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Modelling and Simulation of Solar Water Heater Integrated with Phase Change Material in Solar Collector

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A B S T R A C T

Sun is the source of solar energy. So, the solar energy from the sun at all times energy should be stored and used when needed. Solar energy is important one renewable energy resources. The solar water heater has an important place among solar heating collectors due to the fact that construction of the water heater requires less material than others. the solar water heater maybe used for space heating and drying. the main objective of this project is to increase the thermal efficiency of flat plate collector in solar water heater. to improve the efficiency of the flat plate collector, it is integrated with PCM to enhance the heating rate of the solar water heater the PCM is integrated and stored directly in flat plat collector. The solar water heater is designed using SOLIDWORKS. the performance of the flat plate collector is ANSYS analysis with and without using PCM. The efficiency of the solar collector is increased up to 7 to 20 % while compared with and without using PCM.As a result by comparing with and without using PCM. Myristic acid and paraffin wax PCM has a very good thermal capacity and the heat discharge.the system can be reducing by different type of systems integrate with phase change materials into solar collector. This is for efficient way for storing and trapping solar energy. The application of phase change materials in cooling and heating systems is to improve overall efficiency, reduce electrical power consumption and greenhouse gas emission. The heat storage unit consisting of phase change materials. This study helps to developing a new advancement experimental setup of solar water heating system with phase change materials. The results obtained from ANSYS analysis shows that there is an increase in efficiency of about 6-12 % when we go for solar water heater rather than solar collector.

Keywords: *PCM, ANSYS WORKBENCH, SOLIDWORKS, SWH system, performance improvement.*

1. Introduction

As a renewable energy source, solar energy is free, environmentally friendly and available in abundant. The solar energy is the renewable energy it regenerated in day by day. So, the using solar energy initial cost only. The solar energy it used for heating, coking purpose and electricity generation. The recent days using for phase change materials for storage the thermal energy in solar water heaters for domestic purposes during night time. Solar energy can be converted into thermal energy using solar collectors. Solar collectors are used in many industrial, commercial and domestic applications such as solar water heating, solar space heating, solar drying, solar desalination. Solar radiation is an optional energy source for industrial and domestic applications. Phase change material is a substance with a high heat of fusion which melting & solidifying at a certain temperature. It is capable of storing & releasing large amount of energy. Thermal performance and efficiency of solar water heater depends on its thickness, design parameters, number and type of insulation and glass covers, space between absorber and inner glass. Its performance also depends on climatic and operational parameters. The water circulation in solar water heater is natural due to the density differences between the hot water and cold wate Collector panels are used solar water heating systems to collect the sun's radiation and convert it into useful heat in the form of hot water. A solar collector conjugate with solar water storage reduces the fuel needed for house hold hot water. Solar thermal systems could make a share to space heating as well as furnishing hot water. Water flows through tubes and get in black metal absorber plate. The absorber plate is enclosed with an insulated box with a crystal-clear window to let in sunlight. The hot water is transferred to a tank from where we can use it for home or institutional use.

1.1 INTRODUCTION TO SOLAR WATER HEATER TECHNOLOGY

Solar water heaters are basically a system that uses the sun radiations in order to heat water or air which can be used in domestics or industries. It is not a new technology since it was used in the 19th century, where they painted tanks with black paints in order to absorb sun energy. Solar water heaters have been around since the 1890s, when the first system was patented and became commercialized. The ability to improve this concept has been tried and tried again, especially in recent history and not just in the use of solar energy for heating, but for power as well. Due to the awareness of climate change being evident in the world today, solar energy is being sought out like never before, for example, as in solar lights, solar cookers, solar batteries, solar cameras, etc.

