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Utilization of solar resource using phase change material assisted solar water heater and the influence of nano filler

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A B S T R A C T

The depletion of natural energy resources are the major concern in the world therefore the researcher's focus is to utilize the renewable energy resources such as solar, wind, tidal etc. The importance of the effective usage and utilization of the natural resources are the current focus among scientific community. One of the abundantly available energy resource among all the natural resource is solar energy. Nowadays, Phase Change Materials (PCM) are used for storing the heat energy in the heaters to get efficient system. The function of solar water heater is to heat the water and supply the hot water during day time from the storage tank. But, the PCM installed solar water heater stores the heat energy during day time and supply the hot water even at night time for domestic purposes. Several experiments were conducted to optimize the developed system to get better output. Aluminium Oxide nano fillers are used to find the energy storing capacity and compared the results with and without nanofiller. From the obtained results, PCM absorbs more the heat energy and release the heat for longer duration. The nanofiller also improved the water temperature of 33% more than other commercial water heaters.

Selection and peer-review under responsibility of the scientific committee of the International Conference on Newer Trends and Innovation in Mechanical Engineering: Materials Science.

1. Introduction

For every human activity, energy is the background. In older days, coal and wood were considered as main source of energy. Due to the population growth and demand, renewable energies are considered as game changer for development [1–4]. Solar energy plays a vital role in industrial and domestic applications and it also act as an alternative energy source in many countries. The solar water heater is the common application using solar energy around the world. The demand for energy is increasing drastically as population increases day by day. Increasing demand force the mankind to use the non-renewable resources such as coal, lignite and the dangerous energy source called nuclear. These resources are very less in quantity and it may get deplete very soon [5–7]. Therefore, the need for developing the utilization of renewable resources become the current prerequisite. Many researchers were focused to find new sources of energy and some are try to improve the efficiency of the existing method with few changes. The core problem in renewable energy is it dependent on time. Consider in the case of solar energy, the availability of sun is available only during day time. So the reservoir is required to store the solar energy to use it during night time or during gloomy conditions also. There are several methods to store solar energy as shown in Fig. 1, in which, the use of PCM is one of the significant approach for the active storage of lunar energy [8].

During the selection of PCM the desired thermal properties are suitable for phase transformation using temperature, high latent heat and high heat capacity and thermal conductivity in both solid and liquid phase [9–11]. Similarly, few desired physical properties of PCM comprise of phase equilibrium, Low vapor pressure, more sensitive to volume change and very high density. The preferred kinetics properties for PCS system are it should not have super cooling, it should possess good crystallization and nucleation rate [12–14]. From the literature survey, found that the long-term stability of the solar water heater system is very important. The efficiency of the system severely affected by the many reasons such as corrosion in the container, chemical interaction between the con-

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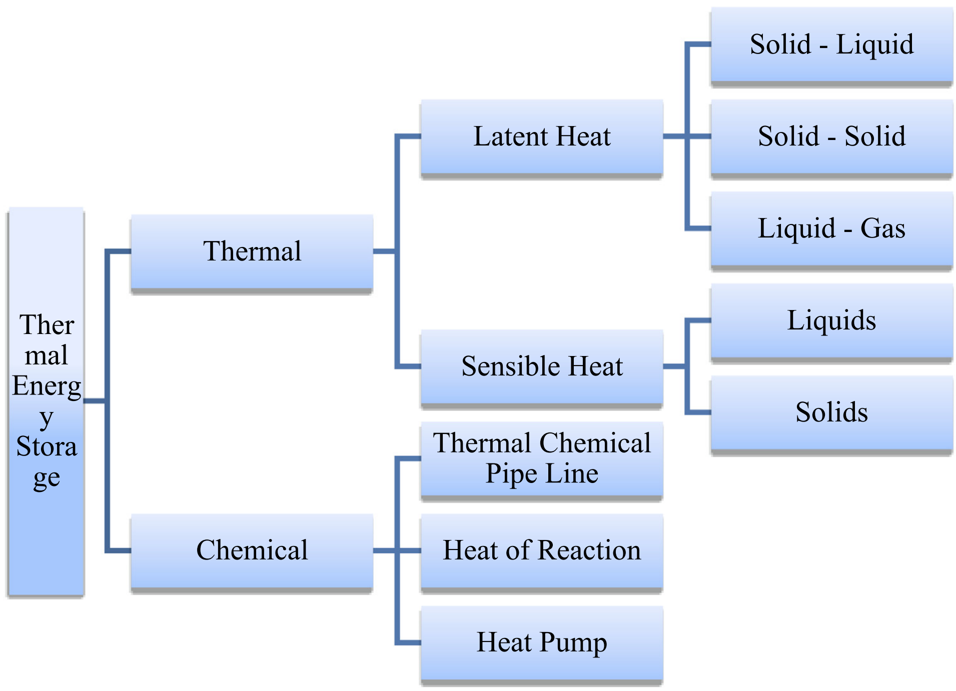

