Experimental Investigation of Solar Water Heater Using Phase Change Material

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Abstract- The country's energy demand has grown to an average of 3.65% per annum over the past 30 years .So it has become a need to harness alternate and renewable energy Sources .Today India has one of the highest potential for the effective use of renewable energy sources. The solar collectors work daytime only, and its power depends on the weather. The hot water consumption in family houses is generally bigger in the evening and in the morning, so it is necessary to store the excess solar energy. The collector transform but not store the solar energy. It is necessary to store the energy in a little space. To store excess solar energy from sun an attempt can be made in this project by providing Phase change materials at the bottom of the absorber plate. During the sunshine hours, the Phase change material (PCMs) absorbs latent heat of solar energy and stores the same energy up to its melting point. Similarly during off-sunshine hours, the phase change materials release the energy and which is used for heat the water in the setup. It could result a higher efficiency of the solar collector system. Thermal energy storage system which yields better efficiency during off sun shine hours and well suited for this situation only. So that the conventional system is well adopted for sun shine hours because of its simplicity and cost consideration.

Index Terms- phase change material, solar water heater, paraffin wax,n-tricosane**.**

1. INTRODUCTION

Energy is essential for the existence of human life and plays vital role in the progress of the nation. However the past few years have witnessed a rapid growth in global population putting a tremendous burden on energy resources .In the present scenario the importance of available energy can't be under estimated. Also due to fast growth of the India's economy, the country's energy demand has grown to an average of 3.65% per annum over the past 30 years. So it has become a need to harness alternate and renewable energy sources[1,15,17]. Today India has one of the highest potential for the effective use of renewable energy sources. The country has also invested heavily in recent years in renewable energy utilization. Solar energy being simple to use, clean, non polluting and inexhaustible has received wide spread attention in recent times [2,12,13]. It provides well abundant energy source if utilized efficiently. But this energy is time dependent energy source with an intermittent character. Hence some form of thermal energy storage is necessary for more effective utilization of this energy source. Phase Change Materials (PCMs) is one of the techniques to store this thermal energy in the form of latent heat.[3,14,18] Organic phase change materials (PCMs) are hydrated salts that have large amount of heat energy stored in the form latent heat which is absorbed or released when materials changes state from liquid to solid or solid to liquid. The PCMs retains its latent heat without any change in physical or chemical properties over thousands of cycles. PCMs has wide range of applications; one of them is in the solar water heater [5,16,21,25]. One of their options is to develop energy storage devices, which are as important as developing new sources of energy. Energy storage not only reduces the mismatch between supply and demand but also improves the performance and reliability of energy systems and plays an important role in conserving the energy. Phase Change Materials (PCMs) and utilizing this energy to heat water for domestic purposes during Night time. This ensures that hot water is available throughout the day. The system consists of two simultaneously functioning heat-absorbing units. One of them is a solar water heater and the other a heat storage unit consisting of PCM (paraffin). India Energy storage not only plays an important role in conservation of the energy but also improves the performance and reliability in wide range of energy systems and becomes more important where the energy source is intermittent in nature such as solar. The thermal energy storage can be used in such places where more variation in temperature difference between day and night. The problem of high compressor discharge temperature caused by high pressure ratios across the compressor can be solved by operating cascade mode at low ambient temperature. The corrugated surface based solar water heater is determined to have a higher operating temperature for longer time than the plane surface

[6,22,27]. A thorough literature investigation into the use of phase change material (PCM) in solar water heating has been considered. It has been demonstrated that for a better thermal performance of solar water heater a phase change material with high latent heat and with large surface area for heat transfer is required. Thermal storage can be an alternative to the present day solar water heater with less complicated design and cost effectiveness

2. SOLAR WATER HEATER

Solar water heaters, sometimes called solar domestic hot water systems, may be a good investment for our family. Solar water heaters are cost competitive in many applications when we account for the total energy costs over the life of the system. Although the initial cost of solar water heaters is higher than that of conventional water heaters, the fuel (sun-shine) is free. Plus, they are environmentally friendly. To take advantage of these heaters, we must have an un shaded, south-facing location (a roof, for example) on our property. These systems use the sun to heat either water or a heat-transfer fluid, such as a water-glycol antifreeze mixture, in collectors generally mounted on a roof [7,23,28]. Some systems use an electric pump to circulate the fluid through the collectors. Solar water heaters can operate in any climate. Performance varies depending, in part, on how much solar energy is available at the site, but also on how cold the water coming into the system is. The colder the water, the more efficiently the system operates. In almost all climates, you will need a conventional backup system. In fact, many building codes require you to have a conventional water heater as the backup. Before investing in any solar energy system, it is more cost effective to invest in making your home more energy efficient.

