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EXPERIMENTAL STUDY OF COMPACT PCM-FILLED THIN TUBE SOLAR WATER HEATERS

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ABSTRACT

Energy storage saves premium fuels and reduces energy waste, making the system cheaper. In most systems, energy supply and demand are mismatched. Overcoming the imbalanced system with energy storage saves capital expenditures. More efficient and environmentally friendly energy utilisation is desired. Thermal energy storage methods have evolved during the past four to five decades. Effective energy storage technologies are needed to use intermittent solar energy. Latent Heat Thermal Energy Storage (LHTES) systems have long been linked to industrial and home solar heating. Latent heat storage systems using phase transition materials can store thermal energy efficiently due to their high energy density and isothermal processes. Compared to typical Solar Water Heating systems, LHTES has a high energy storage density. Thermal energy storage tanks are insulated with glass wool and PUF to reduce heat loss. All 90 copper tubes in the thermal storage tank include phase change elements. After careful analysis of phase change materials (PCM), the thermal storage system's PCM is chosen. To store heat energy in tanks, copper tubes are filled with three paraffin waxes with three phase change temperatures in three packs and the LHTES system is conceived and built.

KEYWORDS: PCM-Filled Thin Tube, Solar Water Heaters, Latent Heat Thermal Energy Storage (LHTES)

1. INTRODUCTION

The foundation of all human endeavour on this planet is energy. Due to the increasing energy consumption in various fields, the demand for energy has been on the rise in recent years. While fossil fuels have met humanity's energy needs for a very long time, they have also caused significant harm to the environment, which has resulted in contemporary environmental crises like climate change and the loss of polar ice caps. On top of that, the rising need for energy means that the price of this fossil fuel will continue to rise, as it did last year. This is in contrast to the diminishing supply of fossil fuels. Thus, it is imperative to find alternatives to fossil fuels in the energy sector. One of the main drivers of energy consumption is renewable power. In addition to being environmentally friendly, renewable energy sources produce significantly less pollution than fossil fuels. Solar power, wind power, biopower, geothermal power, tidal power, and hydropower are just a few examples of the endless varieties of renewable energy. Big bucks are a problem for all these energy sources. Additionally, non-availability all the time defines the intermittent nature of solar, wind, and tidal energy. Variation in accessible energy, an unaudited essential aspect of the aforementioned energy sources, is very sensitive to time scales like days or years. We can tackle this intermittent and fluctuating problem by storing energy.

The ever-increasing levels of greenhouse gas emissions, coupled with the finite resources of fossil fuels, are causing fuel prices to rise. A number of renewable energy sources are motivated by the aforementioned issue. An excellent answer to the aforementioned dilemma is an energy storage device; this is just as critical as finding a new energy source. The issue for technologists is the storage of energy in a suitable form, which is traditionally transformed to a required form. In addition to lowering the supply-and-demand mismatch, energy storage boosts the efficiency, dependability, and performance of energy systems while also playing a crucial role in energy conservation. Energy storage helps to reduce capital cost and energy waste, which in turn saves premium fuel and makes the system more cost-effective. A power generation plant, for instance, could benefit from storage in a number of ways, including load levelling, increased efficiency (leading to more effective energy conversion), and lower generation costs.

Thermoelectric energy storage using phase change materials (PCMs) can store and release vast quantities of energy. Holding and releasing energy in the system is dependent on the material's phase change. Further, energy is required for the processes of melting, solidifying, and evaporation. Transferring a material's state from solid to liquid or liquid to solid causes it to either absorb or release heat. Consequently, PCMs can change their phase with a known amount of energy input and then release that energy at a later time in a well-predictable manner. PCM employs the concept of latent heat storage. As opposed to sensible heat storage, there is no temperature change during storage. In the absence of auditing, all materials are considered phase change materials since, under specific conditions of pressure and temperature, all materials undergo aggregate state transformations. Aggregate state changes involve a lot of energy, thus latent heat that has cooled is either released or held at a relatively constant temperature. As a result, the temporal difference between energy storage and release is negligible.