Fig. 1. Classification of solar thermal storage systems.

tainer and the PCM and heat exchanger tubing hoses [15–19]. Heat transfer between the PCM to water consumer more time thus it affects the efficiency of the system. Several models and methods were reported by earlier researchers to increase the heat exchange and its duration [20].

In this research work, the experiments were carried out and observed that the use of PCM in TES systems, the efficiency of energy storage in heating system increases by nearly 2 to 3.5 times as compared to the system without the use of PCM. For operating the solar energy system, two components are more essential. They are, collector and storage unit. The collector in the system collects the solar radiation and made them to fall on the fluid. The storage unit is mandatory during the absence of solar energy. Occasionally, the radiation from the solar is very less during the winter season. The phase change from solid to liquid or vice-versa is preferred because the operating pressure is lower than liquid to gas or solid to gas phase change [16,21,22]. The main objective of present work is to evaluate the performance of phase change material (PCM) ie., Paraffin Wax incorporated with nanofiller (Aluminium Oxide) in the fabricated solar water heater system [23].

2. Methodology and fabrication of solar heater system

The research methodology of this work is shown in Fig. 2. Initially, the data such as physical and thermal characteristics of the PCM were collected from the peer literature review process. Then the design was created using Autocad 2D drawing software and the expert's suggestions were included in the design. Finally, solar water heater with PCM was fabricated with the help of professional technicians. In the fabricated system, several experiments were conducted to get the optimized results. During the analysis, experiments were tried with and without nanofiller.

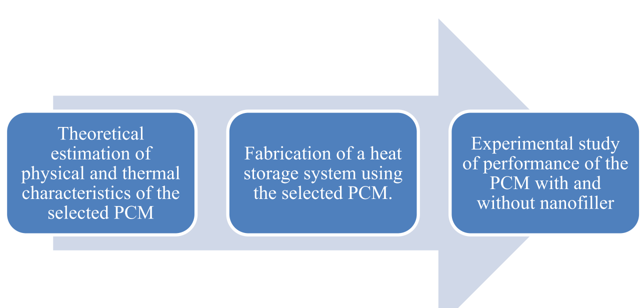

Fig. 2. Research methodology.

2.1. Theoretical estimation of physical and thermal characteristics of the selected PCM

The properties of paraffin wax are white, odorless, waxy solid, tasteless. The melting point is about 46 °C to 68 °C and the density of 900 kg/m^3. As known, the paraffin wax is also insoluble in water, however it is soluble in ether, benzene and certain esters [24–26]. Paraffin's are ideal in nature but it is inflammable. It has heat combustion property of 42 MJ/kg. It is an excellent electrical insulator, with a resistivity of between 10^{13} and 1017 O meter. It is an excellent material for storing heat, with a specific heat capacity of 2.14 to 2.9 J g^{-1}K^{-1} and a heat of fusion of 200–220 J g^{-1}.

2.2. Fabrication of a heat storage system using the selected PCM

The heat storage system was fabricated using the selected PCM is shown in Fig. 3. The system consists of a cold water tank, a timer valve which allows water in regular intervals to the collector, connecting pipes, solar collector, TES tank containing phase change material ie. Paraffin wax. The dimensions and other details of the system is given in the Table 1.

