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Experimental Investigation of Solar Water Heater Integrated with a Nanocomposite Phase Change Material

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ABSTRACT

- This present work contributes to the improvement in thermal energy storage capacity of an all-glass evacuated tube solar water heater by integrating it with a phase change material (PCM) and with a nanocomposite phase change material (NCPCM)..
- Paraffin wax as PCM and a nanocomposite of paraffin wax with 1.0 mass% GeO2 nanoparticles as NCPCM had been used during the experiments.
- Three different cases, namely, without PCM, with PCM, and with NCPCM, were considered.
- The testing procedure involved the observation of total temperature variation in the tank water from 6.00 a.m. to 6.00 a.m. of next morning.

OBJECTIVE

The main objective of my project is to increase the performance of solar water heater integrated storage tank with PCM and NCPCM which would serve the varying demands.

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INTRODUCTION

- Solar water heater is most alternative source to the conventional electric heater to meet the domestic and industrial hot water demand, where energy utilized is from the renewable source. It is abundant renewable energy source. It brings the hopeful scope for the solar thermal industries for producing commercially successful and competent products to cater the customer needs
- Phase change materials (PCMs) are considered to be the potential resources, since they can absorb or release a lot of heat energy at the constant temperature during their phase transitions. They are having great energy densities compared to other form of thermal storage materials

LITERATURE REVIEW

The system consists of two simultaneously functioning heat-absorbing units. The storage unit stores the heat in PCMs during the day supplies hot water during the night.

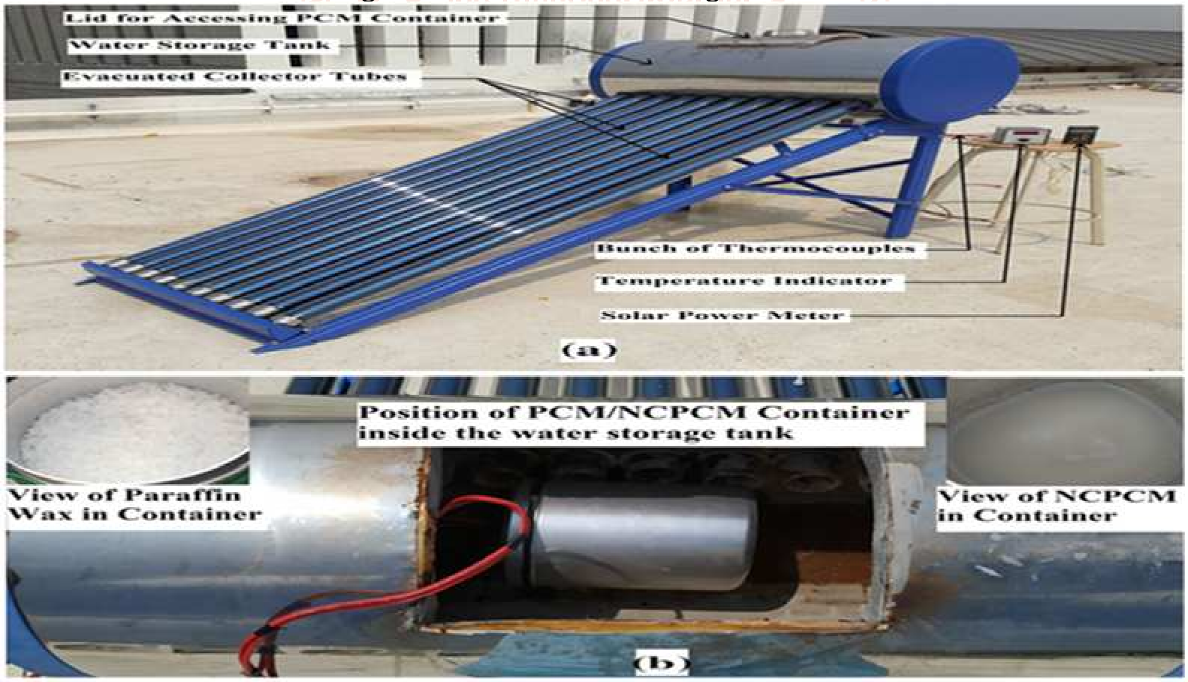
M. V. Kulkarni, Dr. D. S Deshmukh (2017). An Innovative design of solar water heater flat plate collector is developed and tested. The collector is made-up of rectangular aluminium having size 0.97 m X 1.81 m total surface area for heat conduction is 1.9845 m2. The absorber is made of Aluminium box with one large surface exposed to sunlight having size 1.94 m x 1.1 m x 0.1 m, glass 4 mm thick toughened to cover the box large open surface, black paint for absorbing solar radiation and insulation layer. Maximum temperature of water obtained at outlet of collector is 73.3 0C. Also an innovative storage tank is investigated. The storage tank is made up of MS plate, 50 mm puff insulation, outer- cladding cover, inside coating with Fiber Reinforcement plastic and 60%-40% partition for hot and cold water. Due to this FRP coating thermal conductivity of tank material and night heat losses get reduced. In conventional hot water storage tank night temperature losses is found to be 9 0C while in modified FRP coating tank with partition night temperature losses is found to be 4 0C

