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Simulation and modeling of Shell and Tube Heat Exchanger Filled with PCM for Solar Water Heating System A CFD analysis

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A B S T R A C T

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:TES,LHS,SHS,Solar Heating

1. Introduction

Energy is an essential element required for the existence of human life on earth and plays a vital role in the development of human life. The sudden increase in global energy consumption is a result of the rapid expansion of the global economy. As the world is suffering from energy crises, the growth of civilization has largely depended on human efforts to efficiently produce, store, and convert energy into the desired form. The reasons for the energy crisis are a continuous increase in demand, population growth, and the upgradation of living standards. The major energy resources include fossil fuel-based energy sources; however, these are limited, and additionally, their increased usage is adversely affecting the ecology due to the emission of harmful gasses. It became difficult to fulfill the requirement of energy with conventional recourses as there is a scarcity in the availability of fossil fuel and increasing greenhouse-gas emissions. Thus, it is necessary to utilize various forms of natural or renewable resources [1]. Researchers over the world are working hard to overcome this situation by focusing on natural and renewable resources of energy through scientific experiments.. 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.Currently, when researchers around the world, are looking for solar energy to use as an alternativetofossilfueltofulfilltheenergydemand,the mainchallengeis thecontinuoussupply of solar energy. Solar energy though, simple to utilize, non-polluting and everlasting, is time- dependent and has intermittent character.

Nomenclature

1.1 Classification of Thermal Energy Storage

The phase transition of a substance at a fixed temperature is used by the LHS system. It is based on the basic principle that when heat is applied to a substance, it changes its phase from solid to liquid and stores thermal energy as latent heat of fusion. If heat is applied to a liquid, it transforms into a vapor and stores the thermal energy as latent heat of vaporization. A solid-to-

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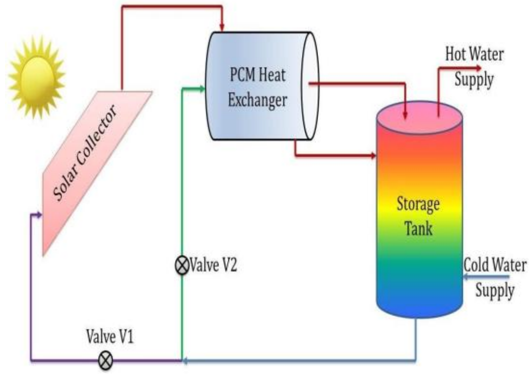
liquid phase transformation is usually achieved by melting & solidifying a material. Liquid to vapor phase transition involves high pressure and a significant volume rise and solid to solid phase change is very slow and has very low energy density. So LHS of solid-to-liquid phase change is the only practical method of storing thermal energy. In solid to liquid phase transition, when a substance melts, heat is transmitted to it,:



The materials used for LHS during phase transition are referred to as phase change materials (PCM). Numerous materials are investigated for PCM, but only a few numbers have found commercial success , primarily because issues including phase separation, subcooling, corrosion, long-term stability
In the past few years, LHS techniques for solar heating and air cooling have attracted a wide variety of interest due to their ability to store enormous energy when a phase transformation occurs at a fixed temperature. The significant amount of heat that must be absorbed or released when a material transforms its phase into liquid from a solid, or vice versa, is called the latent heat of melting [9]. PCMs can be selected so that their phase change temperature optimizes the thermal gradient based on the substance with which heat is being transferred.

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 saltsSection headings Section headings should be left justified, bold, with the first letter capitalized and numbered consecutively, starting with the Introduction. Sub-section headings should be in capital and lower-case italic letters, numbered 1.1, 1.2, etc, and left justified, with second and subsequent lines indented. All headings should have a minimum of three text lines after them before a page or column break. Ensure the text area is not blank except for the last page.