3. PHASE CHANGE MATERIALS (PCMs)

These materials can store energy by the melting at a constant temperature. No material has all the optimal characteristics for a PCM, and the selection of a PCM for a given application requires careful consideration of the properties of various 20,000 compounds and/or mixtures have been considered in PCM, including single component systems, congruent mixtures, eutectics. The isothermal Operating characteristics (i.e. charging/discharging heat at a nearly constant Temperature) during the solidification and melting processes, which is desirable for efficient operation of thermal systems. One of the most important aspects during the selecting of the material is the Convertible melting point and the high latent heat of fusion. The choice of the substances used largely depends upon the temperature level of the application. Residential, commercial and industrial buildings often have hot water requirements at around 60°C and bathing, laundry and cleaning operations in the domestic sector generally need it at about 50°C. The right melting point enables that the phase Changing comes off during every usage cycle. Thereby the latent heat could be fully utilized. According to the required temperature of the domestic hot water the melting point should be between 40 and 50°C. Storage systems using these heat accumulator materials can store the energy from the solar collector at lower temperature level, too in winter[8,27]. The stored energy can be used for pre-heating the cold incoming water.

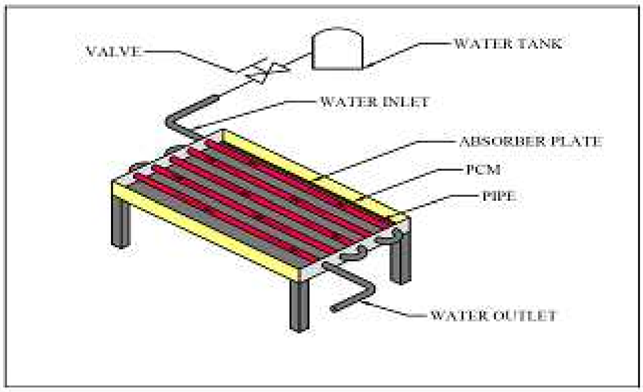


Fig.1. Solar Water Heater without PCM

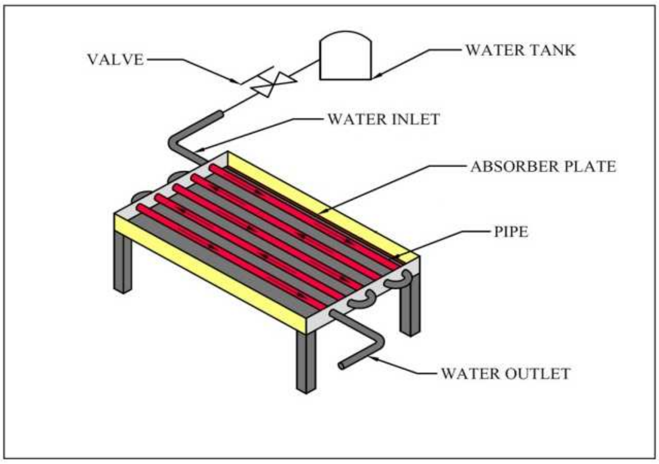


Fig.2.Solar Water Heater with PCM

4. CLASSIFICATION OF PCMs

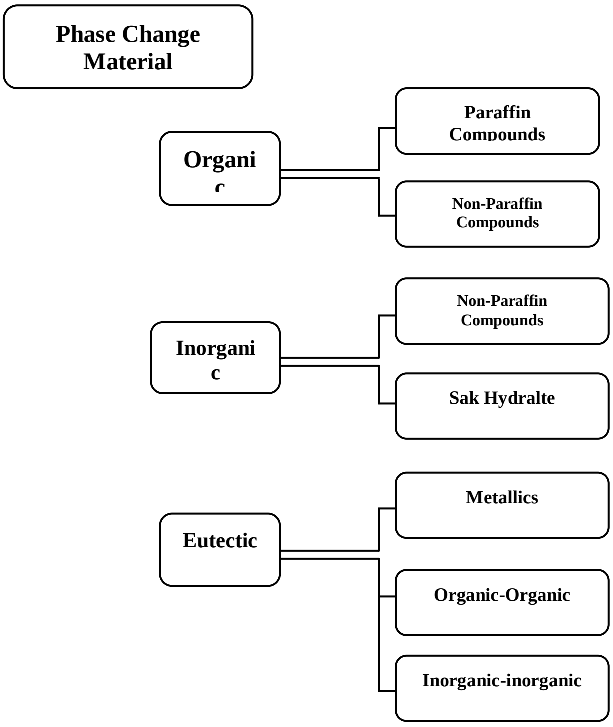


Fig.3. Classification of PCMS

4.1 Organic Phase Change Materials

Organic materials are further described as paraffin and non-paraffins. Organic materials include congruent melting means melt and freeze repeatedly without phase segregation and consequent degradation of their latent heat of fusion, self nucleation means they crystallize with little or no super cooling and usually non-corrosiveness.

4.2 Paraffin's

Paraffin is safe, reliable, predictable, less expensive and non-corrosive. The paraffins are waxes at. room-temperature. These are hydrocarbons. Increasing the number of C-atoms increases the melting point too. The non paraffins of type C_nH2_n+2 are a family of saturated hydrocarbons with very similar properties. Paraffin's between C5 and CI5 are liquids, and the rest are waxy solids[4,9]. Paraffin wax is the most commonly used commercial organic heat storage PCM. Paraffin waxes are cheap and have moderate thermal energy storage density but low thermal conductivity and, hence, require large surface area.

4.3 Non-Paraffin's

The non-paraffin organic are the most numerous of the phase change materials with highly varied properties. Each of these materials will have its own properties unlike the paraffin's, which have very similar properties. This is the largest category of candidate's materials for phase change storage.

5. SOLAR ENERGY ANALYSIS

5.1Heat transfer analysis

Heat in a solar thermal system is guided by five basic principles: heat gain; heat transfer; heat storage; heat transport and heat insulation. Here, heat is the measure of the amount of thermal energy an object contains and is determined by the temperature, mass and specific heat of the object. Solar thermal power plants use heat exchangers that are designed for constant working conditions, to provide heat exchange[10,24]. Heat gain is the heat accumulated from the sun in the system. Solar thermal heat is trapped using the greenhouse effect. The green house effect in this case is the ability of a reflective surface to transmit short wave radiation and reflect long wave radiation. Heat and infrared radiation (IR) are produced when short wave radiation light hits the absorber plate, which is the trapped inside the collector. Fluid, usually water in the absorber tubes collect the trapped heat and transfer it to a heat storage system.