2.3. Experimental study of performance of the PCM with and without nanofiller

The performance of the phase change material is studied by conducting the experiment in the fabricated system with and without nanofiller. Initial, the phase change material alone is present inside the thermal energy storage tank during the first segment [27–29]. The temperature differences are taken during day and night time. When the hot water is present inside the TES tank. This

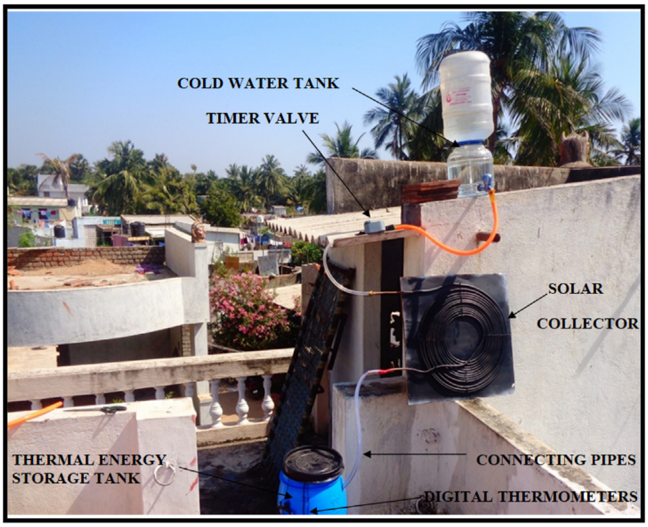

Fig. 3. Solar water heater system with TES tank.

Table 1
Table of dimensions of parts and components used.

Parts	Material	Dimensions in inches
Solar collector base	Plywood	24 × 24, 600 width
Copper tube	Copper	0.25 outer diameter, 0.02 thickness
Absorber plate	Aluminium	24 × 24 Inches
TES tank	Plastic	11 Diameter, 27 Length
PCM cylinder	Aluminium	3 Diameter, 9.8 Length

includes both charging and discharging more heat to transfer between water and PCM [30]. The experimental readings are taken for one full day starting from 12′o clock in the noon upto 8:30 in the night. In the 2nd segment, the phase change material is combined with nanofiller ie., Aluminium oxide and the same process and steps were carried out. The difference in temperatures are calculated now for the system with nanofiller [18,23,25,31,32]. The readings are noted for many variations such as TES tank with 1 Kg of PCM, 750 g of PCM and it is experimentally seen that more number of PCM cylinders enables as shown in Fig. 4.

Fig. 4. PCM tank containing 3 PMC cylinders of 250 g each with 3 g of aluminium oxide.

3. Experimental section

3.1. The experimental process

Foremost, the cold water is passed through the pipe to the copper coil which is placed in a open environment. The total quantity of water used this work was 10 L. The cold tank water quantity of the system is maintained around 20 L to manage the deficiency due to evaporation. Water that passes through the copper coil goes to the TES tank eventually which contains PCM. The water flow rate from the outlet of the copper coil is 0.5 L/min. Therefore, the total time required to fill 10 Liters of water in PCM tank takes 20 min as the flow rate is 0.5 L/min. The timer is set to open at 12.01 PM when there is peak sunlight available. The timer valve had provisions such as valve open time, duration, number of times the valve to be opened etc. The water is allowed to the system at 12:01 PM to heated copper coil. At the end of the 20 min 10 L of water gets stored in the TES tank with a approximate temperature of 65^{0}C.

3.2. Charging process

Once the PCM is surrounded by the hot water, due to temperature raise the phase of the wax changes to liquid and the charging process starts. During charging process, the hot water transfers the heat to the PCM through the aluminium cylinders by conduction. As the time passes, the water temperature gets lower and the PCM temperature starts raising. After sometime, approximately after 2 h both the temperature meet at the same level (equilibrium temperature) then the water is taken out and the tank has only PCM with absorbed heat (i.e., Latent Heat). The heat energy stored by the PCM stays for some time in the tank. In this experiment, the heat storing capacity of the PCM after equilibrium temperature is 4 h. Different hours of heat storing time maybe seen depending upon the quantity and the temperature of the hot water used.

3.3. Discharging process

The heat energy stored by the PCM drops after long time the heat energy has to be withdrawn from the PCM for household purposes. So cold water is again passed to the PCM tank i.e., 10 L to get back the heat from the PCM and this process is called discharging process. In this process, the PCM transfers the stored heat from the hot water in the noon to the cold water that is supplied when required. This discharge process takes nearly an hours depending upon the quantity of the PCM. Again, once the equilibrium temperature is attained, the hot water is taken out and the PCM returns to normal state i.e., solid state [17].

