

An Experimental Investigation on PCM Incorporated Solar Water Heater

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ABSTRACT: The use of a latent heat storage system using phase change materials (PCMs) is an effective way of storing energy in the form of thermal energy. PCM materials have large amount of heat energy stored in them in the form of latent heat. The latent heat of the PCM can be utilized for various thermal energy storage applications. It possess the advantages of high-energy storage density and the isothermal nature of the storage process. The heat energy associated with PCM is clean energy and is a natural phenomenon. There are large numbers of PCMs that melt and solidify at a wide range of temperatures, also which will result in a large number of applications varying from cooling and refrigeration to heating and insulation. This paper summarizes the investigation and analysis of the available thermal energy storage systems incorporating PCMs for use in a solar water heater. The demand of hot water available is inversely proportional to the available of solar energy. The system proposed here incorporates PCM inside the water tank of solar water heater to store more heat that can be utilized further. The modified PCM incorporated tank was more efficient than the conventional ones with less amount of expenditure and is a onetime investment. Energy associated with PCM is clean and natural energy and hence possess no environmental issues or no hazards.

KEYWORDS: Latent Heat Storage, Phase Change Materials (PCM), Thermal Energy Storage Systems (TES).

I. INTRODUCTION

The continuous increase in the level of greenhouse gas emissions and the climb in fuel prices are the main driving forces behind efforts to more effectively utilize various sources of renewable energy. In most parts of the world, direct solar radiation is considered to be one of the most prospective sources of energy. The scientists all over the world are in search of new and renewable energy sources. One of the options is to develop energy storage devices, which are as important as developing new sources of energy. The storage of energy in suitable forms, which can conventionally be converted into the required form, is a present day challenge to the technologists. 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. It leads to saving of premium fuels and makes the system more cost effective by reducing the wastage of energy and capital cost. For example, storage would improve the performance of a power generation plant by load levelling and higher efficiency would lead to energy conservation and lesser generation cost. One of prospective techniques of storing thermal energy is the application of phase change materials (PCMs). Unfortunately, prior to the large-scale practical application of this technology, it is necessary to resolve numerous problems at the research and development stage. Thermal energy storage can be stored as a change in internal energy of a material as sensible heat, latent heat and thermochemical or combination of these. The storage capacity of the LHS system with a PCM depends on its latent heat of fusion. Phase change materials (PCM) are "Latent" heat storage materials. The thermal energy transfer occurs when a material changes from solid to liquid, or liquid to solid. This is called a change in state, or "Phase." Initially, these solid-liquid PCMs perform like conventional storage materials, their temperature rises as they absorb heat. Unlike conventional (sensible) storage materials, PCM absorbs and release heat at a nearly constant temperature. The main objective of this paper is to utilize the latent heat of PCM

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for Thermal Energy Storage applications and also to conduct an experimental investigation on the application of Phase Change Materials as Thermal Energy Storage Systems (TES) inside a solar water heater.

II. RELATED WORK

Atul Sharma et al. [1] studied about different applications and analysis of Phase Changing materials. Their study ranged from small thermo flask to solar water heating systems to solar cookers to Green buildings. They analysed a built in storage type water heater containing a layer of PCM filled at the bottom. During the sunshine hours, the water gets heated up which in turn transfers heat to the PCM below it. The PCM collects energy in the form of latent heat and melts. During off sunshine hours, the hot water is withdrawn and is substituted by cold water, which gains energy from the PCM.

Zi Tao Yu et al. [2] studied the inclusion of highly-conductive particles to form suspensions/composites is a straightforward and promising approach to increasing thermal conductivity of the matrix materials. This technique has been attempted and practiced for many decades with meso- to micro-scale additives, and has recently turned to the use of emerging nanometer-sized candidates due to size effect-related advantages offered by such ultrafine materials. Utilization of engineered nanoparticle suspensions for heat transfer applications, coined as Nano fluids has been the subject of tremendous archived research areas in the past decade.

