EXPERIMENTAL INVESTIGATIONS ON THERMAL ANALYSIS OF PARAFFIN WAX AS PHASE CHANGE MATERIAL IN SOLAR STILL FOR THERMAL ENERGY STORAGE APPLICATIONS

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Abstract:Objective: This study was undertaken to analysis of thermal features of paraffin wax as Phase Change Material &studied under different solar intensity to store latent heat energy.**Methods**:Experimentally investigation was carried out in box type solar Stillwith Paraffin wax. Paraffin wax analysed through solidification and melting characteristics curve for thermal performances.**Finding:**Examined the solidification and melting curve of paraffin wax box type solar Still for storage of energy in latent form. Theusage of phase change materials (PCMs) has been shown to develop the thermal enactment of solar storage.**Novelty:**Paraffin wax is a type of phase change material (PCM) that has been used in various uses, mainly deals with storage of latent form of thermal systems. The novelty of using paraffin wax as a PCM in a solar Still application is its ability to store thermal energy effectively and release it slowly when needed, making it an ideal candidate for use in a solar Still. In future research, the development of Nano-Enhanced phase change materials (NEPCMs) could further enhance the thermophysical properties of PCMs, making them an even more promising solution for meeting energy requirements through renewable baseslike solar energy. The utilization of renewable energy sources through a green approach can have a favourable effect on the environment. By using Phase Change Materials (PCMs) with solar energy systems, there is a possibility to considerably decrease energy consumption and greenhouse gas emissions, which can contribute to a sustainable and cleaner future.

Keywords: Latent Heat, Solar Energy, Paraffin wax, Solidification and Melting

Introduction: The growing population and economy are increasing the demand for energy, and we cannot rely solely on fossil fuels to meet this demand due to their adverse effects on the environment. We need to shift to sustainable energy forms such as wind and solar power, which have great potential in energy production. However, their intermittency and inconsistency can cause issues with reliability and availability of energy supply, especially during peak times. Energy storage technologies can play a crucial role in overcoming these issues and ensuring a constant supply of energy.

The reliability and availability of clean energy can be improved throughstorage form by renewable energy during periods when it is abundant and releasing it when it is needed. This approach ensures that the supply of clean energy is consistent and stable, even during times when renewable sources are not actively generating power. [1] There are various energy stowagemethods availablewith batteries, impelled hydro stowage, compressed air, and storage of thermal energy.

Theimprovement&implementation of storagethe energy methodsrequire to be growing rapidly, and it is becoming an essential component of the conversion to a cleaner and more viablefor storage energy. Governments and businesses worldwide are investing in energy storage research and development to accelerate the growth in renewable energy sector and reduce greenhouse gas discharges.

Overall, storage of energy technologies shows a crucial part in the evolutionsince fossil fuels to sources of renewable energy. By using energy storage, we can ensure a constant and reliable supply of energy, even when renewable energy sources are intermittent or inconsistent, paving the way for a cleaner and brighter future for future generations.

Phase Change Materials:PCMs are compounds that can absorb and release large amounts of thermal energy during phase shifts like melting and solidification. Paraffin wax is a type of PCM that has been used in numeroususes, including storage of thermal energy. Because paraffin wax has a high latent heat of fusion, it can absorb a large amount of thermal energy when it transitions from a solid to a liquid form. When the temperature drops, the paraffin wax solidifies again and releases the stored energy. This property makes it an excellent candidate for use as a PCM in various thermal energy storage applications.

One of the advantages of using paraffin wax as a PCM is its low cost and easy availability. It is also not toxic and corrosive, making it safe to handle and environmentally friendly. Additionally, paraffin wax has a relatively low melting point, which makes it suitable used in low-temperature for storage of thermal energy. However, there are also some limitations to by means of paraffin wax. One limitation is that it has a relatively low thermal conductivity, which can affect the amount at which thermal energy is shifted between the PCM and the surrounding medium. Another limitation is that paraffin wax can undergo phase separation, which can reduce its effectiveness as a PCM.

Overall, paraffin wax is a promising material for use asPCMs into various energy uses. Due to high latent heat of fusion, low cost, easy availability and environmental friendliness of paraffin wax itsown excellent candidates in heat storage systems. However, further research and development are needed to address its limitations and optimize its performance in specific applications.

Classification of PCMs: Phase change materials (PCMs) can be classified into three main categories based on their chemical composition: organic, inorganic, and eutectic.