All these products share one thing in common, which is converting solar energy into another form of energy for a solar water heater, the emphasis is on converting solar energy to thermal energy. For this reason, materials that conduct and insulate are of great importance, specifically, ones that have high conduction and convection coefficients. Another important factor is the ability to harness solar energy, especially when it comes to the emissivity of the components. This design is dependent on the sun, and when and how much radiation is available. With these factors taken into consideration, the costs and benefits of designs can be compared. The heat transfer is the main point of analysis in experimentally determining these factors. By determining efficient conductive and inductive materials and perfecting solar energy absorption with emissivity, the design of a solar water heater can be cost effective and maximized in benefits. The aim therefore, is to try and produce a more efficient solar water heater that can be used in all parts of the world and can be affordable. The proposed design is efficient and therefore the operating parameters for mechanism of heat and heat transfer properties are modelled and optimized for efficient operation. The tool of stochastic material property was identified at the optimal heat transfer mechanism. Empirical data was obtained to validate the theoretical derived in solar water heater. The efficiency of a flat plate solar collector is defined as the amount of energy captured by the collector divided by the amount of energy available in the incident solar radiation. The efficiency of a collector decreases as the temperature of the collector increases. The efficiency of a collector is highest when the collector is directly facing the sun and the radiation intensity is at its peak. The efficiency of a collector increases with the size of the collector surface area. The efficiency of a collector varies depending on the design and materials used in the construction of the collector. Heat losses from the collector due to convection, conduction, and radiation decrease the efficiency of the collector.

2. Problem Statement

This project is intended to design a water heating system by using solar technology. Improve the thermal performance of the solar collector by incorporating a phase change material to store and release thermal energy, which can lead to a more consistent and stable supply of hot water. The need to be analysed to determine the efficiency of the flat plate solar water heater with PCM in the solar collector. This would involve analysing parameters such as temperature distribution, heat transfer rate and phase change behaviours.

2.1 OBJECTIVES OF THE PROJECT

The objective of a project involving a solar water heater with a solar collector containing a phase change material can be to:

I. Design and develop an efficient solar water heating system that utilizes a renewable energy source solar radiation to provide hot water.

II. Improve the thermal performance of the solar collector by incorporating a phase change material to store and release thermal energy, which can lead to a more consistent and stable supply of hot water.

III. Analyse the thermal performance of the solar water heater with and without the PCM to determine the effectiveness of the PCM in enhancing the efficiency and performance of the system.

IV. Optimize the design of the solar water heater to achieve maximum efficiency and performance.

V. Study the effects of various factors such as solar radiation intensity, absorptivity of the collector, overall heat transfer coefficient, mass flow rate of the water, and inlet and outlet temperatures of the water on the performance of the solar water heater with and without the PCM.

VI. Compare the performance and efficiency of the solar water heater with PCM to those of conventional solar water heaters to demonstrate the benefits and advantages of using a PCM in solar collectors.

Present the results of the analysis and optimization in the form of performance curves, efficiency calculations, and recommendations for further improvements to the design and operation of the solar water heater.

3. Literature review

[1] Rout et al-performed a detailed economic analysis using Monte Carlo simulation and net present value (NPV) tool. The NPV based on eight dynamic variables assures the competence of domestic SWH as a viable option irrespective of its high initial investment cost.

[2] Peres-experimentally investigated the long-term performance of an FPC and an ETC based SWH system under the meteorological conditions of Sweden. The reported findings suggest that the ETC had better performance in comparison with that of the FPC based SWH system.

[3] Zambian and Col-presented a theoretical and experimental analysis to determine the daily efficiency of a flat-plate and an ETC based SWH. The observed findings suggest that ETC based SWH has higher efficiency over wide operating conditions with limited heat losses.

[3] Sokhansefata *et al*-reported a thermo-economic analysis performed on a flat-plate and an ETC based SWH system. The TRNSYS-16 software predicted the annual collector energy output and the outlet temperature. The ETC based SWH system was economical and outperformed the FPC system by 41%.

[4] Budihardjo and Morrison-presented an experimental and numerical analysis to determine the optical and heat loss characteristics of evacuated tube SWH. The results suggest that the tank size was less significant for evacuated collectors in comparison with FPC.

[5] M. E. El-Agouz et al- studied the performance of a flat plate solar water heater with a PCM layer placed between the absorber plate and the water flow channel. The PCM also helped to maintain the temperature of the water at a more constant level during periods of low solar radiation. Other studies have investigated the use of different PCMs and different configurations of the solar collector and the PCM layer. **[7] H. M. N. Al-Furjan et al-** studied the use of a flat plate solar water heater with a PCM layer placed on the bottom of the water tank. The PCM used in this study was a eutectic mixture of stearic acid and palmitic acid with a melting temperature of 61°C. The results showed that the system with PCM had a higher efficiency and lower heat loss compared to the system without PCM. The PCM also helped to maintain the temperature of the water at a more constant level during periods of low solar radiation.