2. REVIEW OF LITERATURE

Amagour, M. E. H., Rachek, A., Bennajah, M., & Touhami, M. E. (2018) This research details the development and testing of a heat-transfer enhancement–based latent heat storage device. A natural phase transition material with Moroccan origins was experimentally investigated for its possible use in energy storage. Geometrical challenges arise from the compact finned-tube heat exchanger's improved heat transfer surface. Hence, a novel approach was devised and implemented for the purpose of calculating the effective heat transfer surface area, which is based on the efficiency of corresponding circular fins. This approach was then applied to the system that was being studied. Experimental charging and discharging were carried out for various heat transfer fluid flow rates to carry out the performance analysis for this novel system. Researchers discovered that the melting time is divided by 2.5 and the solidification time is divided by 4 when the flow rate is increased from 0.2 to 1 l/min. At 0.2 litres per minute, the average efficacy was 0.95, but at 1 litre per minute, it dropped to 0.63, proving that the effectiveness decreased during charging. Similarly, the heat exchanger's efficacy drops from 0.99 to 0.7 when the discharge process's flow rate is increased from 0.2 to 1 l/min. Empirical correlation was derived by combining the effectiveness-number of transfer units' technique with the procedure used to compute the effective heat transfer area. The finned-tube compact storage device was evaluated against alternative heat and cold storage units using this equation.

Fadl, M., & Eames, P. C. (2019) In this study, the authors examine the practical usefulness of a latent heat thermal energy storage system (LHTESS) for DHW uses. A thermal store that was built, manufactured, and described included a rectangular container filled with phase change material (PCM) paraffin wax RT44HC and a vertically oriented multi-pass tube heat exchanger. In order to assess the system's heat transfer, transient temperature distribution, cumulative thermal energy stored, charging and discharging duration, and instantaneous charging and discharging power, the experimental examination included the following measurements. All of the experiments were carried out in a controlled environment, with varying input temperatures of the heat transfer fluid (HTF) and volume flow rates for charging and emptying the store. Natural convection in the melt was determined to have a crucial function during the charging process. When the LHTESS is being discharged, thermal conduction is the main factor and natural convection plays a minor role. This occurs because the PCM solidifies around the tubes used for heat transfer, raising their thermal resistance and decreasing the amount of heat that can reach the liquid PCM below. The time it took to charge the store was drastically reduced when the HTF inlet temperature was higher. Charging took 3.5 hours less when the HTF inlet temperature was raised to 70°C, and melting took 2 hours less when the temperature was raised to 80°C.

3. METHODOLOGY AND EXPERIMENTAL WORK

The exceptional performance of phase transition materials in thermal systems is what draws researchers' attention. Due to its increasing capacity for heat storage, phase change material (PCM) has become more significant in thermal engineering, building construction, and other fields. But as a phase-changing material, paraffin wax melts between 300 and 1200 degrees Celsius. In order to improve heat storage and retrieval, paraffin is melted at temperatures between 500 and 600 degrees Celsius.

The copper tubes are filled with molten paraffin waxes. The fabrication of PCM encased copper tubes requires 9 kilogrammes of paraffin waxes, which is derived from the usage of 90 copper tubes filled with 100 grammes of molten wax apiece. To construct a PCM encased storage tank, the copper tubing is put inside the tank. The 100-liter storage tank can hold a lot of water. The solar thermal collector is linked to the storage tank that is encased with PCM. Heat from the sun is transferred to the cold water using solar collectors. In order to carry out the studies, a solar water heater encapsulated with PCM is manufactured.

Utilising computational fluid dynamics and finite element analysis, we examine the heat transmission in copper tubes encased with phase change materials (PCM) and the distribution of temperatures inside the heat transfer fluid. The steady-state temperature distribution of the heat transfer fluid (HTF) and phase change material (PCM) as a function of time and heat absorption is depicted in the computational fluid dynamics (CFD) model.

3.1 MATERIALS FOR PHASE CHANGES AND THEIR EVALUATION

Organic, inorganic, and eutectic PCMs are the three main categories. The chemical, economic, thermodynamic, and kinetic properties of organic PCMs are the ones used for selection. The solar water heater's copper tubes were coated with paraffin for this paper. To increase and decrease the heat transfer rate from the working fluid (water), a trio of PCM types are employed. The characteristics of paraffin are as follows.

- Thermodynamic Properties of PCM
- Kinetic Properties of PCM
- Chemical Properties of PCM
- Economic Properties of PCM

The appropriate grade PCM was determined by administering the following tests:

- To determine the temperature at which various forms of PCM undergo phase change.
- In order to determine the volume of the molten phase-change substance.
- Determine the volume of solid phase change materials.
- Determine the PCM's volumetric difference when it melts and solidifies.