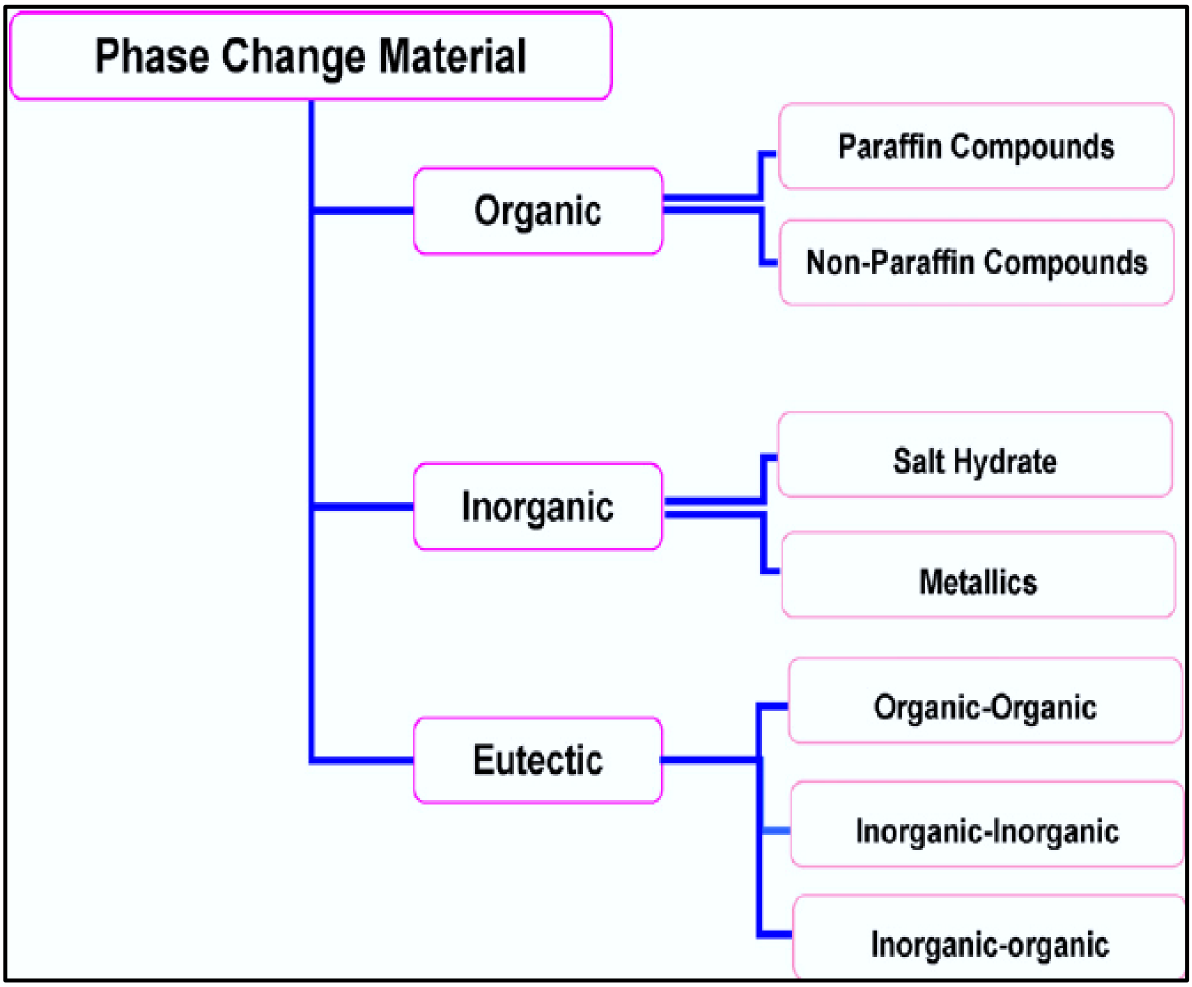


Figure No 1 Classification of PCM [3]

Organic Phase Change Materials:These PCMsare a class of provisions that can store and release thermal energy by undergoing a reversibleprocesses while phases transformation. These belongings are useful in anextensivevariety of uses, such as storage of energy, building isolation, temperature regulation in various industries. Organic PCMs are typically made up of long-chain hydrocarbons, fatty acids, or polyethylene glycols (PEGs). These materials involve a high latent heat of fusion, which means absorb or release a large amount of heat throughout the melting or solidification process, respectively. Some of advantages and Disadvantages are as follows:

Advantages:

- Extensive range of melting temperatures, making them appropriate for several thermal energy storage uses.
- High latent heat of fusion, which can store significant thermal energy during melting and release it during solidification.
- Can be tailored to specific temperature ranges and melting temperatures.