5.2 Energy analysis

The energy analysis is based on the first law of thermodynamics and the corresponding first law efficiency has been calculated. The energy analysis is based on the fact that it is an upper limit of efficiency.

5.3. Exergy analysis

The rate at which exergy is collected by the solar collector can be increased by increasing the mass flow rate of the working fluid. Since the collector tubes are the most expensive component of any solar thermal system which needs advanced material and associated technology to build, therefore, it requires large investment[11,19]. In order to reduce the capital cost, we need to optimize the dryer area, as the fuel (sunlight) is free. Again, for large mass flow rates, the fluid outlet temperature is very low and requires more power to pump/blow air/fluid through it [20,26]. On the other hand, low flow rate results in high outlet temperature of the working fluid with high specific work potential. But due to the nature of entropy generation, exergy losses increase due to the temperature differences and hence, the optimum mass flow rate is required. The exergy analysis has been performed based on the configuration of solar air heater collector. The exergy received by collector.

6. EXPERIMENTAL SETUP

The setup is essentially similar to conventional, commercially available, solar water heating systems with a few differences. It consists of four south-facing flat plate 1.94 m x 0.76 m x 0.15 m collectors with a tilt angle of 25°to the horizontal. The collectors, which have ordinary single glass covers and black painted absorber plates, are connected to the main water supply and the hot water storage tank through a set of three valves enabling open-loop and closed-loop operation. A standard 80W circulation pump, with a maximum capacity of 9 l/min, is also available on the collectors-storage tank loop to enable forced circulation investigations, in addition to natural circulation. The galvanized steel storage tank is cylindrical in shape having a length of 645 mm, an inner diameter of 470 mm and a volume of 109.4 l. It is insulated with 80-mm thick layer of rock wool insulation. a detailed cross-sectional view of the storage tank. The tank contains a total of 38 thin walled, cylindrical, aluminum containers. Each container has a volume of 1.4 l, and contains 2.0 kg of paraffin wax which was used in this investigation as the PCM. The PCM is encapsulated in Aluminium cylinders of internal diameter 36mm and height 120mm, with wall thickness 4mm. Each cylinder contains 75gm of PCM by wt. The cylinders are packed in layers one over the other, with every two layers separated by a wire mesh to enhance the rigidity of the setup The PCM containers are arranged in the tank on two levels, each containing 17 containers, with the aid of two perforated sheet metal separators. The choice of these containers was meant to reach a relatively large heat transfer surface area in comparison with the volume of the PCM, and to minimize the thermal resistance between water and the PCM. The total volume of the PCM containers is 49.4 l, with water occupying the remaining 58 l in the storage tank. The bottom section of the storage tank also contains an auxiliary 4 kW electrical heater, in order to enable controlled conditions. Paraffin wax and N-Tricosane was selected as a LHTESS due to its thermal storage, safety, reliability and low solar reduction is measured by using a pyranometers.