[8] B. Kanimozhi, and B. R. Ramesh Bapu, they give review the heat transfer enhancement techniques are required for many latent heat thermal energy storage system; various methods are proposed to enhance the heat transfer in latent heat thermal energy storage system, such as metallic filters, metal matrix structures and finned tubes were used to improve thermal conductivity of phase change materials. This paper presents work to analyse the application of the PCM in thermal energy storage systems, and the enhancement of the heat transfer from the solar tank to the PCM storage tank. PCM materials and their performance of charging and discharging of a storage tank were tested experimentally.

[9] Thomas Hasenohrl, This paper briefly discusses the physical reason for this property and some important applications of PCMs. Moreover, the major advantages and drawbacks of salt hydrates and paraffins used as PCMs and some solutions to cope with the low thermal diffusivity of paraffins are presented.

[1o] Thirugnanam.C, Marimuthu.*P [3]*, A significant amount of heat is wasted in manufacturing process, electricity generation, chemical and industrial process. Recovery and reuse of this energy through storage can be useful in conservation of energy. In the present study, experiments were performed for two different mass flow rates and inlet temperature of heat transfer fluid (HTF) is maintained at constant in charging process.

Outcomes of Literature Review

Overall, the use of PCM in flat plate solar water heaters has shown promising results in improving their efficiency and reducing heat loss. However, more research is needed to optimize the configuration of the solar collector and the PCM layer and to investigate the long-term performance and durability of these systems.

4. Methodology

The According to our requirements, it has to select the materials which depends on thermal conductivity having higher and lower for the inner and outer tubes respectively. A model is created using our specified dimensions by Ansys Design Module software. Then import the model to Finite Element Analysis and made a Computational Fluid Dynamics analysis using Ansys Workbench software. Finally, discuss the result obtained by CFD analysis and give conclusion.

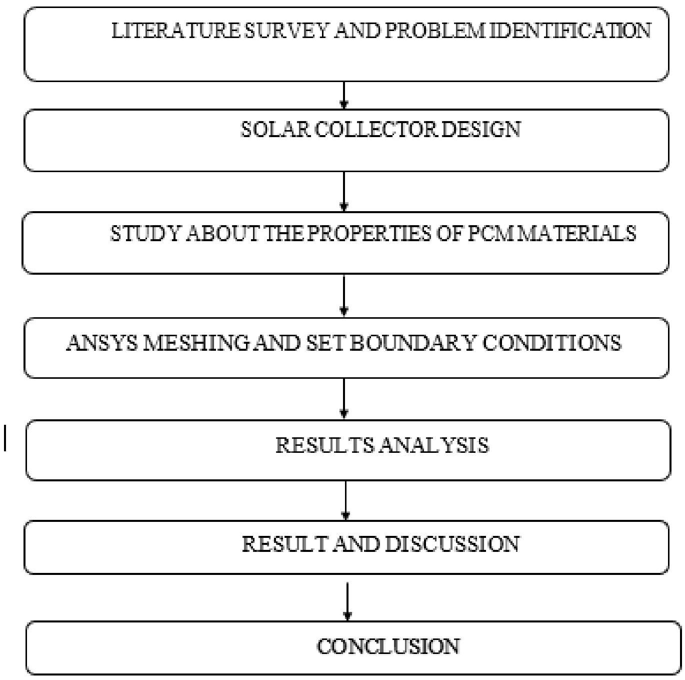


Fig 4.1 Methodology

5. Material selection

5.1. PCM SELECTION:

The select a suitable PCM that can store the thermal energy collected by the solar collector during the day and release it at night or when the demand for hot water is high. The PCM should have a melting point that is close to the operating temperature of the solar collector and a high latent heat of fusion to maximize the amount of energy stored.