Their Results showed that As compared to this baseline value, thermal conductivity of the suspensions increased almost linearly with increasing the loading of each carbon additive. The extent of relative increase, however, was clearly distinct among the various carbon additives. The suspensions with LMWCNTs demonstrate marginal increase that the absolute value of thermal conductivity was only increased by 0.012 W/mK for the highest loading of 4 wt.%. In addition, although a recent study postulated and verified that clustering of the additives dominates heat conduction in Nano fluids, the clustering size is not shown based suspensions as a function of the loading of various carbon additives to have monotonic influence

Razali Thaib et. al[3] conducted experiments of solar water heater based on paraffin wax as the PCM. Solar power system has been applied to heat water for night time home activity in rural areas. The system will provides hot water availability out the day. The system consist of a solar water heater and a heat storage unit filled by Phase Change Material (PCM). The solar water heater used for supplying hot water during the day. Storage unit stores the heat in PCM during the day and convert to be hot water during the night. Type of solar water is thermosyphone. The main component of solar water heater is a solar collector box, insulating material, circulation tubes and absorber plate. The heat storage that filled paraffin wax integrated with solar collector unit for absorbing solar heat. Paraffin wax that commercially available in the market used for heat storage material.

K Dharma Reddy et al. [4] studied the behaviour of a packed bed latent heat thermal energy storage system is analysed. The packed bed utilizes the spherical capsules filled with paraffin wax as phase change material (PCM) usable with solar water heating system. The equations are numerically solved, and the results obtained are used for the thermal performance analysis of both charging and discharging process. The effect of inlet heat transfer fluid temperature (Stefan number), mass flow rate and phase change temperature on the thermal performance of capsules of different radii have been investigated. The application of Taguchi's robust design coupled with fuzzy based desirability function approach for optimizing multiple bead geometry parameters of submerged arc welding and Fuzzy inference system has been adapted to avoid uncertainly, imprecision and vagueness in experimentation as well as in data analysis by traditional Taguchi based optimization approach

Ravikumar et al. [5] studied the natural Cooling of building with phase change material was studied. The heat entering in to the room was maximum with RCC laid roof, because the thermal conductivity of RCC is high value. So almost all the heat entering the roof was transferred to the room. When WC was laid along with RCC and WC with PCM laid roof the heat entering the room was reduced by 46.88% and 71.16%.As the PCM is having low thermal conductivity, it offers the resistance for the heat flow and heat transfer was reduced by 45.71 compared to the RCC with WC roof. With various combinations of PCM, the test can be repeated to find the best and effective material for cooling application. As a demand for air conditioning increased greatly during the last decade, large demands of electric power and limited reserves of fossil fuels have led to a surge of interest with efficient energy application.

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III. MATERIALS AND METHODS

Water heated by the sun is used in various ways. While perhaps best known in a residential setting to provide domestic hot water, solar hot water also has industrial applications, e.g. to generate electricity. Designs suitable for hot climates can be much simpler and cheaper, and can be considered an appropriate technology for these places. The global solar thermal market is dominated by China, Europe, Japan and India.

Solar power system has been applied to heat water for night time home activity in rural areas. The system will provides hot water availability out the day. The system consist of a solar water heater and a heat storage unit filled by Phase Change Material (PCM). The solar water heater used for supplying hot water during the day. Storage unit stores the heat in PCM during the day and convert to be hot water during the night. Type of solar water is thermo-syphone. The main component of solar water heater is a solar collector box, insulating material, circulation tubes and absorber plate. The heat storage that filled paraffin wax integrated with solar collector unit for absorbing solar heat. Paraffin wax that commercially available in the market used for heat storage material.

PCMs latent heat storage can be achieved through any of the solid-solid, solid-liquid, solid-gas, and liquid-gas phase change. However, the only phase change used for PCMs is solid-liquid change. Initially, the solid-liquid PCMs behave like sensible heat storage materials; their temperature rises as they absorb heat. When PCMs reach the temperature at which they change their phase they absorb large amounts of heat at an almost constant temperature. The PCM continues to absorb heat without a significant rise in temperature until all the material is transformed to the liquid phase. When the ambient temperature around a liquid material falls, the PCM solidifies, releasing its stored latent heat. A large number of PCMs are available in any required temperature range from -5°C up to 190°C . Within the human comfort range between $20\text{-}30^{\circ}\text{C}$, some PCMs are very effective. They store 5 to 14 times more heat per unit volume than conventional storage materials such as water, masonry or rock.

