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# A REVIEW PAPER ON SIMULATION AND MODELING OF SHELL AND TUBE HEAT EXCHANGER FILLED WITH PCM FOR SOLAR WATER HEATING SYSTEM A CFD ANALYSIS

Mr. Sachin Baraskar<sup>1</sup>, Pankaj yadav<sup>2</sup>

<sup>1</sup>Assistant Professor, Department of Mechanical Engineering, SSSUTMS, Sehore, M.P., India.

<sup>2</sup>Research Scholar, Department of Mechanical Engineering, SSSUTMS, Sehore, M.P., India.

## ABSTRACT

Solar energy, the most promising source of energy, requires thermal energy storage (TES) due to its intermittent nature. Storage of thermal energy can take the form of sensible heat storage (SHS), latent heat storage (LHS), and thermo-chemical storage (TCS). The amount of energy that is stored in SHS depends on the specific heat of the substance, the change in temperature, and the mass of the storage material since heat energy is retained by raising the temperature of the storage material without going through a phase transition. However, LHS involves a phase transition, when heated to the constant temperature, between solid-liquid, solid-solid, and liquid- gas states and vice versa. Solid-solid phase transitions require a lower energy storage capacity than liquid-gas phase transitions which require a large increase in volume. As a result, the solid- liquid transformation is most commonly used in LHS applications because it is more efficient than other transformations.

Keywords: Solar energy, Thermal Energy, Phase change Material

## 1. INTRODUCTION

For steady and sure development and progress of any country, it is necessary to develop alternative resources of energy. To fulfill the increasing energy demand, renewable energy is one of the best options. There are a number of renewable energy resources, out of which solar energy is the most important form of thermal energy. Energy received by the earth from the sun is many thousand times larger than the present consumption rate of all commercial energy sources. This makes it the most promising source of energy. Fortunately, India is blessed with abundant solar radiation available almost throughout the year. In recent years, the Indian government has taken a keen interest in the solar energy sector and is continuously investing huge amounts in the utilization of solar energy.

Currently, when researchers around the world, are looking for solar energy to use as an alternative to fossil fuel to fulfill the energy demand, the main challenge is the continuous supply of solar energy. Solar energy though, simple to utilize, non-polluting and everlasting, is time- dependent and has intermittent character. As the availability of solar energy at night is the main challenge, one of the complementary tasks for the researchers is to develop and utilize advanced thermal energy storage (TES) systems i.e. to store solar energy in suitable forms that can be efficiently converted into the required form. TES systems, which utilize heat available from solar and other energy sources, have become one of the essential components for increasing efficiency and environmental friendliness of energy supply and demand but also upsurges the performance and reliability of the systems, and contribute to energy conservation

## Thermal Energy Storage Cycle

Where Q denotes the amount of heat retained by the substance (kJ), m denotes the mas of storage substance (kg), cp denotes the specific heat of the substance (kJ/kg-K), T1 and T2 are initial and final temperature (K). Since cp depends on temperature, to get the total quantity of thermal energy stored, we may utilize equation (1). In order to account for the variation of cp, equation

(1) might be written as though the temperature range is very small.

Q = m. cp(avg). (T2 - T1)(2)

where the average specific heat between temperature T1 and T2 is represented by cp(avg) [6]. Based on equations (1) & (2), a large specific heat capacity cp, may significantly impact the amount of thermal energy retained. To be employed as storage material in SHS, materials must have a large thermal capacity, be widely available, and be inexpensive. After many thermal cycles, the heat storage material will not degrade much because of its long-term stability. Density, specific heat, thermal conductivity and diffusivity, vapor pressure, compatibility with container materials, and chemical stability are the factors considered when choosing an appropriate material. It is possible to store sensible heat in solid or liquid media (air storage systems are bulkier but can also be used).



Thermo-chemical heat storage

#### **1.2 Comparison of TES Types**

The design of SHS systems is less complex than that of LHS or TCS systems, but SHS has the negative effects of being larger and unable to store or supply energy at a constant temperature. The charging process results in energy losses due to the storage of sensible heat. These losses depend on the thermal characteristics of the storage material, storage time, temperature, volume, and shape. The characteristics of the storage medium have a significant influence on the price of the SHS solution. It is highly usual to use very inexpensive materials as the storage medium for solids like rocks, sand, and refractory as well as liquids like oils, water, and some inorganic molten salts. SHS method with water as a storage medium appears to be the most advantageous from a thermodynamic standpoint because of the high specific heat of the water and the potential for high capacity rates for charging and discharging. Corrosion from prolonged operation is the major issue with water storage systems. The volume of the storage may be extremely big for significant heat capacities, making the system as a whole very heavy. This is another drawback of water storage systems. Controls are necessary since stratification is an issue with big storage facilities as well. There are no issues with corrosion or scale formation when using rock storage, although the system's volume may grow as the cost rises.