5.1.1 PCM INTEGRATION:

The PCM is then integrated into the solar collector by placing it in direct contact with the absorber plate. When the solar radiation is absorbed by the absorber plate, it heats up the PCM, causing it to melt and store the thermal energy. When the demand for hot water arises, the water is circulated through the collector, and the heat stored in the PCM is transferred to the water.

When selecting materials for a phase change material (PCM) in a solar water heater project, several factors should be considered, including the thermal properties of the material, its compatibility with the surrounding materials, and its cost and availability.

Paraffin wax and myristic acid are two commonly used PCMs in solar water heaters. Paraffin wax has a melting point in the range of 50-70°C and a specific heat capacity of around 2.0-2.5 kJ/kg-K. Myristic acid, on the other hand, has a melting point of around 55°C and a specific heat capacity of around 2.3 kJ/kg-K.

Both paraffin wax and myristic acid have good thermal properties for use as PCMs in solar water heaters, but they have different advantages and disadvantages. Paraffin wax is widely available and relatively low cost, but it can degrade over time and release volatile organic compounds into the environment.

Myristic acid is more stable and has a higher heat of fusion than paraffin wax, but it is more expensive and less readily available

In addition to these factors, it is also important to consider the compatibility of the PCM with the materials used in the solar water heater, such as the piping, storage tank, and collector. The PCM should not react with these materials or cause any degradation or corrosion.

Ultimately, the choice of PCM will depend on the specific requirements and constraints of the solar water heater project. It may be beneficial to perform simulations and experiments to evaluate the performance and compatibility of different PCMs under different conditions.

6.1 DESIGN OF SOLAR WATER HEATER:

The design of a solar collector with PCM involves the selection of appropriate materials and the configuration of the collector. The following factors should be considered in the design of a solar collector with PCM:

I. The type of PCM: The PCM should have a high latent heat of fusion and should be able to withstand repeated phase change cycles.

II. The melting temperature of the PCM: The melting temperature of the PCM should be selected based on the operating temperature range of the solar collector.

III. The thermal conductivity of the PCM: The thermal conductivity of the PCM should be high enough to facilitate rapid heat transfer.

IV. The configuration of the collector: The collector should be designed to ensure good contact between the PCM and the absorbing surface.

6.1. Transient Thermal Analysis:

The ANSYS thermal and analysis determines temperatures and other thermal quantities that vary over time. Engineers commonly use temperatures that a transient thermal analysis calculates as input to structural analyses for thermal stress evaluations. Many heat transfer application sheet treatment problems, nozzles, engine blocks, piping systems, pressure vessels, etc., involve transient thermal analyses.

A transient thermal analysis follows basically the same procedures as a steady-state thermal analysis. The main difference is that most applied loads in a transient analysis are functions of time.

The full geometry of collector was created in the SOLIDWORKS Software using the various features available in solar water heater to create various parts of collector with the help of specifications to get the model of the solar collector which is shown in fig 6.1, Computational mesh is used as a pre-processor for the CFD solver and post – processor, namely FLUENT in gambit.The 3D geometry of solar water heater was modelled using SOLIDWORKS Design Modeler with all the geometrical constraints same as in the experimental setup. The three-dimensional model geometry of Solar water heater along with its unstructured meshes is shown in figure 6.3. The physical model of the building was then meshed using 3D hexahedral meshing consist of in ANSYS's workbench MESHING. Mesh generation is one of the most critical aspects of engineering simulation.

ANSYS meshing technology provides a means to balance the requirement and obtain the right mesh for each simulation in the most automated way possible. Meshing ensure that best design is made. It checks the defect of the model. It also checks whether there is any miss alignment in the design. By integrating best in class meshing technology into a simulation driven workflow, ANSYS meshing provides a next generation meshing solution through a wide variety of methods