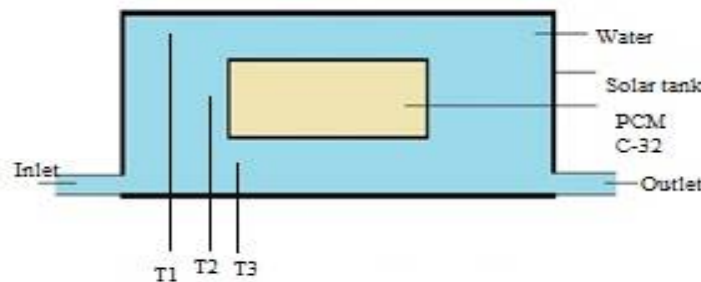


Figure: PCM Integrated Solar Water Heater

The schematic diagram of tank is as shown above. Temperatures of 3 different layers were measured and temperature of PCM as well as inlet and outlet temperatures were measured.

In order to heat water using solar energy, a collector, often fastened to a roof or a wall facing the sun, heats a working fluid that is either pumped (active system) or driven by natural convection (passive system) through it. The collector could be made of a simple glass-topped insulated box with a flat solar absorber made of sheet metal, attached to copper heat exchanger pipes and dark-colored, or a set of metal tubes surrounded by an evacuated (near vacuum) glass cylinder. In industrial cases a parabolic mirror can concentrate sunlight on the tube. Heat is stored in a hot water storage tank. The volume of this tank needs to be larger with solar heating systems in order to allow for bad weather], and because the optimum final temperature for the solar collector is lower than a typical immersion or combustion heater. The heat transfer fluid (HTF) for the absorber may be the hot water from the tank, but more commonly (at least in active systems) is a separate loop of fluid containing anti-freeze and a corrosion inhibitor which delivers heat to the tank through a heat exchanger (commonly a coil of copper heat exchanger tubing within the tank). Copper is an important component in solar thermal heating and cooling systems because of its high heat conductivity,

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resistance to atmospheric and water corrosion, sealing and joining by soldering, and mechanical strength. Copper is used both in receivers and primary circuits (pipes and heat exchangers for water tanks).

A phase-change material (PCM) is a substance with a high heat of fusion which, on melting and solidifying at a certain temperature, is capable of storing and releasing large amounts of energy. Heat is absorbed or released when the material changes from solid to liquid and vice versa; thus, PCMs are classified as latent heat storage (LHS) units. PCMs latent heat storage can be achieved through solid–solid, solid–liquid, solid–gas and liquid–gas phase change. However, the only phase change used for PCMs is the solid–liquid change. Liquid–gas phase changes are not practical for use as thermal storage due to the large volumes or high pressures required to store the materials when in their gas phase. Liquid–gas transitions do have a higher heat of transformation than solid–liquid transitions. Solid–solid phase changes are typically very slow and have a rather low heat of transformation.

Initially, the solid–liquid PCMs behave like sensible heat storage (SHS) materials; their temperature rises as they absorb heat. Unlike conventional SHS, however, when PCMs reach the temperature at which they change phase (their melting temperature) they absorb large amounts of heat at an almost constant temperature. The PCM continues to absorb heat without a significant rise in temperature until all the material is transformed to the liquid phase. When the ambient temperature around a liquid material falls, the PCM solidifies, releasing its stored latent heat. A large number of PCMs are available in any required temperature range from -5 up to 190 °C. Within the human comfort range between 20 – 30 °C, some PCMs are very effective. They store 5 to 14 times more heat per unit volume than conventional storage materials such as water, masonry or rock.

Solar water heating (SWH) is the conversion of sunlight into renewable energy for water heating using a solar thermal collector. Solar water heating systems comprise various technologies that are used worldwide increasingly. Evacuated tube collectors (ETC) are a way in which heat loss to the environment, inherent in flat plates, has been reduced. Since heat loss due to convection cannot cross a vacuum, it forms an efficient isolation mechanism to keep heat inside the collector pipes. Since two flat sheets of glass are normally not strong enough to withstand a vacuum, the vacuum is rather created between two concentric tubes. Typically, the water piping in an ETC is therefore surrounded by two concentric tubes of glass with a vacuum in between that admits heat from the sun (to heat the pipe) but which limits heat loss back to the environment.