A separate experiment was carried out to ensure the phase change temperature and percentage of volumetric variations in the PCM, as these parameters were previously provided by the vendors during PCM procurement along with the material's physical and chemical properties.

3.2 VARIOUS FORMS OF PARAFFIN WAX

Paraffin wax is a colourless or white material that is soft and composed of a mixture of hydrocarbon molecules with twenty to forty carbon atoms. It is extracted from coal, oil shale, or petroleum. At ambient temperature, it is solid; nevertheless, it melts at temperatures above about 37°C (99°F), and it boils at temperatures below 370°C (698°F). Paraffin wax is commonly used for a variety of purposes, such as lubrication, electrical insulation, and candles. It may also be transformed into crayons by adding pigment. Paraffin is a different word for kerosene and other petroleum products.

A wide variety of organic substances, waxes are solid, pliable, and lipophilic at room temperature. The low-viscosity liquids produced by their melting include higher alkanes and lipids, which usually have melting points greater than approximately 40°C (104°F). While organic, nonpolar solvents can dissolve waxes, water has no effect on them.

- **Plant and Animal Waxes**

Numerous plant and animal species are capable of synthesising waxes. Wax esters made from various carboxylic acids and fatty alcohols make up most of the ones that are obtained from animals. It is possible for unsterilized hydrocarbon mixtures to be more prevalent than esters in plant-based waxes. Both the organism's species and its geographic location have a role in its composition.

- **Animal Waxes**

Most people know about beeswax as an animal wax, but other insects also produce waxes. Myricyl palmitate, which is an ester of triacontanol and palmitic acid, is a big part of the beeswax used to make honeycombs. 62°C to 65°C is the point at which it melts. There are a lot of spermaceti in the sperm whale's head oil. It is mostly made up of cetyl palmitate, which is another ester of a fatty acid and a fatty alcohol. Lanolin comes from wool and is a wax made up of esters of sterols.

- **Plant Waxes**

Plants put waxes into and on top of their cuticles to control how much water evaporates and how much they stay wet. Plant epicuticular waxes are made up of a variety of long-chain aliphatic hydrocarbons that have been replaced. They include fatty acids, diols, ketones, aldehydes, and primary and secondary alcohols. When it comes to business, carnauba wax, a hard wax that comes from the Brazilian palm Copernicia prunifera, is the most important plant wax. It can be used for many things, like coating candy and other foods, polishing cars and furniture, covering floss, and making surfboard wax. It contains the ester myricyl cerotate. Some of the other, more specialised veggie waxes are ouricury wax and candelilla wax.

- **Petroleum Derived Waxes**

Many natural waxes have esters in them, but paraffin waxes are made up of hydrocarbons, which are mixtures of alkanes that generally have the same chain lengths. A big part of gasoline is made up of these substances. They are made better by vacuum distillation. Paraffin waxes are made up of naphthenes, saturated n- and iso-alkanes, and aromatic compounds that are replaced with alkyl and naphthene. A normal alkane paraffin wax chemical makeup is made up of hydrocarbons with the formula C_nH_{2n+2}, like Hentriacontane, which is $C_{31}H_{64}$. How many branches there are has a big effect on the qualities. A less common type of petroleum-based wax, microcrystalline wax has a higher share of iso paraffinic (branched) hydrocarbons and naphthenic hydrocarbons.

A system that includes phase change materials, copper tubes, a storage tank, and solar panels. There is a PCM storage tank with a 100-liter water capacity. The tank houses a PCM storage unit, which has 90 copper tubes. Each tube contains at least 100 grammes of PCM, for a total of 9 kilogrammes of PCM. The tank is well-insulated. The fluid that transfers heat moves through the copper tubes due to convection. The adiabatic state of the storage tank is correct; it does not undergo any heat transfer. Two cylinders, 79 cm in length, arranged in a circle formed the experimental test unit.