#### **1.3 Phase Change Materials**

Latent heat thermal energy storage (LHTES) devices use PCMs as storage substances to store heat energy. In this instance, a material changes its state by absorbing heat energy from the surrounding area during the phase transition, and when reverse operation is needed, the stored energy is released back into the environment. As the temperature rises, PCMs initially act similarly to other conventional materials, but when heated at higher temperatures and close to the phase transition, energy is absorbed. PCMs are composed of materials that absorb or release thermal energy at constant temperatures, unlike traditional materials. In contrast to conventional storage materials like water or rock, a PCM typically absorbs and releases thermal energy 5 to 14 times more quickly

#### 1.4 Organic PCMs

Organic PCMs are possibly the most crucial element. Over several phase change cycles, organic PCMs display no modification in performance structure additionally, organic PCMs do not exhibit supercooling phenomena. It is distinct how organic PCMs are categorized. Their application contexts serve as the major basis for this classification. They are often divided into two main groups, namely paraffin and non-paraffin parts. Paraffin is one of the most common PCMs. Waxy solid paraffin is the common name for PCMs made of paraffin. Usually, paraffin has a large latent heat capacity. Paraffin waxes may typically be obtained in a wide variety of temperatures and are generally considered to be secure, trustworthy, affordable, and non-irritating chemicals. The majority of technical grade waxes may be utilized as PCMs in LHTES systems, which is advantageous economically. Paraffin waxes are stable and inactive from a chemical perspective. Although they have low vapor pressure, they have moderate volume changes during melting. The PCMs made of paraffin are typically highly stable over a large number of solidification-melting cycles.

## 2. LITERATURE REVIEW

H. M. Teamah, et al. [1] studied multi-tank thermal storage systems for multi-residential solar domestic hot water applications. The thermal storage system includes phase change materials of different melting temperatures incorporated in the tanks. The hybrid tank model was linked with the collector performance. The multi-tank hybrid system thus allowed for over 50% reduction in the required storage volume. It was found that cascading four 75 L tanks containing PCMs of melting temperatures 54°C, 42°C, 32°C and 16°C gives a similar solar fraction to that for a 630 L water-only tank. A thorough economic analysis requires a detailed optimization study for the hybrid system and is planned for future research.



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Yaxue Lin, et al. [2] studied thermal conductivity enhancement, thermal properties, and applications of PCMs in TES. It is found that the addition of thermal conductivity enhancement fillers is a more effective method to improve the thermal conductivity of PCMs. The methods for enhancing the thermal conductivity of PCMs, which include adding additives with high thermal conductivity and encapsulating phase change materials are reviewed. The applications of PCMs in solar energy systems, buildings, cooling systems, textiles, and heat recovery systems are introduced as well. It is said that both carbon-based additives and metal-based ones possess excellent thermal conductivity; however, carbon-based additives are better than metal-based additives in terms of density and stability.

Kandasamy Hariharan, et al. [3] investigated the phase change behavior of paraffin phase change material in a spherical capsule for solar thermal storage units. The melting and solidification behavior of paraffin phase change material encapsulated in a stainless-steel spherical container has been studied. In the melting process, the hot air, used as the heat transferfluid enters the test section and flows over the spherical capsule resulting in the melting of PCM. In the solidification process, the ambient air flows over the capsule and received heat from phase change material resulting in the solidification of phase change material. A computational fluid dynamics analysis has also been performed for the encapsulated PCM during the phase transition process. The reasons for the deviation between the results are analyzed. The CFD results show that the time needed for solidification is 33% more and the time needed for melting is 30% more compared to the respective experimental results.

Solar water heater with PCMs such as LHTES is getting popularity since they are simple to fabricate, easy to maintain, and relatively inexpensive. Internationally the demand for solar water heaters is increasing significantly in the last decade. Solar water heating system is generally very simple using only sunlight to heat the water. Working fluid water is brought in contact with a dark surface which is exposed to sunlight, causing the rise in temperature of the fluid. They can be classified into two main categories: (a) Active systems in which pumps are used to circulate the water or a heat transfer fluid, (b) Passive systems (or thermosyphon systems) in which the water or a heat transfer fluid is circulated by natural convection. The solar water heater performance is improved by connecting the solar water heater in series or by adding energy storage material into the storage tank.

Various methods are attempted to improve the functionality of solar water heaters by adding PCMs to the tank. Some of these techniques are (i) To get hot water in off sunshine period; the solar water heater containing the layer of PCM-filled capsules is used. (ii) A system having a double rectangular enclosure in which water is filled in the bottom enclosure and paraffin wax is filled in the top enclosure. (iii) Identical eight typical solar water heaters were connected serially with the PCM, and small aluminum cylindrical containers containing paraffin wax [4].

Abdul Jabbar N. Khalifa et al. [5] used solar collectors integrated with the back layer of paraffin wax for their experimental investigation. Evaluation of various parameters regarding the collector plate shows the plate temperature is increased up to a certain distance after which it is nearly constant which clearly shows the storage of the energy in the PCM.