International Journal of Scientific Engineering and Research (IJSER) (2015). We are blessed with Solar Energy in abundance at no cost. The solar radiation incident on the surface of the earth can be conveniently utilized for the benefit of human society. One of the popular devices that harness the solar energy is solar hot water system (SHWS). The solar energy is the most capable of the alternative energy sources. Due to increasing Demand for energy and rising cost of fossil type fuels (i.e., gas or oil) solar energy is considered an attractive source of renewable energy that can be used for water hearing in both homes and industry. Heating water consumes nearly 20% of total energy consumption for an average family. Solar water heating systems are the cheapest and most easily affordable clean energy available to homeowners that may provide most of hot water required by a family. Solar heater is a device which is used for heating the water, for producing the steam for domestic and industrial purposes by utilizing the solar energy. Solar energy is the energy which is coming from sun in the form of solar radiations in infinite amount, when these solar radiations falls on absorbing surface, then they gets converted into the heat, this heat is used for heating the water. This type of thermal collector suffers from heat losses due toradiation and convection. Such losses increase rapidly as the temperature of the working fluid increases.

Journal of Engineering and Development, Vol. 18, No.2, March 2014 The crucial point in designing any solar collector is to allow maximum possible amount of solar radiation to reach the absorber part of the collector, and concurrently, reducing thermal losses from the absorber to the minimum. Evacuated-Tube Solar Collector (ETSC) offers feasible solution to this problem. An evacuated tube is composed of two coaxial glass tubes forming an annulus (Figure. 1). The space between the two tubes is evacuated to eliminate convective losses. The outer tube is the transparent cover while the inner tube is the absorber which is coated from outside (vacuum side) with a selective paint to maximize solar absorptance. One end of the evacuated tube is closed while the other is left open. The solar collector usually incorporates several evacuated tubes forming a parallel array. Heat can be extracted from the tubes by a variety of ways. The simplest way is achieved by the direct connection of the tubes to the storage unit. The working fluid can be either a liquid or a gas. When water is used as the working fluid, it is directly circulated between the tank and tube cavity via natural circulation. The temperature range in this type is limited by water boiling point. However, air or other gases may also be used as working fluids which necessitates the use of an appropriate fan or blower to circulate the fluid.

The first systematic study on an ETSC was done by Eberlein (1976). He analyzed thermal performance of an ETSC employing air as the working fluid. The solar collector studied by Eberlein consisted of an array of several evacuated tubes. Air is introduced in the middle way between top and bottom of each tube using additional concentric delivery conduit. It circulates in the annular space between the delivery conduit and the absorbing tube to collect solar thermal energy. This analytical study proposed several mathematical models useful in the design of air ETSCs but it was not validated by experimental tests. A detailed numerical study on the natural circulation inside the evacuated tube cavity was done by Gaa F.O. et. al. (1998). A numerical model of the inclined open thermosyphon has been developed using a finite difference algorithm to solve the vorticity vector potential form of the Navier-Stokes equations. The study was experimentally verified using laser doppler anemometry to measure the velocity profile at the tube exit.