Paraffin wax is an excellent material for storing heat, with a specific heat capacity of 2.14 – 2.9 J g⁻¹ K⁻¹ (joules per gram kelvin) and a heat of fusion of 200 – 220 J g⁻¹. This property is exploited in modified drywall for home building material: a certain type of wax (with the right melting point) is infused in the drywall during manufacture so that it melts during the day, absorbing heat, and solidifies again at night, releasing the heat. Paraffin wax phase-change cooling coupled with retractable radiators was used to cool the electronics of the Lunar Rover. Wax expands considerably when it melts and this allows its use in wax thermostatic element thermostats for industrial, domestic and, particularly, automobile purposes. Exemplar based inpainting technique is used for inpainting of text regions, which takes structure synthesis and texturesynthesis together. The inpainting is done in such a manner, that it fills the damaged region or holes in an image, with surrounding colour and texture. The algorithm is based on patch based filling procedure. First find target region using mask image and then find boundary of target region. For all the boundary points it defined patch and find the priority of these patches. It starts filling the target region from the highest priority patch by finding the best match patch. This procedure is repeated until entire target region is inpainted.

The algorithm automatically generates mask image without user interaction that contains only text regions to be inpainted.

IV. EXPERIMENTAL METHODOLOGY

Conventional Solar water tank of capacity of 60 L of an evacuated type solar water heater was modified and a cylindrical PCM tank was fabricated holding a volume of 14 liters of PCM made up of steel. Solar water heater tank was opened and the PCM filled PCM tank was installed to the tank. Temperature measuring knob was installed inside the arrangement at various locations of the solar water heater including the inlet and outlet to the tank. The entire set up consisted of two stages each consisting two phases. First stage consisted of charging the PCM during morning and monitoring its discharge with and without PCM and Second stage consisted of charging it post noon to monitor the discharge during evening so as to use the hot water during night times.

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Phase 1: Solar Water Tank incorporated with PCM

Weather Conditions for Day 1

- ◆ Date : 14 January 2016, Thursday
- ◆ Experiment Start Time : 08:30 AM IST
- ◆ Coordinates : 10.795050, 76.560976
- ◆ Temperature : 26 °C
- ◆ Weather : Haze
- ◆ Wind : 6 km/hr
- ◆ Humidity : 83%
- ◆ Visibility : 4 km
- ◆ Pressure : 1016 mbar

Phase 1: Solar Water Tank incorporated with PCM

1. Fabrication was completed and PCM tank was installed within the solar water heater tank and the experiment setup was completed.
2. PCM box was filled with Paraffin C-32 as the PCM material which has a melting point of approximately 66°C - 69°C.
3. Experiment was started by 08:30 AM IST.
4. Connections were turned on so as water entered tank and solar water heater was turned on and water started heating.
5. PCM was allowed to charge and temperatures of inlet, outlet, PCM, water was noted using thermometer with knobs inserted to the spaces where temperature to be measured.
6. When charging was completed the tubes were disconnected and temperature knob were adjusted so as to obtain temperatures of other places and were placed inside tanks to record thermal stratification and PCM temperature as well as ambient temperature was measured with respect to time.
7. Graphs were plotted with temperature on y-axis and time on x-axis.
8. Stratification temperature was also noted down and graphs were plot.