Disadvantages:

- Limited thermal conductivity, which may have an impact on how quickly heat is transferred from the PCM to the surrounding medium.
- Some organic PCMs can be flammable, requiring additional safety precautions.

Inorganic Phase Change Materials: Unlike organic PCMs, which are typically made up of hydrocarbons or fatty acids, inorganic PCMs are usually composed of metals, salts, or hydrated salts.

Advantages:

- High thermal conductivity, which allows for effective heat transfer.
- High thermal stability, making them suitable for high-temperature uses for storage of energy.

Disadvantages:

- Limited range of melting temperatures compared to organic PCMs.
- Lesser latent heat as compared to organic PCMs.
- Can be more expensive than organic PCMs.

Eutectic Phase Change Material: This are the type of storage of thermal energy material that undergoes a phase change (i.e., a transition between solid and liquid state) at a specific temperature called the eutectic point. At the eutectic point, the PCM has the lowest melting point and the highest heat of fusion. They can collect and release a lot of heat energy throughout the melting and solidification processes, which makes them valuable for thermal energy storage applications.

Advantages:

- They have a high latent heat of fusion, which allows them to store a lot of heat during melting and release it during solidification.
- Can have a lower melting point and wider temperature range compared to other types of PCMs.

Disadvantages:

- Limited thermal conductivity, which can affect the amount of heat transfer amongst the PCMs.
- Limited availability and higher cost compared to other types of PCMs.

Overall, the choice of PCM depends on the specific application and its requirements. Organic PCMs are versatile and can be tailored to specific temperature ranges, while inorganic PCMs are suitable for high-temperature applications. Eutectic PCMs offer a wider temperature range but can be more expensive and less readily available. All types of PCMs have limitations regarding thermal conductivity, which can affect their efficiency in thermal energy storage applications.
The addition of nanoparticles can enhance the thermal properties and performance of PCMs, making them more efficient and effective for storage thermal utilization.

However, the type and concentration of nanoparticles should be carefully chosen to avoid affecting the properties of the PCM. Further research is needed to optimize the use of nanoparticles in PCMs and improve their overall performance.The dependability, cost, and thermal show of the system with energy storage have been the main considerations in the enlargement of concerted solar power (CSP) systems. Heat transmission in latent heat storingmethods proved higher efficiency then sensible heat.[2] Thermal energy storage heat is used in heat recapture systems, energy storage schemes, reheating and freezingconstructionsuses, solar Still, solar greenhouse, solar air heating systems.[3]

They observed that Paraffin wax is good PCMs for storage energycapacity. PCMs that can store thermal energy through latent heat and has aappropriateconversion temperature range of 50-60°C with a high latent heat of 206 kJ/kg was studied. This PCM does not exhibit sub-cooling. The temperature supply of the PCM was observed during charging and discharging at three different mass flow rates of 15, 11, and 7 kg/min. Melting curves during charging and solidification curves during discharging were obtained for each mass flow rate by measuring temperature variations of the PCM over time. The PCM used for this study had a melting temperature range of 42 to 60°C. [4] Throughout the charging procedures, the PCM's temperature over time and the sun intensity were measured.

The melting &solidification curve showed to the paraffin as PCMs and have been studied through an experimental examination. [5] By analyzing experimental results they concluded that thermal efficiency improves by 8.56% for 4 kg paraffin wax.The most crucial factor to consider when choosing a PCM for solar applications is its melting point; hence PCMs with easily adjustable melting points would be required. Latent heat made up over 95% of the stored energy, with sensible heat accounting for the remaining 5%. [6]

Utilization of Phase Change Materials:PCMs find utility in applications where thermal energy storage is required. PCMs possess the property of absorbing and releasing substantial amounts of thermal energy while transitioning between solid and liquid states. PCMs are utilized in diverse applications, including construction, HVAC systems, thermal energy storage, electronics cooling, and transportation, among others. PCMs are used in numeroususes, such as:

- Storage of thermal energy: During melting and solidification, PCMs have significant thermal energy storage and release capacity. To lower peak energy demand and boost the effectiveness of energy utilisation in buildings, solar thermal systems, and other applications, they are employed in thermal energy storage systems.
- Temperature control: PCMs can be used to regulate temperature in applications where temperature control is critical, such as in electronics cooling, food preservation, and medical applications. [7]
- Heat transfer enhancement: The addition of PCMs to heat transfer fluids can improve the efficiency of heat transfer in various applications, including refrigeration and air conditioning systems, as well as industrial processes.
- Thermal management in electronics: PCMs can be used in electronic devices to absorb and release heat, helping to prevent overheating and extend the life of electronic components.
- Textile industry: PCMs can be incorporated into textiles to provide thermal comfort, regulating body temperature and reducing the need for additional heating or cooling.
- Building and Construction: PCMs are used in building materials, such as wallboards, roofs, and ceilings, to increaseheatproductivity by reducing reheating and chilling.
- HVAC Systems: PCMs are used in HVAC (Heating, Ventilation, and Air Conditioning) systems to store thermal energy during off-peak hours and release it during peak hours, thus reducing energy consumption and cost.
- Electronics Cooling: PCMs are used in electronics cooling applications, such as laptops and smartphones, to absorb excess heat generated by the electronics and maintain a stable temperature.
- Transportation: PCMs are used in transportation applications, such as refrigerated trucks and containers, to maintain a stable temperature during transport and storage of temperature-sensitive products.
- Energy conservation: PCMs can be used in energy-efficient building design, reducing energy consumption by storing and releasing thermal energy during peak and off-peak periods. [8]

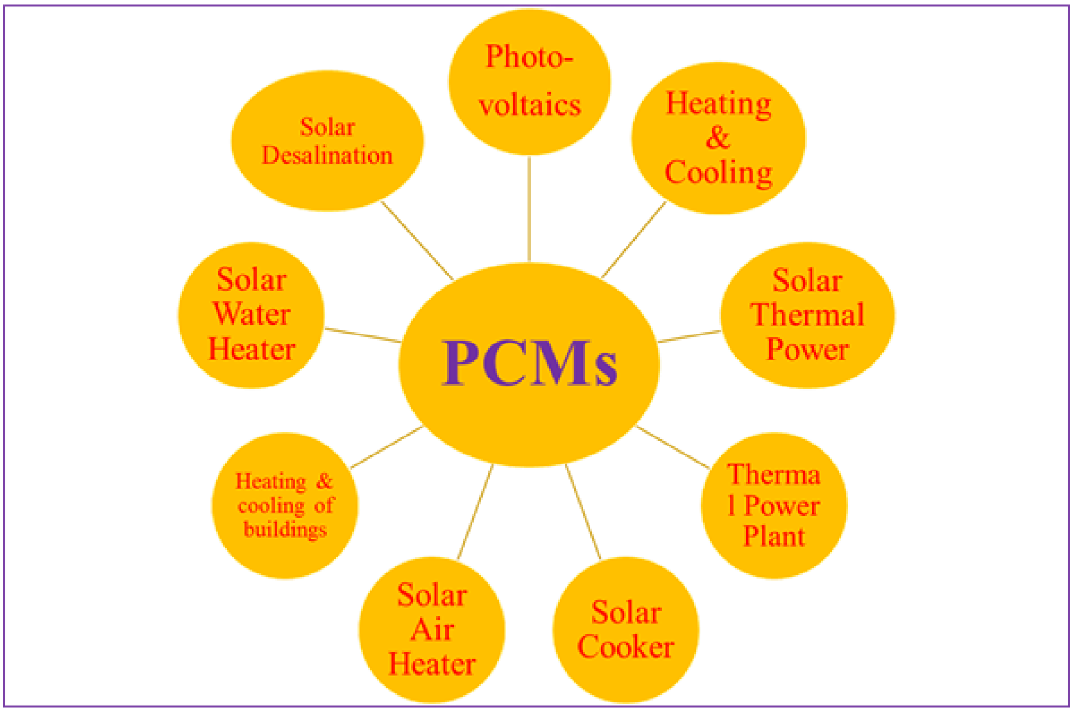


Figure No: 2Applicationsof PCMs

Overall, PCMs offer a versatile and effective solution for thermal energy storage and temperature regulation in a wide-rangingofuses. With ongoing research and development, the potential uses of PCMs are likely to expand in the future.