4. Results and discussions

4.1. Effect of temperature during daytime in solar water heater without nanofiller

In this process, the experiment is carried out with 3 PCM cylinders containing 750 g of paraffin wax in each cylinder. The peak temperature at 12:30 PM is 61^{0}C. As we can see from the graph the charging process takes 2 h (11:30 to 1:30 PM). The heat storing capacity of the PCM in this setup is 2 h. Then it starts the discharge process and it takes 2 h to transfer the heat back to the cold water in other words to become equilibrium state. As depicted in the Fig. 5, the outlet temperature of the water at 4 to 7 PM is 32 to 35^{0}C which is considerably low. Adequate, preliminary studies were conducted to optimize the parameters such as no. of PCM, Quantity of wax and incorporation of nano particles to get the

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maximum output from the fabricated system. The trials done using fabricated system are:

1. The experiment is carried out with 4 PCM cylinders containing 250 g of paraffin wax in each cylinder. The peak temperature at 1 PM is 65°C. As we can see from the graph the charging process takes 1 and half hour (1 to 2:30 PM). The heat storing capacity of the PCM in this setup is 2 h (from 2:30 to 4: 30). Then comes the discharge process and it takes 1 h 40 min to transfer the heat back to the cold water. The outlet temperature of the obtained water at 7:30 PM is 33°C which is also considerably low.
2. The experiment is carried out with 3 PCM cylinders containing 250 g of paraffin wax in each cylinder. The peak temperature at 1 PM is 68.2°C. The charging process takes 1 h (1 to 2 PM). The heat storing capacity of the PCM in this setup is 2 h (from 2 to 4). Then comes the discharge process and it takes 30 min to transfer the heat back to the cold water. The outlet temperature of the water at 8 PM is 31°C, which is also very low.

4.2. Temperature vs time plot for 750 g of PCM with nanofiller

In this process, the experiment is carried out with 3 PCM cylinders containing 750 g of paraffin wax in each cylinder with nanofiller. The peak temperature at 1 PM is 61.5°C. As depicted from the graph the charging process takes 1 h 30 min (11:30 to 1:00 PM). The heat storing capacity of the PCM in this setup is nearly 4 h (from 1:20 to 4:30) as shown in Fig. 6. Then comes the discharge process and it takes 40 min to transfer the heat back to the cold water. The outlet temperature of the water at 8:30 PM is 39.5°C which is good for household purposes.

4.3. Comparison of solar water heater with and without nanofiller (750 gms)

From the Fig. 7 and Fig. 8, the parameters such as charging time, heat storage capacity discharge time and outlet water temperature are improved significantly when compared to the system without nano filler. The final temperature/ outlet temperature of the water has increased to 39°C with 3 g of nanofiller. Whereas in the case of without nanofiller, the final temperature is only 33°C, which is very low for household purposes (washing, bathing etc). Therefore, Aluminium oxide has created an impact in absorbing and releasing heat energy effectively. Hence, Aluminium oxide can be used as a suitable nanofiller for Paraffin Wax. Similarly, many nano materials can be used to increase the capacity of storage of heat with the phase change material. The percentage improvement in results in the solar water heater system with nanofiller when compared to a system without nanofiller is 33%.

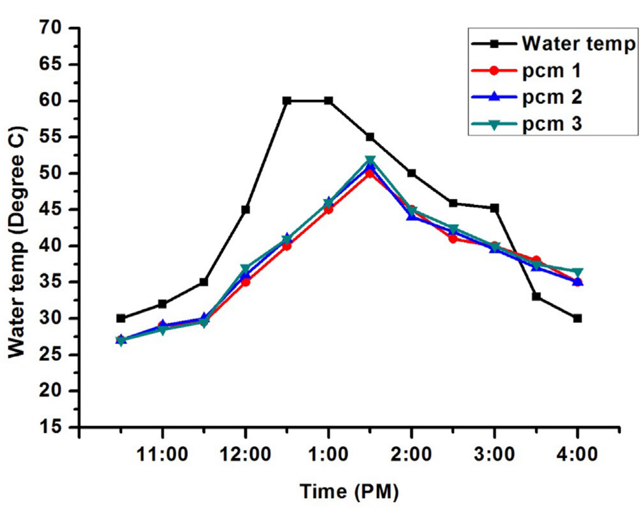

Fig. 5. Temperature vs time plot.