Figure 1: Solar Water Heater Setup

Figure 2: Fabricated PCM's Storage Tank

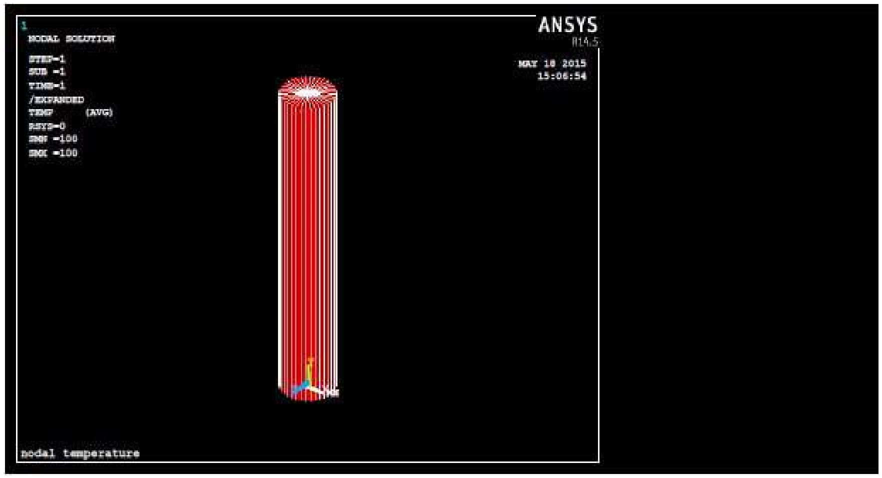
A stainless steel (304L) cylinder with an inner diameter of 37 cm and an exterior diameter of 40 cm was housed inside the tank, along with a number of copper tubes that had dimensions of 75 cm in length, 1.2 cm in diameter, and 0.8 mm in thickness. The storage tank was strategically insulated with glass wool to minimise heat transfer to the surrounding environment. As the HTF, water was cycled through the tank via the copper tubes.

The PCM Tube Analysis

Many of us have felt the refreshing blast of cold air as we opened the fridge door on a hot day, allowing the air to flow past us. We experience the cold air rushing past us because of a thermal quantity known as a thermal gradient. There are two physical variables that define a thermal gradient. One of them is temperature. Whether an object is hot or cool can be measured by its temperature. When we say something like "it's really hot today, it's a 100oC," we're actually referring to a temperature of 100°F.

Secondly, length is what defines a thermal gradient. The formula for thermal gradient is the ratio of the temperature difference between two points to the distance between them. Ansys meshes the PCM tube's digital model. A 1 mm mesh element size is utilised for the model, and an unstructured triangle element is employed for area meshing.

An external load in the temperature range of 1000C is applied to the copper tube's surface. Following the completion of the thermal analysis model, the copper tube's middle section displays the lowest temperature, while the top and bottom sides display the highest.



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1
NODAL SOLUTION
STEP=1
SUB =1
TIME=1
/EXPANDED
TEMP     (AVG)
RSYS=0
SMN =100
SMX =100
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Figure 3: Nodal Temperature of PCM Tube

4. CONCLUSION

The internal core of the PCM cannot transport all of the heat to the tubular shell due to the reduced cross-section of the tubes. In the scientific community, there is no need for further methods to improve heat transport. The complete heat must be released from the PCM during the discharging process in order to reach the innermost core, without any heat being retained. The system can store heat of any temperature since the three different kinds of PCM are placed in descending temperature order from top to bottom, each with a different melting point. Low temperature PCM is typically found towards the bottom of the horizontal PCM encased tubes since that's where the cold water is usually available in the container. Heat absorption of the PCM and HTF are depicted using CFD analysis in steady state conditions at different planes. More heat from HTF is absorbed by the inlet side of the PCM. As the HTF temperature drops, the PCM's heat absorption rate drops as well, both at the beginning and the end. Significant heating occurs in the PCM and HTF's central plane. In transient conditions, CFD analysis shows that the HTF and PCM temperatures rise with time variation. The manufactured thermal storage tank makes use of three sets of thin copper tubes to boost thermal storage. Because of their narrower diameter, copper tubes are able to transmit heat more efficiently between the PCM and the Heat transmit Fluid (HTF) and vice versa while the PCM is being charged or discharged. Recovering heat from the PCM during discharge allows for its subsequent utilisation with minimal loss. An ANSYS study of a copper tube reveals that its top and bottom ends are the hottest parts, while its central section is the coldest. The PCM and HTF heat absorption is shown on a graph using the CFD analysis in steady state conditions at different planes. More heat from HTF is absorbed by the inlet side of the PCM. As the HTF temperature drops, the PCM's heat absorption rate drops as well, from start to finish.

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