Methodologies:

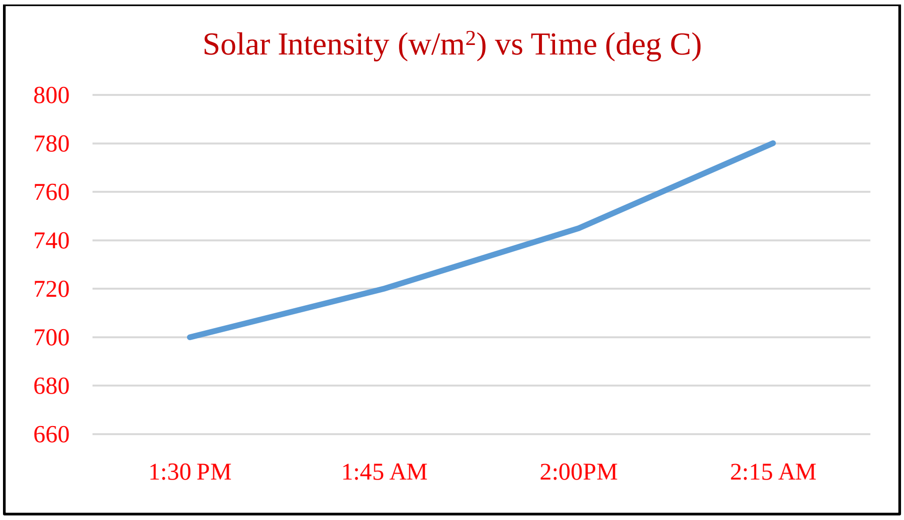
A box type solar still has been considered as a form of latent heat storage systems.notwithstanding with a shorter duration of storage. During the day, the black-painted interior of the box absorbs solar radiation and converts it into heat energy, which is stored inside the box. This stored thermal energy is then used store energy inside the box. The insulated walls of the box help to reduce heat loss, consequently increasing the efficiency. In this way, the box type solar Still acts as a passive, with the solar radiation serving as the heat input and the heat output Overall, box type solar Stills are a simple and effective way to harness solar energy for store through paraffin wax energy as thermal energy storage system.In this research, a known quantity of paraffin wax was placed inside a solar Still, and the solar intensity was measured at regular intervals. The time and temperature were recorded for different solar intensity readings, with the melting of paraffin wax noted at 59°C. The reaction time for melting was found to vary depending on the solar intensity, ranging from 30 to 60 minutes.

The melting and solidification temperature of the paraffin wax were noted for different solar intensity levels. A temperature controller was used to measure the temperature, while an intensity meter was used to measure solar intensity. Overall, this research aimed to investigate the behaviour of paraffin wax as a phase change material in a solar Still under different solar intensity levels.

Figure No: 3Experimentally Setup of Solar Still

Result and Discussions:

The experiment involved measuring the time and temperature changes during the melting and solidification of pure paraffin wax. Solar intensity was also noted and found to vary with temperature. The results showed that it took 30 to 60 minutes for the pure paraffin wax to completely charge, and at the end of the charging process, the wax reached a temperature of 59°C. The variations of PCM temperatures with time during the charging of pure paraffin wax are depicted in Graph No. 1. These findings are relevant to research on energy storage and thermal management systems.



Graph No: 1 solar intensity vs Time

To analyze the temperature variation during storage, pure paraffin wax samples were placed in a tray for 30 to 45 minutes.The temperature drop of the pure paraffin wax at the end of 45 minutes of storage was found to be 59^0C. Table No. 1 shows the variations of PCM temperatures with time during the storing of pure paraffin wax, along with the corresponding solar intensity and temperature. These findings are relevant to research on energy storage and thermal management systems, particularly for applications involving the storage of paraffin wax.

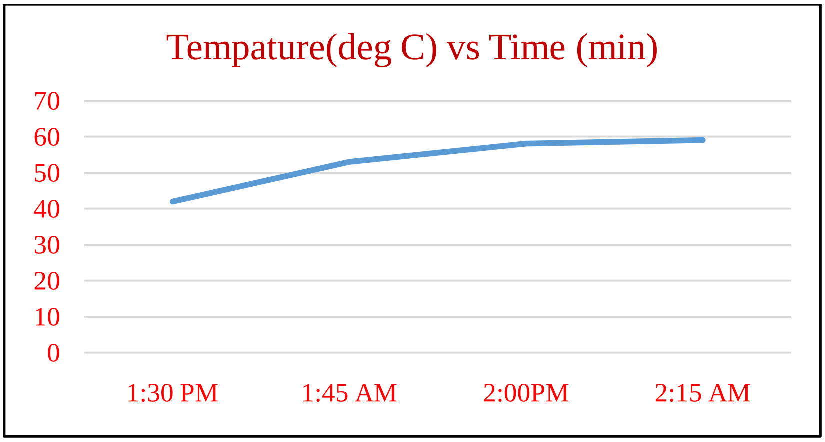
Table No: 1SolarIntensity, Time and Temperature

Time	Solar Intensity (w/m^2)	Temperature (degree ^{O}C)
1:30 PM	700	42
1:45 PM	720	53
2:00PM	745	58
2:15 PM	780	59

The charging and discharging processes of pure paraffin wax were analyzed, and it was found that the charging process took around 30 to 40 minutes, while the discharge process was comparatively shorter, taking only 1 hour. At the completion of the discharge process, the temperature of the paraffin wax was still around 42°C, indicating that a significant amount of energy was still stored in the sample.