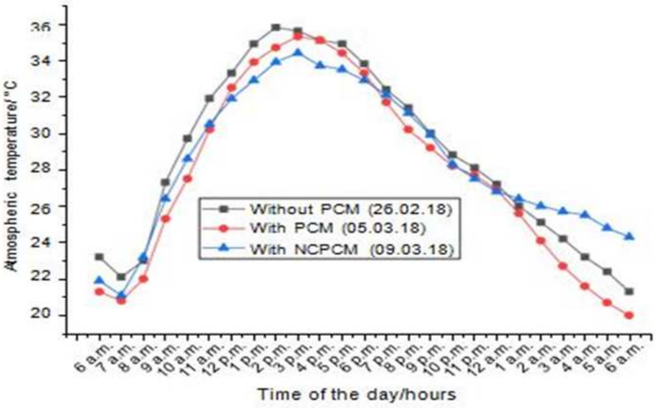
Photographic view of an experimental setup of evacuated tube solar water heater with measuring instruments b PCM/NCPCM containers and their integration with the water storage tank



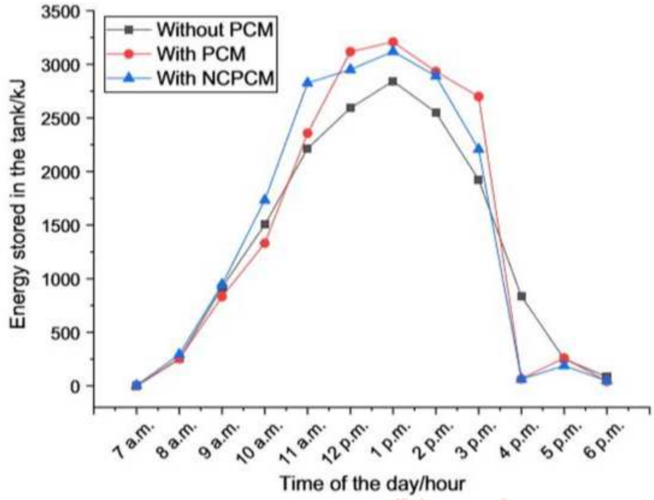
Experimental procedure

The experiments were conducted during the months of January, February, and March of 2020, and the average of at least 3 days for each case had been monitored to ascertain the reliability and accuracy of the results. The test results belonging to the days having similar solar insolation were deliberated for the further analysis. The water temperature of the collector storage tank was monitored with three K-type thermocouples with an accuracy of ± 0.1 °C, which had been placed in equidistance from the bottom of the tank in order to measure the average hot water temperature during the experiment.

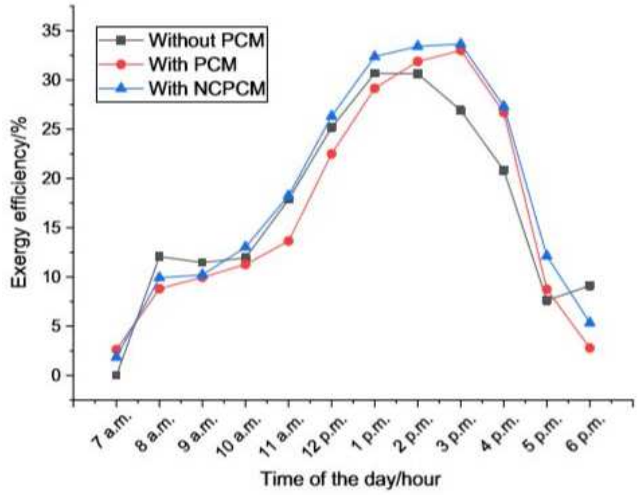
Hourly measurement of atmospheric temperature for the three cases on three similar solar days



Energy stored in the solar collector tank for the three cases of experiments



Exergy efficiency of the evacuated tube solar collector for the three cases of experiment



Energy analysis

$Q_i = Q_s+Q_b+Q_l$ 1

$Q_s = Q_w + Q_{PCM}$ 2

$Qs= [m_w xC_{p,w}(T_{w,f}-T_{w,i})] + \{m_{pcm}[C_{p,pcm}(T_{pcm,f}-T_{pcm,i}) + a_m \ \Delta h_{pcm}]$ 3