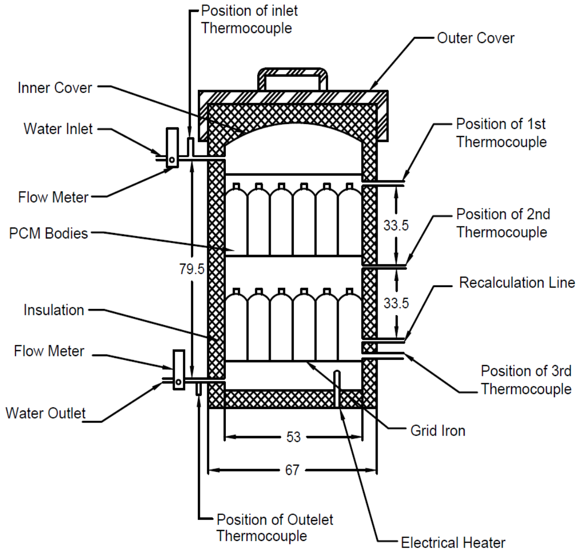


Fig.4.Schematic Line Diagram of Solar Water Heater

The measurement system includes a total of seven pre-calibrated K-type thermocouples: One at the inlet line and one at the outlet line of the storage tank, three distributed at the upper, middle, and lower sections of the storage tank, one thermocouple inserted in a PCM container at the central section of the tank, and one to measure the ambient air temperature. All thermocouples are connected to an HP 34970A-type data logger connected to a PC to enable the continuous recording of the temperature readings during various test scenarios. In the experiments described in the following section, temperature readings were continuously recorded with 1, 5, or 10 min intervals between each reading and the other, depending on the experiment requirements.

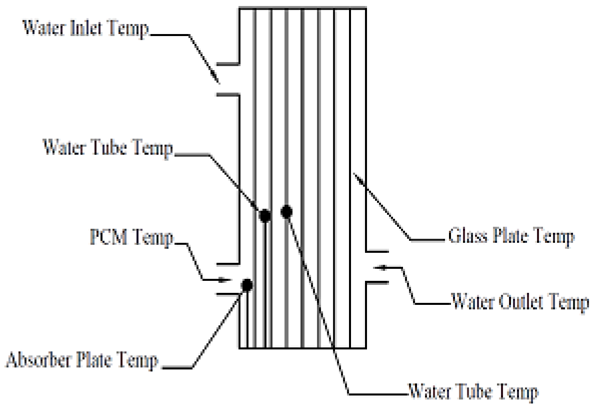


Fig.5.Details of Thermocouple Position in the Experimental set-up

7. DESIGN SPECIFICATION

Table-1. Specification of set up

Material for collector	Stainless steel
Length of collector	lm
Width of the collector	0.5m
Area of the collector	$0.5m^2$

Air gap between glass plate	5 cm
Total Quantity of PCM	3kg
Total number of heat reservoir	12

Fig.6.Photographic view of Experimental setup

Fig.7. Photographic view of Paraffin wax plate temperature (°c)