Pasam Bhagyalaxmi et al. [6] selected paraffin wax and palmitic acid as PCM mixed in different proportions (40-60%, 50-50%, and 60-40% PW-PA) and investigated their thermal behavior through DSC and further similar studies were also conducted by mixing copper oxide Nano-powder with paraffin wax.

Murali G., et al. [7] investigated the effect of stratification in the solar water heater tank providing latent thermal energy storage with the ratio of improved surface to volume and compared the stratification caused by in-flow from the open side inlet and open bottom inlet attained with a diffuser.

Al-Hinti I., et al. [8] investigated experimentally, the performance of water as a phase change material to store thermal energy for use with conventional solar water heating systems. The forced convection used for a short time shows the minimum effect on the performance of the system. The performance of the system was analyzed under an open-loop operation pattern, simulated with the daily used pattern.

#### 2.1 Research Gaps

As solar energy is the most abundant, cleanest, renewable energy source available, it is widely used in domestic solar water heating systems. Its main drawback is that it is available only in the daytime. To bridge the gap between available solar energy and the demand for hot water, an effective TES system is required. Conventional solar water heaters store energy by increasing the temperature of water in the form of sensible heat. LHTES system store thermal energy as latent heat by changing the phase from solid to liquid, therefore, offers greater energy storage compared to conventional solar water heating system. PCM is a material used in LHTES systems to store thermal energy by transforming its phase from solid to liquid or vice-versa. Change of phase from liquid to vapor involves a large change



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in volume and high pressure, therefore it is not a good practice. In PCMHE-based solar water heating systems, energy can be stored in the daytime when solar energy is available and used later in the nighttime.

## 2.2 Research Objectives

The main objective of this research is to enhance the performance of a PCMHE by employing a suitable geometric configuration that gives maximum heat transmission from tubes the following objectives have been formulated for carrying out the present research work.

(i) CFD Modeling and simulation of PCM Heat exchanger of Shell & tube type filled with PCM having circular tubes.

(ii) CFD Modeling and simulation of PCM Heat exchanger of Shell & tube type filled with PCM having elliptical tubes.

(iii) CFD Modeling and simulation of PCM Heat exchanger of Shell & tube type filled with PCM having circular tubes with fins.

(iv) A comparison of the results of the circular tubes, elliptical tubes, and circular tubes with fins and the best-suited configuration of the PCM Heat Exchanger is selected.

## **3. METHODOLOGY**

2D CAD models have been developed and investigated in Ansys Fluent for heat transfer analysis in circular and square shell PCMHE. The equations of conservation of mass, momentum, and energy for the current model have been developed and solved using CFD in Ansys Fluent. To fulfill identified research objective following research methodology will be adopted.

(i) Literature study of PCMs in LHTES for solar water heating systems for domestic applications.

(ii) Study of CAD (Solid Works) and CFD software (Ansys Fluent) for modeling and simulation of geometries of PCMHE.

(iii) 2D Modelling of all geometries of PCMHE of circular and square shells having circular and elliptical tubes with and without fins.

(iv) CFD simulation of all geometries of PCMHE of circular and square shells having circular and elliptical tubes with and without fins.

(v) CFD Simulation result comparison of all geometries of PCMHE of circular and elliptical tubes with and without fins.

(vi) Selection of best-suited PCMHE geometry for solar water heating system.

(vii) Conclusion and future scope.

## 4. CONCLUSIONS AND FUTURE SCOPE

## 4.1 Conclusions

This research work is conducted with the objective of enhancing the performance of a PCMHE by using such a configuration that gives a maximum heat transfer rate with the minimum meltingtime of PCM. To find such a type of best-suited configurations numerical investigations are carried out.

PCMHE is used to analyze the phenomenon of melting. Two- dimensional CFD models of PCMHE of the square and circular shell having four tubes of different shapes (circular, square, and elliptical) with and without fins on the outer surface of the tubes have been generated. The effects of the shape of tubes, the introduction of fins on the outer surface of the tubes, and the number of fins on the heat transfer rate at different temperatures applied on the outer surface of the tubes have been analyzed and discussed in detail with the helpof various contours available from simulations. The thermal performance data with different configurations of PCMHE is compared to choose a configuration that gives the best thermal performance having minimum melting time.

## 4.2 Future Scope of Present Work

Here in the present analysis, CFD modeling and simulation of PCMHE of shell & tube type filled with PCM having square, circular, and elliptical tubes with and without fins for Gallium as a PCM has been studied and the best suitable geometry of PCM heat exchanger has been selected for the thermal energy storage for domestic solar water heating system. The recommendations for future work are as follows.

- The study can be performed with the other shape of tubes and can be optimized for the best one.
- The analysis can be performed with the other shapes of fins on the tubes of PCMHE.
- The study can be utilized for other types of PCMs like organic, inorganic, and salt hydrates.
- The study can be used with the mixing of higher thermal conductivity materials with the PCM to increase the heat transfer rate.



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