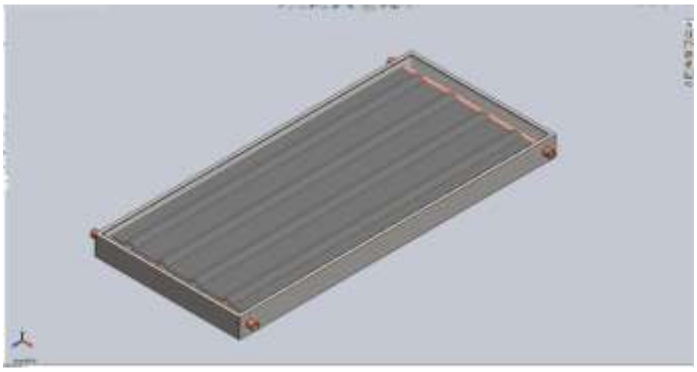


Figure 7.1 Model of Solar Water Heater

6.2. Modelling Of solar water heater

Modelling of the Fins done using CATIA V5R20 has been explained in detail. Fins models designed with the material selection of aluminium alloy 6061, magnesium alloy, grey cast iron and Two Fins model designed here, Trapezoid fins and Rectangular fins. Fins model with type of Trapezoid and

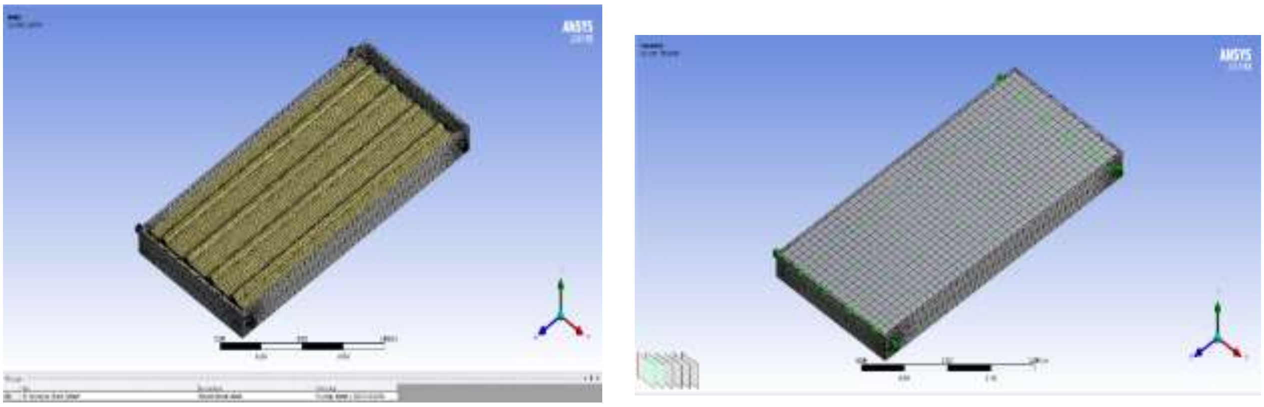


Figure 7.2 Assembled model of Solar Water Heater

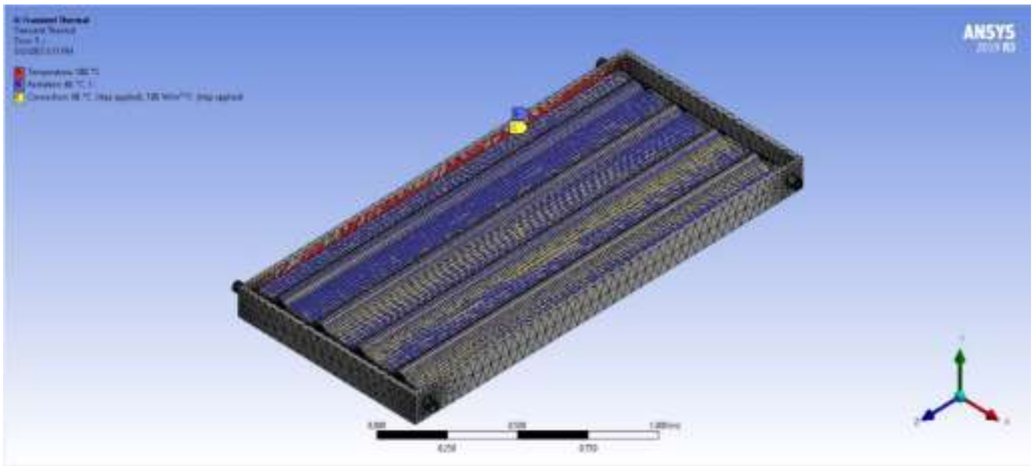


Figure 7.3 Modelling of solar water heater

The model comprises all the nodes, elements, material properties, real constants, boundary conditions and additional features that are used to characterize the physical system. all models be generated then specific boundary conditions will be applied on the specific nodes then final analysis will be conducted.