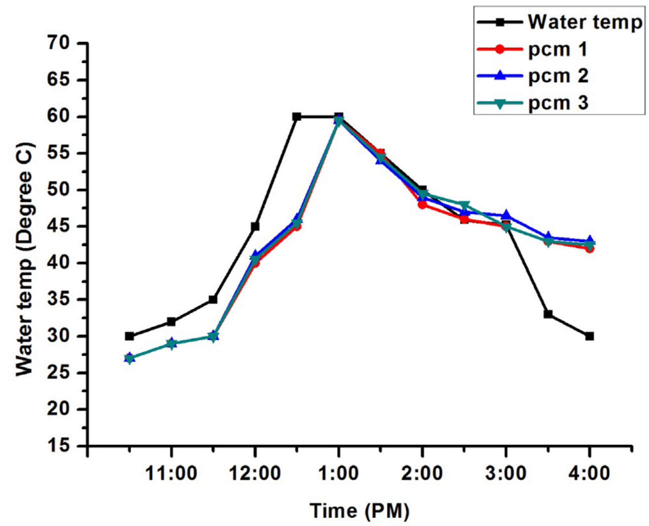

Fig. 6. Temperature vs Time plot for 750 g of PCM with nanofiller.

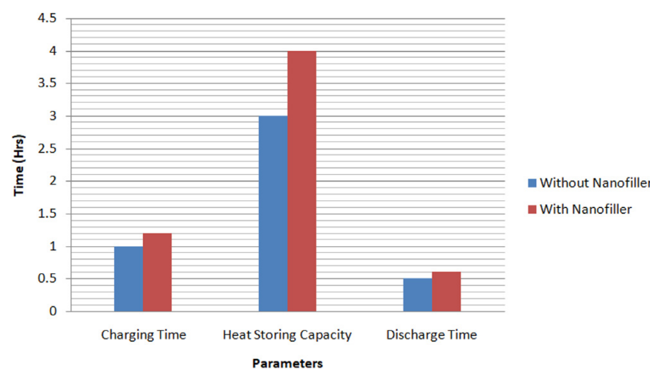

Fig. 7. Comparison of various parameters of solar water heater with and without nanofiller with 750 gms of PCM.

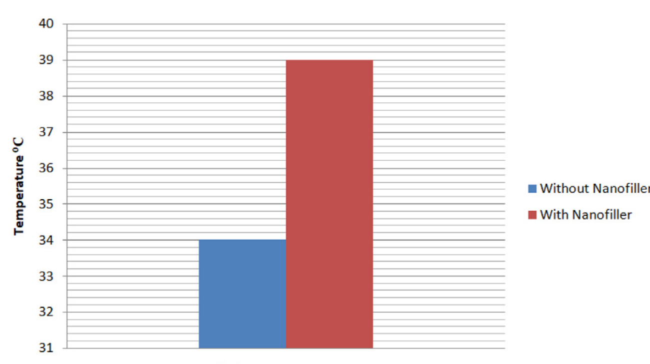

Fig. 8. Outlet water temperature from the fabricated solar system.

5. Conclusions

In the current investigation, the heat absoprtion nature of the PCM is studied with and without nanofiller. From this work, the following observations are acquired.

- The hot water temperature achieved at the end of the process with nanofiller is higher when compared to hot water temperature without nanofiller. Thus the results showed the alumina nanofiller can be used to increase the thermal conductivity of the PCM effectively and helps in storing more heat for longer duration.
- The latent heat of the phase change material stores heat greatly. The heat energy is available even during night time, it can reduce the usage of electricity and the comsumption rate of power could be reduced significantly.
- Paraffin wax showed very good combination with alumina nanofiller but other materials also available in market at cheaper cost. It might work prodigious with suitable nanofiller. Future scope of this work is to attempt different nanofiller in the fabricated system to develop efficient system.
- Optimization techniques can be implemented to get the better output using different process parameters and its materials it may leads to yield exciting outcomes.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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