8. RESULTS AND DISCUSSIONS

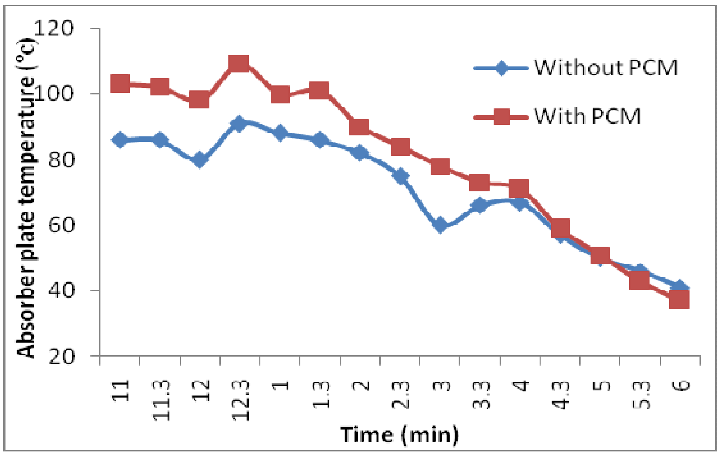
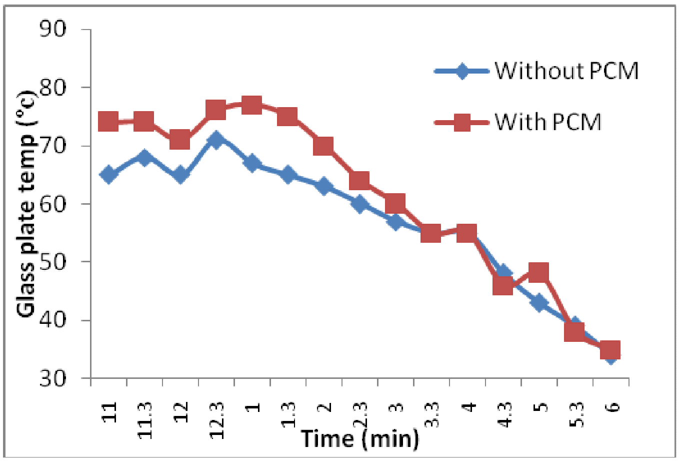


Fig.8.Variations of Time Vs Absorber

In Figure 8 shows the variations of Absorber plate temperature with time for Solar Water heater with and without PCM. It is observed that on 11.02.2014 the maximum value of Absorber plates temperatures obtained for with PCM was 91°C at 12.30 pm and for without PCM was 109°C at 12.30 pm respectively. Absorber plate temperature has less value in PCM unit, because of the fact mat the storage medium absorbs some amount of energy during sun-shines.



Fi.9. Variations of Time Vs Glass plate temp (°C)

In Figure 9. shows the variations of glass plate temperature with time for solar water heater with and without PCM. It is observed that on 11.02.2014 the maximum value of glass plates temperatures obtained for with PCM was 76°C at 12.00 pm and for without PCM was 71°C at 12.30 am respectively. The temperature difference may be due to high orientations to sum-ays.

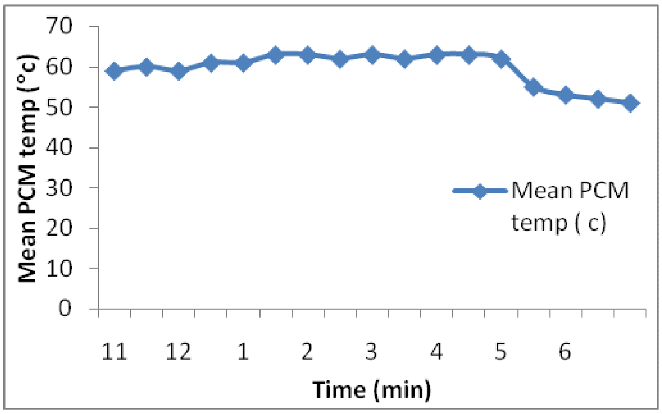


Fig.10.Variations of Time Vs Mean PCM temp (c)

In Figure 10. Show the variations of PCM Temperature with time. It is observed that on 12.02.2014 the maximum value of PCM Temperature obtained was 63°C at 1.30pm.

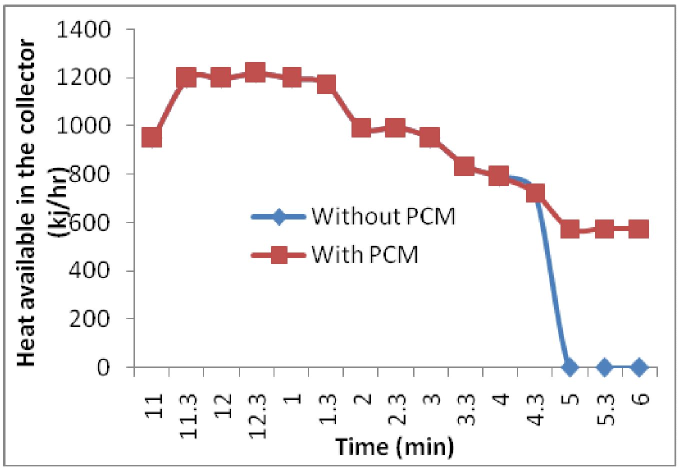


Fig.11.Variations of Time Vs Heat available in the collector (kj/hr)

In Figure 11. show the variation of heat available in collector with time. It is observed that on 12.02.2014 the maximum value of Heat available in collector was 1219.66kJ/hr at 12.30 pm.