Phase 2: Solar Water Tank without PCM

Weather Conditions for Day 2

- ◆ Date : 15 January 2016, Friday
- ◆ Experiment Start Time: 08:30 AM IST
- ◆ Coordinates : 10.795050, 76.560976
- ◆ Temperature : 25.6 °C
- ◆ Weather : Haze, Cloudy
- ◆ Wind : 7 km/hr
- ◆ Humidity : 81%
- ◆ Visibility : 4 km
- ◆ Pressure : 1014 mbar

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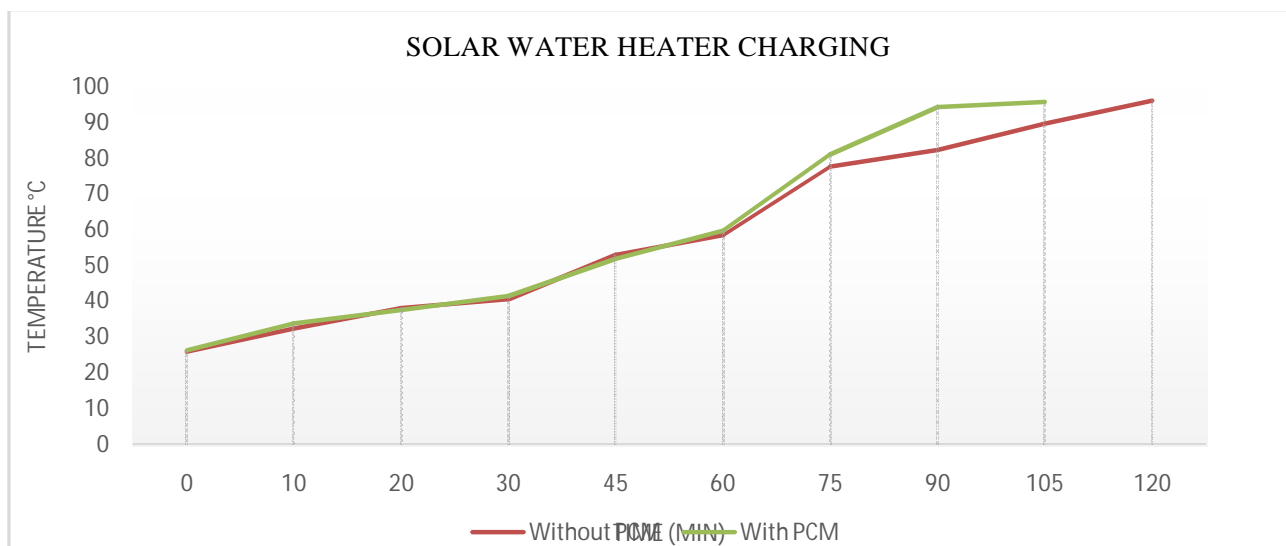
Phase 2: Solar Water Tank without PCM

The second stage of experiment was on Day 2 using PCM encapsulated box placed inside the tank. Same time schedule as that of previous day is maintained. Experiment procedure is as follows.

1. Fabrication was completed and PCM tank was installed within the solar water heater tank and the experiment setup was completed PCM tank was made empty.
2. Connections were turned on so as water entered tank and solar water heater was turned on and water started heating.
3. Experiment was started by 08:30 AM IST.
4. Water was allowed to charge and temperatures of inlet, outlet, water was noted using thermometer with knobs inserted to the spaces where temperature to be measured.
5. When charging was completed the tubes were disconnected and temperature knob were adjusted so as to obtain temperatures of other places and were placed inside tanks to record thermal stratification as well as ambient temperature was measured with respect to time.
6. Graphs were plotted with temperature on y-axis and time on x-axis.
7. Stratification temperature was also noted down and graphs were plot. Material is kept inside PCM box. The double walled PCM box contains formic acid in between and the box. The box is made of anodized aluminium to ensure maximum heat transfer and not to react with acid.

V. RESULTS AND DISCUSSION

The graph showing charging and discharging of PCM is plotted below. Shaded portion indicates the Phase Change of the PCM.



While charging the solar water heater in the case of without PCM the water ran upto a temperature of more than 90° C with 105 minutes with that of PCM to 120 minutes. The 15 minutes of lag was found. But during peak times of solar availability this difference tend to reduce.

