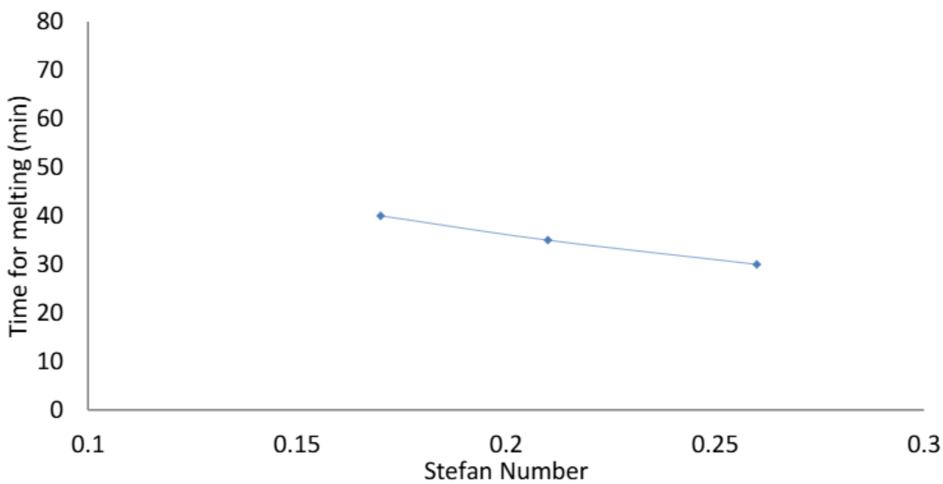

Fig. 12. Influence of the Stefan number on melting time during discharging process

$$S_t = C_p \frac{(T_m - T_i)}{H} \tag{4}$$

where T_{st}=T_{htf} -T_m during the charging procedure, as well as T=T_m - T_{htfin} and sensible heat of PCM are indicated along with the latent and sensible heat of PCM, respectively.

The values obtained during experimentation are presented in Table 4 during charging and discharging process.

Table 4
Effect of St Number during charging and discharging process

Temperature of HTF ^{0}C	70	75	80	Process
Stefan Number	0.11	0.16	0.21	Charging Process
	0.26	0.21	0.17	Discharging Process

4. Conclusions and Future Scope

The performance of proposed latent heat storage thermal system, extensive experimentation is conducted and evaluated. According to the experiment's findings, the investigation's results include the performance parameters, Reynolds number, Stefan number, time needed for PCM to melt, and PCM temperature at various points throughout the experiment. The key findings from the present research work are as follows:

i. The results are interpreted as indicating that a decrease in Stefan number and a rise in Reynolds number both shorten the time needed for PCM melting.
ii. In this experiment, the average time to complete several experiments are conducted. by raising the source tank's HTF temperature to 70 °C, which takes about 15-20 minutes, and charging the PCM, which takes about 30 – 45 minutes.
iii. The amount of hours used for the experiment determines the heat storage capability. The maximum storage time for maximum efficiency is 6–10 hours, and the discharging time required based on flow rate and ranges from 15–30 minutes.
iv. The experimental findings demonstrate that the method of energy storage the melting and solidification time have been reduced. The proposed method will help to increase the overall performance of the thermal energy storage system.

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