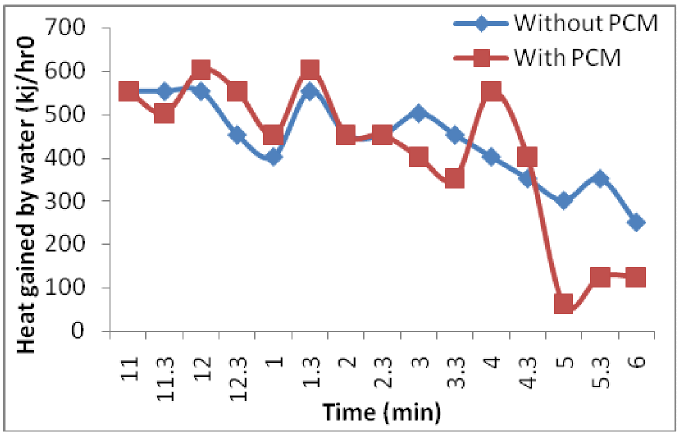


Fig.12.Variations of Time Vs Heat gained by water (kj/hr)

In Figure 12. shows the variations of heat gained by water with time for solar water heater with and without PCM .It is observed that on 12.02.2014, the maximum value of Heat gained by Water for with PCM was 602.78 kj/hr at 1.30 pm and for without PCM was 552.52 kj/hr at 12.00 pm respectively.

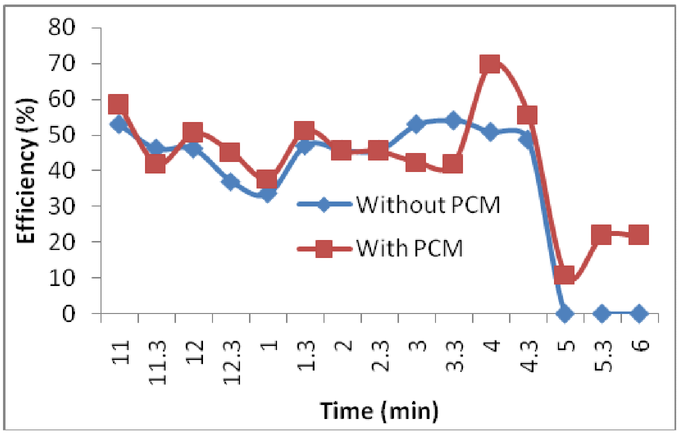


Fig.13.Variations of Time Vs Efficiency (%)

In Figure 13. shows the variations of Efficiency with time for solar water heater with and without PCM .It is observed that on 12.02.2014, the maximum value of efficiency was obtained in the setup with PCM was 69.89% at 4.00 pm and for without PCM was 54.09 % at 3.30pm respectively. The conventional unit has comparatively high efficiency than unit with PCM during sun-shine hours. Similarly the unit with PCM produces little better efficiency due to the presence of thermal energy during evening hours.

9. CONCLUSIONS

- The performance of the collector can be enhanced by increasing the area of the absorber plate and increasing the size of the water tubes.
- During day time the performance of the solar water heater with PCM is comparatively lower than solar water heater without PCM. It is because some of the heat is absorbed by the PCM.
- The performance of solar water heater with PCM can be improved by selecting the appropriate PCM with high thermal storage capacity.
- The performance of absorber plate can be enhanced by fixing at better orientations.
- It is also improved by increasing the quantity of PCM and also heat transfer area.
- During off sunshine hours, the thermal storage system is used to raise the temperature of water outlet. This may be enhanced by increasing the no of thermal energy storage units.
- The solar water heater with PCM causes enhancement of solar water performance during sunshine hours.
- The set up with PCM gives better efficiency at higher flow rates during off- shine hours due to higher heat transfer area presence.
- Select proper phase change material for the system which has excellent thermo – physical properties which yields higher efficiency.
- Select proper flow rates for solar water heater set-up with PCM gives better efficiency.
- Similarly the unit with PCM is proposed for during evening hours (or) partially cloudy days due to the presence of thermal energy storage medium which yields better efficiency.

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