7. Results and Discussion

Static For this study, the use of PCM (phase change material) in solar collectors is a promising approach to improve the efficiency of solar water heaters. In this simulation, paraffin wax was used as the PCM. ANSYS Workbench is a powerful software tool that can be used to simulate the behaviour of heat transfer and fluid flow in complex systems such as solar collectors with PCM.

The simulation results can provide insights into the temperature distribution and heat transfer in the system. The temperature difference between the inlet and outlet of the solar collector is a critical parameter that indicates the efficiency of the system.

Based on the simulation results, it was observed that the use of PCM in the solar collector led to a significant reduction in the temperature difference between the inlet and outlet. This reduction in temperature difference indicates that the PCM is effectively absorbing and storing the thermal energy from the solar radiation.

Additionally, the use of PCM leads to a delayed melting process, which helps to maintain the temperature of the water at a relatively constant level. This delayed melting process is beneficial because it enables the solar collector to provide hot water for a longer period of time, even after the solar radiation stops.

The simulation also showed that the heat transfer coefficient increased as a result of using PCM in the solar collector. This increase in heat transfer coefficient is due to the higher thermal conductivity of the PCM compared to the water.

In summary, the simulation results show that the use of paraffin wax as a PCM in solar collectors can significantly improve the efficiency of solar water heaters by reducing the temperature difference between the inlet and outlet, maintaining a constant temperature, and increasing the heat transfer coefficient. ANSYS Fluent provides various tools to visualize and analyse the heat transfer, temperature distribution, and other relevant parameters. The results can be used to optimize the design of the solar collector and the PCM layer for improved performance.

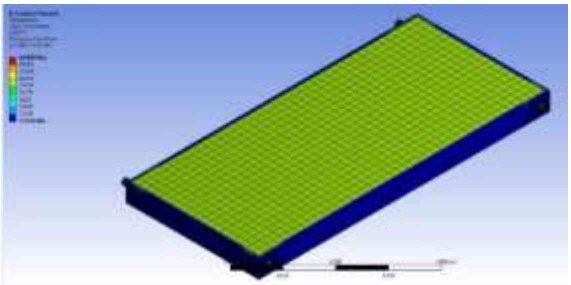
Overall, using ANSYS software to simulate a flat plate solar water heater with a PCM in the solar collector can provide valuable insights into the performance of the system and help in the design and optimization of the system for optimal energy efficiency.

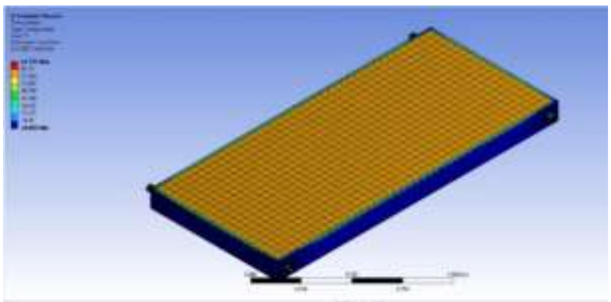
7.1. COMPARING THE RESULTS OF SWH WITHOUT PCM AND WITH PCM IN SOLAR COLLECTOR:

In a flat plate solar water heater without PCM, the rate of heating is primarily determined by the heat transfer coefficient between the absorber coating and the fluid circulating through the collector. This coefficient depends on factors such as the fluid flow rate, the material properties of the absorber coating, and the surface area of the collector. The higher the heat transfer coefficient, the faster the fluid will heat up as it flows through the collector.

In a flat plate solar water heater with PCM, the rate of heating can be affected by the phase change properties of the PCM. When solar radiation is absorbed by the collector, the PCM can undergo a phase change from solid to liquid. During this phase change, the PCM can store a large amount of energy, which can slow down the rate of temperature rise in the collector. However, once the PCM has fully melted, it can continue to absorb heat and raise the temperature of the fluid more rapidly than a collector without PCM. Therefore, the rate of heating in a flat plate solar water heater with PCM can be slower initially but faster later on, compared to a system without PCM.