$Qi = A_c x H_t$ 4

$A_c = N xLxD$ 5

$\eta_c= (Q_s/Q_i)x\ 100$ 6

$Ex_{in} = Ex_{stored} + Ex_{loss}$ + Irrevesibility 7

$Ex_{in} = A_c H_t [1+1 / 3 (T_a/T_{sun})^4 \ 4/3 (T_a/T_{sun})]$ 8

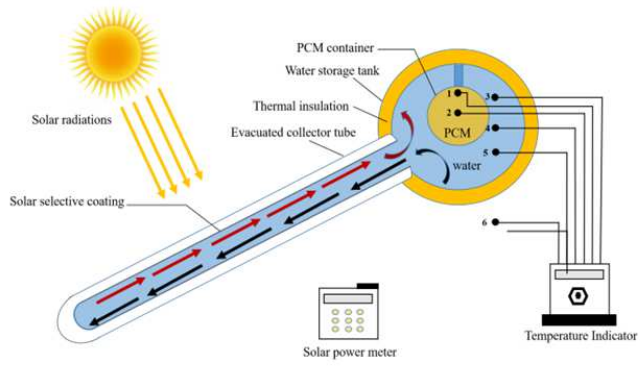
$Ex_{stored} = Ex_w + Ex_{pcm}$ 9

$Ex_w = m_w xC_{p;w} [(T_{w,f} - T_{w,i}) - T_a In (T_{w,f} / T_{w,i})]$ 10

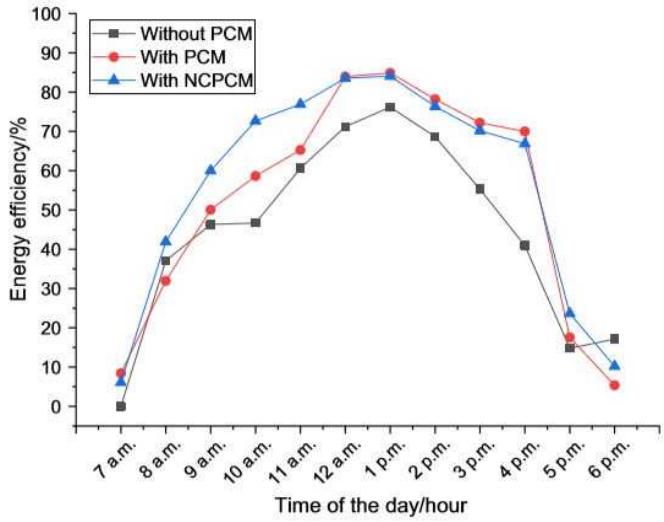
$Ex_{pcm} = Q_{pcm} (1- T_a/ T_{pcm})$ 11

$\psi_c = Ex_{stored} /E_{xm}$ x 100 12

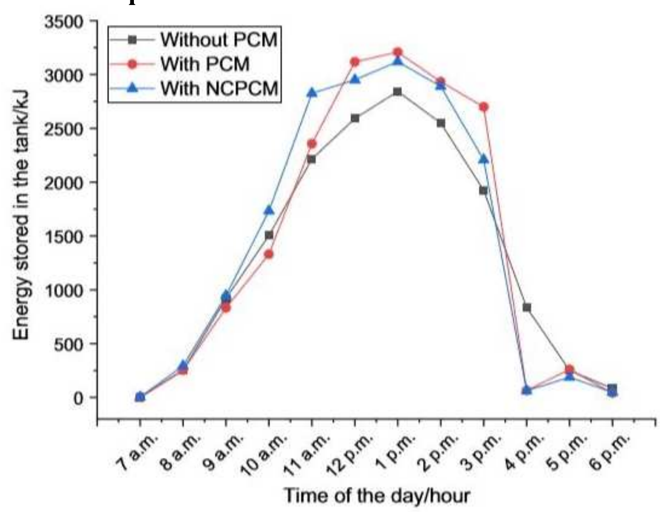
Schematic diagram of the all-glass evacuated tube solar water heater with PCM container and measuring instruments.