As the storage duration prolonged, the sample continued to release the stored heat energy. To improve the show of pure paraffin wax as astorage energy systems medium, further studies can be conducted to optimize the charging and discharging processes.

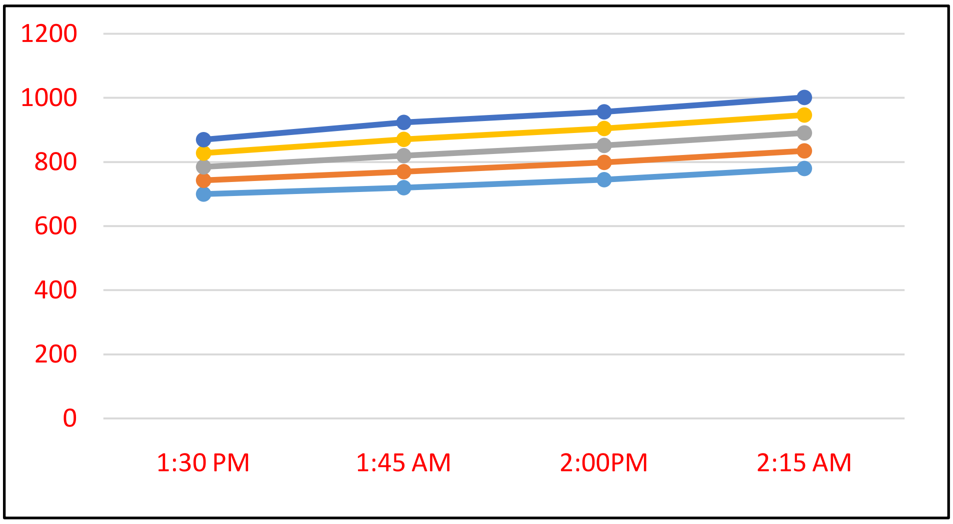
For example, use of PCMs with enhanced thermal conductivity or the integration of passive or active cooling systems can potentially increase the efficiency and reduce the charging and discharging durations.Graph No: 2 Temperature vs Time. These findings are relevant to the development of thermal management systems and renewable energy storage technologies.



Graph No: 2 Temperature vs Time

Two regions coexist during the melting process of PCMs during charging: the non-melted PCM regionin the solid phase, as illustrated in Graph No. 3 solar intensity and Temperature with time, and the melted PCM region in the liquid phase. Conduction inside the solid matrix is how heat is transferred within the solid PCM region.

Solar intensity and Temperature vs time



Graph No: 3Solar intensity and Temperature vs time

This sectionobtains heat from the melted part through convection. When the solid PCM matrix melts, buoyant forces caused by density gradients as a result of temperature differences generate convection within the melted PCM, which in turn drives the heat transfer process.

This recirculation within the melted PCM enhances mixing and heat transfer. In comparison to points at the lower part, it has been found that places close to the upper part of the melted PCM achieve melting temperatures more quickly. These results are pertinent to studies on the design and optimization of phase change material energy storage systems, especially in terms of the thermal control and heat transfer procedures during charging and discharging.

Conclusion:

Due to high latent heat of 206 kJ/kg and adequate transition temperature range of 50–60°C, paraffin wax has been recognized as a promising phase change material (PCM) for energy storage in latent heat storage systems. It also does not show any sub-cooling. The melting and solidification properties of paraffin wax as a PCM were examined experimentally, and the findings offer important knowledge about the processes involved in the melting and solidification of phase change materials. These results lead to the conclusion that this work offers practical recommendations for improving the thermal performance and design of latent thermal energy storage systems.

Furthermore, the solidification process was exposed to be faster closer to the solar still, indicating that the presented arrangement can be used for thermal energy storage in solar applications. Furthermore, the system is inexpensive to implement, making it a cost-effective solution for energy storage. These findings are applicable to research on renewable energy storage technologies and can aid in the development of efficient and cost-effective energy storage systems.

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