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 quicklyFile naming and delivery

2. Literature Review

Regin et al. [41] reported on the melting characteristics of paraffin wax contained in cylindrical capsules. Studies have been carried out with the parameters namely, natural convection, contact melting, and phase change temperature and their effects on heat transfer characteristics.Results show that magnitude of Stefan's number governs the melting process. The PCMs are also used with spherical geometry which has a number of advantages over other geometries. It has a favorable ratio between the volume of energy stored and the area for heat transfer.
J. P. Bedecarrats et al. [42] reported on the performance of PCM encapsulated in spherical containers during the charging and discharging process. In this study water with nucleating agent was used as PCM. Results show faster heat storage for lower inlet temperature and larger flow of heat transfer fluid.
Determination of a feasible heat storage material was carried out by,
M. Veerappan et.al. [43] with 35 mol% lauric acid and 65 mol% capric acid, calcium chloride hexahydrate, n-octadecane, n-hexadecane, and n-eicosane inside spherical enclosures. Results were validated with the modeldeveloped for melting and solidification in a sphere with conduction, natural convection, and heat generation. The investigation shows that calcium chloride hexahydrate has excellent characteristics for solar latent heat storage applications. The parametric study shows that during solidification higher heat flux is released at lower fluid temperature and thereafter drastic

decrement in the heat flux was observed. Numerical and experimental studies for constrained and unconstrained melting in the spherical capsule were carried out to understand the buoyancy- driven convection for the constrained melting process [44,45].

LeventBilir and ZaferIlken [46] numerically formulated the inward solidification problem of PCM encapsulated in a spherical/cylindrical container. A dimensionless total solidification time of PCM was set in terms of the Biot number, Stefan number, and superheat parameter.PCMs can be used for various applications and storage of solar energy is one of them. However, this source is diluted and scattered which depends upon the day-night cycle and weather conditions. Due to its uneven nature, it is difficult to apply it effectively in domestic use, particularly in solar water heating systems. In solar water heaters, energy is stored during day time, and hot water is consumed in the evening and in the morning. Therefore, it is necessary to store the energy which is available during day time. The use of PCMs is the valid solution to this complexity because of their isothermal behavior, small unit size, and high heat storage capacity during charging and discharging [47]. The next part of the review gives different methods which are applicable for enhancing the performance of solar water heaters by applying different kinds of PCMs.

G. Murali et al. [48] Examined the performance of PCM-incorporated thermosyphon solar water heating system. PCM cylinders are used in water tank charging to carry out charging anddischarging experiments. The discharging experiments with and without PCM are validated by CFD simulation.

H. M. Teamah, et al. [49] 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.

Yaxue Lin, et al. [50] 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. KandasamyHariharan, et al. [51] 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. PasamBhagyalaxmi et al. [56] 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. [57] 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.

3. Methodology

3.1 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 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.

3.2 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.

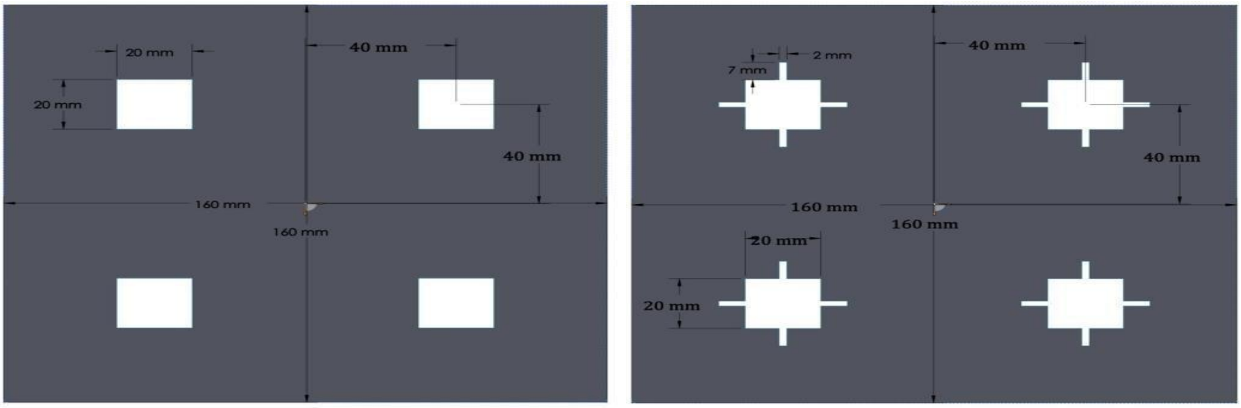
(iii) CFD Modeling and simulation of PCM Heat exchanger of Shell & tube type filled with PCM having circular tubes with fins.