Energy efficiency of the evacuated tube solar collector for the three cases of experiments

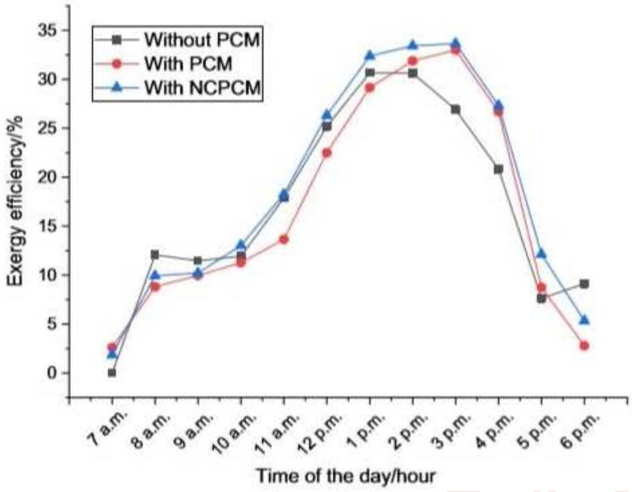


Energy stored in the solar collector tank for the three cases of experiments

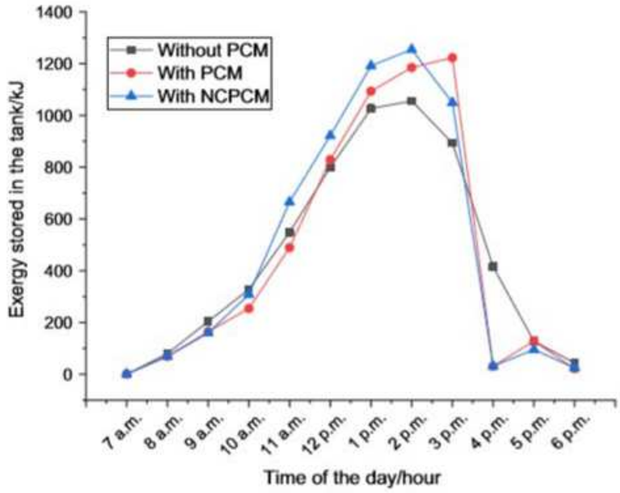


Daily energy efficiency of solar water heater for the three different cases

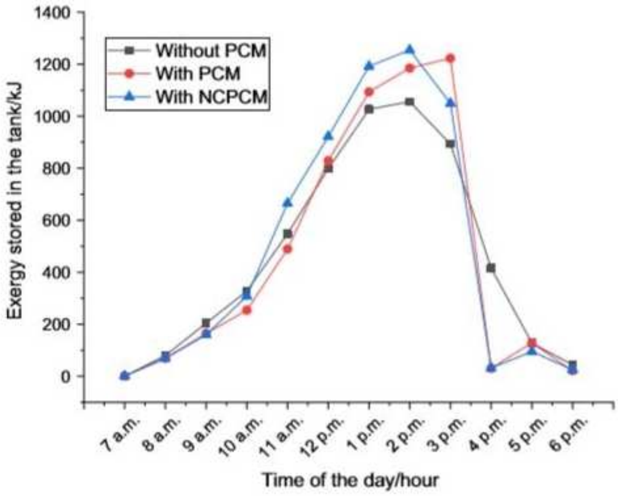
Description	Description Daily energy efficiency (g)/%
Solar water heater without PCM	58.74
Solar water heater with PCM	69.62
Solar water heater with NCPCM	74.79



Exergy stored in the solar collector tank for the three cases of experiments



Exergy stored in the solar collector tank for the three cases of experiments



Conclusions

The all-glass evacuated tube solar water heater was fabricated with built-in storage tank.

The experiments were conducted for 24 h from 6.00 a.m. to 6.00 a.m. of next day morning for all the cases.

The performance of the collector was investigated in terms of energy efficiency, exergy efficiency, and temperature of hot water supply during next day morning for the three cases, namely, the first case without PCM, the second case with PCM, and the third case with NCPCM.

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