The thermal stratification refers to a change in the temperature at different depths in the tank, and is due to the change in water's density with temperature. Cold water is denser than warm water and the epilimnion generally consists of water that is not as dense as the water in the hypolimnion. The system consist of a solar water heater and a heat storage unit

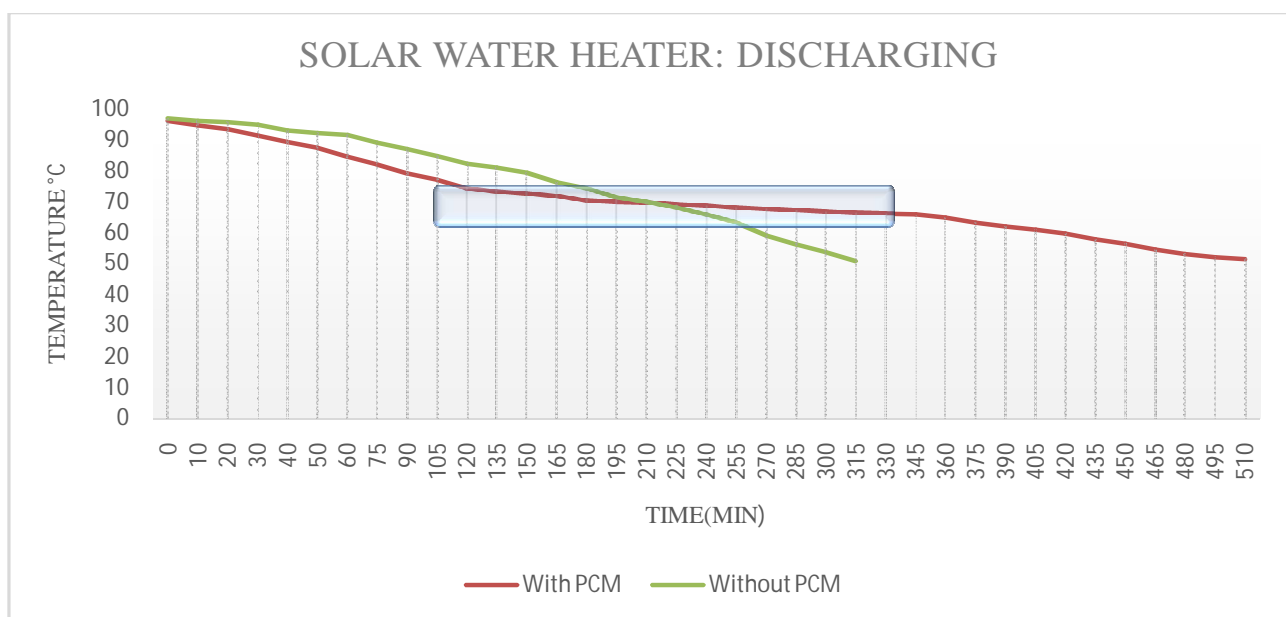
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filled by Phase Change Material (PCM). The PCM selected was paraffin wax 32 and graph below shows the variation of temperature with time in the case of charging the PCM.

The discharging of solar water heater when using PCM and without using PCM is shown below. The lower limit temperature was fixed to 40°C. Temperature is measured along y axis and time along x axis. Without using PCM the temperature fall to 40°C occurred by 315 minutes with that of PCM encapsulated till 510 minutes. The phase change area is shown in the graph with shaded box.



VI. CONCLUSION

Experimental tests have been carried out to investigate the temperature fall inside the tank of a solar water heater using phase change materials at same thermal loads so as to get the hot water for longer period.

Without the use of PCM inside the tank the discharge to normal temperature of water was completed by 5 hours and 15 minutes. But when paraffin C-32 was incorporated as the PCM material inside the tank, discharge was completed only at 8 hours and 30 minutes. Hence by a small change inside the solar water heater tank an increase of 3 hours and 15 minutes was obtained to discharge water to the minimum temperature. By the proposed system hot water can be made available even during late night. The variations in the time taken by both systems to charge do not show much difference and are subject to available thermal energy.

The main advantage of the PCM is that they can store large amount of energy as thermal energy. It is a natural process and hence caused no pollution or hazards. Incorporating the Paraffin C-32 as PCM in solar water heater prolonged time to which hot water was available was obtained. Also the PCM holds the heat till night so as to make available hot water by solar water heater during night time also. In the cases described above the PCM acts as the thermal energy storage component as well as an insulator. In solar water heater an increase in time of 220 minutes was obtained with that of PCM to without PCM.

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