(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.

The main challenge with PCMHE is the low heat transfer rate due to the lower thermal conductivity of PCMs. To overcome this problem, a different configuration of PCMHE with & without fins & different shapes of the tubes are modeled in this chapter. To accelerate heat transmission and to reduce PCM's melting time, a number of fins are incorporated into the tubes of different shapes.The CFD simulation of all the geometries of PCMHE has been done in Ansys Fluent after creating a finite element model (FEM) by meshing the physical model. A 3D model of PCMHE has a very large number of elements in FEM and takes a very long computational time to solve the mass, momentum, and energy equations. Also, the results are much better in 2D analysis compared to 3D analysis [88]. Hence a 2D CAD model of PCMHE is selected for this study. Geometrical modeling of PCMHE of shell and tube type, in which a solid PCM is filled in the outer shell and four tubes of different shapes has been done in Solid Works in 2D. In this work, the outer shell of PCMHE is selected in two different shapes: square and circular. The tubes inside the outer shell of PCMHE are also selected in different shapes i.e. circular, square, and elliptical as well as in different configurations i.e. with and without fins.

S.N.	Parameter	ConfigurationofHeatExchangers		
1	Geometry	CircularTube	SquareTube	EllipticalTube
2	SurfaceArea	37173 mm^2	37191 mm^2	37179 mm^2
3	Dimensionsof tubes	Ø30mm	26.5 mm ×26.5 mm	38.7 mm ×23.2mm

A different investigation has also been made in a square shell geometry having square tubes. To enhance the heat transmission and to reduce the PCM's melting time, four fins are inserted on the outer surface of the square tubes. Two configurations of PCMHE with square shell geometry,square tubes without fin and square tubes with four fins, have been modeled in this study. The dimensions of the square shell in both configurations of PCMHE are taken to be 160×160 mm. The size of the square tubes in the square shell is taken as 20×20 mm and the distance of the center of the tubes from the center of the square shell is kept at a distance of 40 mm horizontally as well as vertically for the uniform melting of PCM. Four rectangular fins are mounted on the square tubes and the dimension of the fins are 7×2 mm

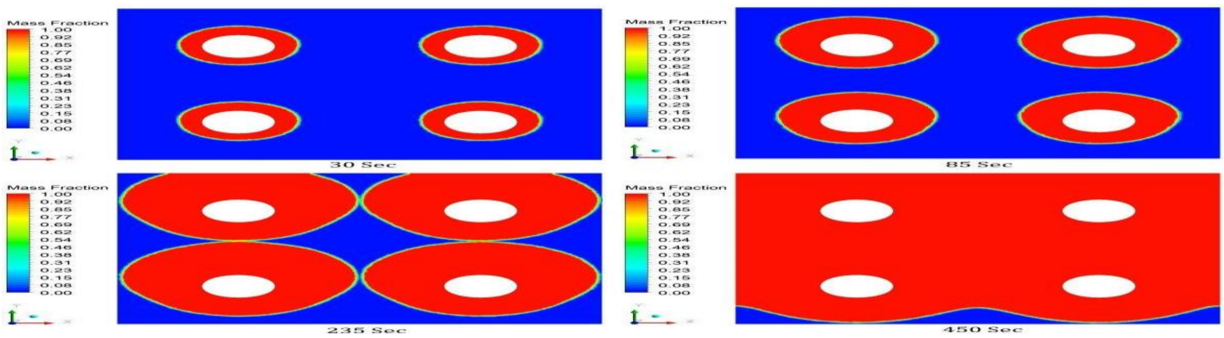


PhysicalmodelingandgeometricaldimensionsofthesquareshellPCMHE having square tubes with and without fins

A 2D CFD computational investigation is then performed on the PCMHE having a square shell filled with solid PCM and an HTF fluid flows at a higher temperature compared to the starting temperature of the PCM in the circular, square, and elliptical tubes.