After giving all the necessary inputs properties of various volumes of the collector to the software as shown in table and figure was performed the calculations inside it and gives the related output in the form of contours for distribution of parameters, reports which include data at various faces and graphs.





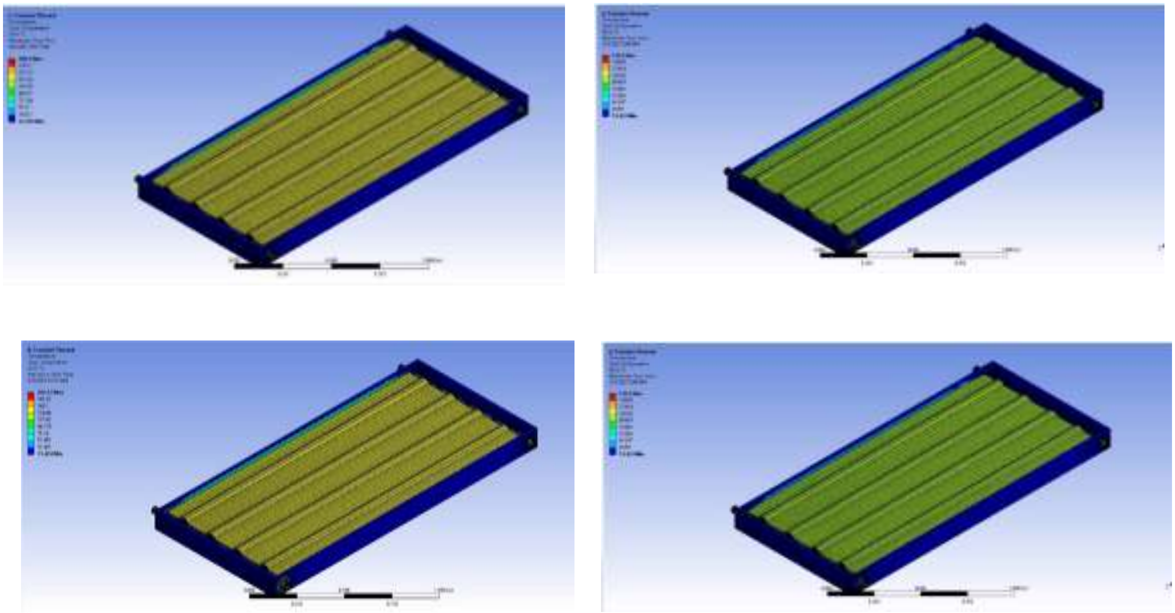
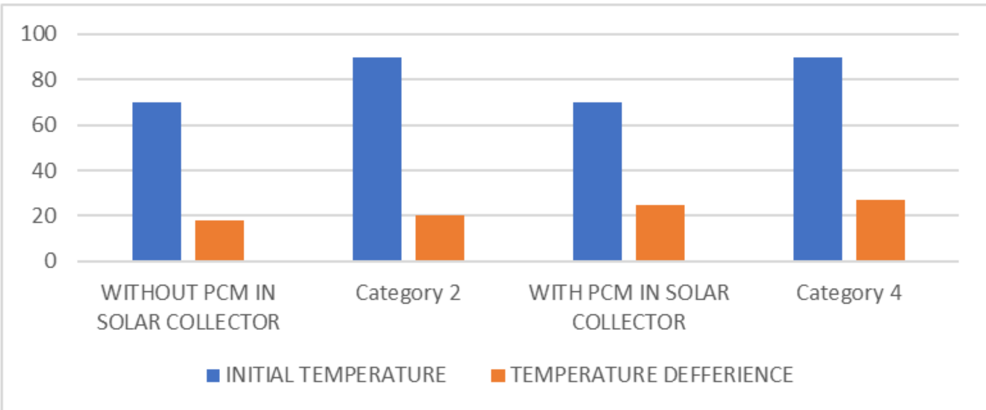


Figure. 7.4: Temperature difference of solar water heater with and without PCM in solar collector

Overall, the rate of heating in a flat plate solar water heater with or without PCM can vary depending on the specific design and operating conditions of the system. It is important to consider the performance and efficiency of the system as a whole, rather than just the rate of heating. Additionally, the design and configuration of the PCM-based solar water heater can significantly affect the system's performance. The selection of appropriate PCM material, its quantity and location, and the design of the heat exchanger can all influence the system's efficiency and overall performance.