4. ResultsandDiscussion

A 2D CFD investigation for the melting of PCM and heat transfer characteristics of the square shell PCMHE having circular, square, and elliptical tubes are analyzed in this study. The variation in the shape of the tubes at a fixed temperature of 60oC applied on the outer surface of the tubes has been utilized for the analysis and the effect of the shape of these tubes on the melting of PCM in terms of liquid proportion and melting time has been analyzed. The melting duration of PCM is 745 seconds for a configuration with circular tubes, 650 seconds for a configuration with square tubes, and 740 seconds for a configuration with elliptical tubes. The duration by the PCM to reach 60oC from the initial temperature of 27oC with a melting temperature of 30oC for a configuration with circular tubes is 800 seconds, for a configuration with square tubes is 725 seconds, and for a configuration with elliptical tubes 770 seconds. Hence it is indicated by the results that the lowest melting time of PCM can be obtained by the heat exchanger having square tubes followed by elliptical tubes and circular tubes at a temperature of 60oC.



Because of the similarity of the geometry around the axial direction, the melt regions are similar in shape around the circular tubes during the beginning of the melting process, when conduction accounts for the majority of heat exchange in PCM. Heat transmission inside PCM occurs due to free convection after 85 seconds when the majority of the melting around the circular tubes goes upward because of buoyancy effects, as seen in the contours

5. Conclusions and Future Scope

5.1 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 melting time 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 help of 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.

5.2 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.

References

[1] A.F. Regin, S.C. Solanki, J.S. Saini, Heat transfer characteristics of thermal energy storage system using PCM capsules: A review, Renew. Sustain. Energy Rev. 12 (2008) 2438–2458. https://doi.org/10.1016/J.RSER.2007.06.009

[2]]. I. Purohit, P. Purohit, Performance assessment of grid-interactive solar photovoltaic projects under India's national solar mission, Appl. Energy. 222 (2018) 25–41. https://doi.org/10.1016/j.apenergy.2018.03.135

[3]A. Sharma, V. V. Tyagi, C.R. Chen, D. Buddhi, Review on thermal energy storage with phase change materials and applications, Renew. Sustain. Energy Rev. 13 (2009) 318– 345.https://doi.org/10.1016/J.RSER.2007.10.005.

[4]L.F. Cabeza, Thermal energy storage, Elsevier Ltd., 2012. https://doi.org/10.1016/B978-0- 08-087872-0.00307-3. H. Mehling, L.F. Cabeza, Heat and Cold Storage with PCM: An Up to Date Introduction Into Basics and Applications, 2008. https://doi.org/10.1007/978-3-540-68557-9

[5]. F.P. Incropera, D.P. DeWitt, Fundamentals of Heat and Mass Transfer, 1996. https://doi.org/10.1016/j.applthermaleng.2011.03.022

[6]. S.M. Hasnain, Review on sustainable thermal energy storage technologies, Part I: heat storage materials and techniques, Energy Convers. Manag. 39 (1998) 1127–1138. https://doi.org/10.1016/S0196-8904(98)00025-9.

[7] A.I. Fernandez, M. Martnez, M. Segarra, I. Martorell, L.F. Cabeza, Selection of materials with potential in sensible thermal energy storage, Sol. Energy Mater.Sol.Cells. 94 (2010) 1723–1729. https://doi.org/10.1016/J.SOLMAT.2010.05.035.