8.1 COMPARING THE RESULTS OF SWH WITHOUT PCM AND WITH PCM IN SOLAR COLLECTOR:

WITHOUT PCM IN SOLAR WATER HEATER		WITH PCM IN SOLAR WATER HEATER	
//TEMERATURE INLET (°C)	TEMPERATURE DIFFERENCE (°C)	TEMERATURE INLET (°C)	TEMPERATURE DIFFERENCE (°C)
70	18	70	25
90	20	90	27
150	15	150	20
200	11	200	16



GRAPH 8.1 WITHOUT Vs WITH PCM IN SOLAR WATER HEATER

Conclusion

The SWH system absorbs solar energy and converts into thermal energy in the form of heat which further utilized to produce hot water. Since solar energy is free available and environmentally friendly which having significant potential for the use to hot water through SWH system. Thermal energy materials are available in the temperature range of 50-70°C temperature ranges which can integrate with the SWH system to store energy during daytime and recovered it during night time to produce hot water. This manuscript offers an outline of the latest investigations for SWS system and its performance by the integrating different solar collectors with the PCM unit. This type of new innovative systems has vast possibilities for domestic and industrial sector to reduce energy consumption for hot water production. A solar collector-storage water heating system is extremely endorsed for low/medium temperature applications as they can solar energy in the form of latent heat during daytime hot water. Flat plate solar water heaters with PCM integrated into the solar collector can provide an effective and efficient way to utilize solar energy for water heating. The results have shown that the integration of PCM in the solar collector can significantly improve the performance of the system, increasing the overall efficiency. The results obtained from ANSYS analysis shows that there is an increase in efficiency of about 6-12 % when we go for solar water heater rather than solar collector. It was found that the PCM's based Solar Water Heating systems having high potential to replace existing system to enhancing the thermal efficiency of SWH system. Future research should focus on optimizing the design and configuration of PCM-based solar water heaters to further improve their performance and increase their adoption in residential and commercial applications.

REFERENCES

[1]. MNRE Annual Report: 2006–2007. Ministry of New and Renewable Energy (MNRE), Government of India, CGO Complex, Lodhi Road, New Delhi (2007).

[2]. A. Mani, S. Rangarajan, Solar Radiation over India (Allied Publishers Private Limited, New Delhi, 1982).

[3]. H. C. Hottl, B. B. Woertz, The performance of flat-plate solar heat collectors, Transactions of the American Society of Mechanical Engineers 64 (1942) 91–104.

[4]. S. A. Kalogirou, Environmental benefits of domestic solar energy systems, Energy Conversion and Management 45 (2004) 3075–3092.

[5]. T. Noguchi, Overview on thermal application of solar energy in Japan, Solar & Wind Technology 2 (1985) 155–171.

[6]. S. C. Bhattacharya, S. C. Kumar, Renewable Energy in Asia: A Technology and Policy Review, World Renewable Energy Congress (WREC), Brighton, UK (2000).

[7]. J. K. Kaldellis, K. El-Samani, P. Koronakis, Feasibility analysis of domestic solar water heating systems in Greece, Renewable Energy 30 (2005) 659–682.

[8]. M. N. Nieuwoudt, E. H. Mathews, A mobile solar water heater for rural housing in Southern Africa, Building and Environment 40(2005) 1217–1234.

[9]. Y. Zhiqiang, Development of solar thermal systems in China, Solar Energy Materials and Solar Cells 86 (2005) 427–442.

[10]. T. T. Chow, K. F. Fong, A. L. S. Chan, Z. Lin, Potential application of a centralized solar water-heating system for a high-rise residential building in Hong Kong, Applied Energy 83 (2006) 42–54