DESIGN AND DEVELOPMENT OF SOLAR WATER HEATING SYSTEM USING PHASE CHANGE MATERIAL

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Abstract - *Solar energy is readily available almost all year long and can be used to generate electricity and heat. Over time, interest of public and government in solar energy has skyrocketed. However, it has the drawback of not producing as intended during off-seasons. A useful method of storing thermal energy that offers the benefit of high energy storage density and isothermal storage is by the usage of a latent heat storage system with PCM. Energy is stored using PCM, which is then used to heat water for domestic usage at night. This makes sure that hot water is accessible all day long. This system consists of solar water heating setup along with a PCM based tube in shell heat exchanger is designed in this work which will be integrated with solar water heating system.*

Key Words: *Phase Change Material (PCM), Solar Water Heater, Thermal Energy Storage System, Heat Transfer Fluid*

1.INTRODUCTION

The main driving cause behind efforts to more effectively utilize different renewable energy sources are the continual rise in greenhouse gas emissions and the rise in fuel prices. Direct solar radiation is regarded as one of the most promising energy sources in many parts of the world. Researchers are looking for novel, sustainable energy sources all across the world [1, 2]. A current difficulty for technologists is the storage of energy in acceptable forms that can be traditionally converted into the needed form [3]. Energy storage plays a significant role in energy conservation by lowering the imbalance between supply and demand as well as enhancing the efficiency and dependability of energy systems [4]. A useful method of storing thermal energy that offers the benefits of high energy storage density and isothermal storage is the usage of a latent heat storage system that uses PCMs. Fully refined paraffin wax is used in the system [5]. PCMs are frequently used in latent heat thermal storage system for solar engineering, spacecraft thermal control applications and heat pumps. PCM applications for building heating and cooling have been studied within the last ten years. PCMs are appealing in a variety of applications due to they are abundant and can melt and solidify at a wide range of temperatures [6].

1.1 OBJECTIVES

- To design a cheap and easy to integrate energy storage system for solar water heating system.
- To study and select optimum PCM for the system.
- To Fabricate a scale model of the solar water heating setup with PCM.

1.2 SCOPE

This work includes, design and development of a small heat exchanger, in order to establish the effectiveness of using paraffin wax as a suitable PCM in solar water heating system. The paraffin wax is incorporated in the heat exchanger, which acts as thermal energy storage device.

2. SELECTION CRITERIA FOR PCM

The selection of PCM is crucial for solar thermal energy storage. There are different ways to classify PCMs such as phase change temperature, material properties etc. Common factors during the selection of PCMs include: thermodynamic properties, kinetic properties, chemical properties and economic properties. The normal paraffins of type C_nH_{2n+2} is a family of saturated hydrocarbons with very similar properties. Paraffins between C5 and C15 are liquids, and the rest are waxy solids. Paraffin wax is used widely in commercial organic heat storage PCM. It contains of straight chain hydrocarbons which have melting temperature from 23° to 67°C. Paraffin wax is chosen due to its no tendency to segregate, stable properties after 1500 cycles and affordability. The effects of super-cooling during the crystallization can be dealt with by means of adding a nucleating agent.

Table-1: Thermo-physical properties of commercial grade paraffin wax

Sr. No.	Material	Melting Temp/°C	Latent Heat/Jg^{-1}
1	Fully Refined	61	253
2	Paraffin Wax (Grade RT42)	42	200-249
3	L-PW Wax	18-23	213-237
4	H-PW Wax	56-58	253
5	Eutectic Mixed	54	255-256
6	Grade Paraffin Wax (GradeRT50)	49	238
7	Soft Paraffin Wax	40-60	209-269
8	Hard Fischer-Tropsch Wax	77	213-269

As in thermal energy storage the water temperature varies in between 40 to 60 °C and the melting temperature of paraffin wax is 54 °C it is the most suitable.

3. WORKING

During sunshine period, as mentioned in Fig-1, valve 1 is kept open and valve 2 is kept closed. The cold water from the storage tank goes through the solar collector, absorbing heat energy from the solar radiations. It then passes completely through the PCM heat exchanger, where it loses its heat and transfers it to the PCM. It then goes back to the storage tank. In this way, the PCM gains heat energy which will be then used to heat water during non-sunshine period. During non-sunshine period, valve 1 is kept closed and valve 2 is kept open. The normal water from the storage tank flows through the PCM heat exchanger, absorbing heat energy from the heat stored in the PCM. It then goes back to the storage tank. By this way the water is heated by absorbing the heat stored in the PCM.

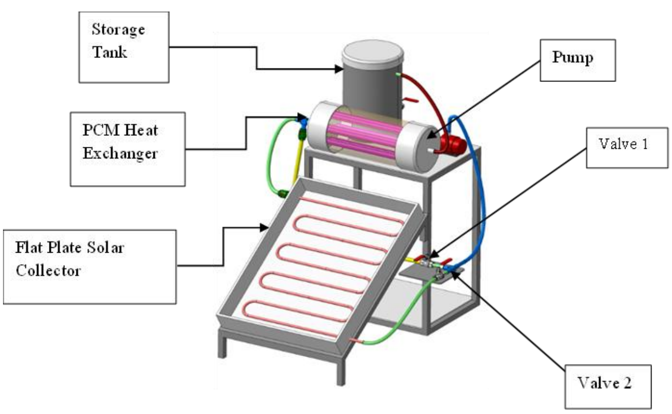

Fig-1: Solar Water Heating System with PCM integration

4. DESIGN

a) *Design of Energy storage unit*

- Amount of hot water to be stored

An average home needs about three buckets of water each day when it is not sunny. Using a 20 litres bucket as an example, the total volume needed is 60 litres. However, we are considering developing a heat exchanger to heat 10 kg of water for our experimental purposes. A higher-requirement system might be designed using the same method.

- Amount of heat energy to be stored

The water in the tanks is typically available during the winter months at a temperature of 15 to 20°C. Water needs to be around 40°C to be comfortable for bathing in the winter. So, 20 to 25°C is the temperature differential we need to reach for a comfortable bath.

- ➢ Initial temperature of water

$T_i = 15°C$

- ➢ Final (desired) temperature of water

$T_f = 40°C$

$T_f - T_i = 25°C$

- ➢ Heat capacity of water,

$C_v = 4.187$ kJ/kg

- ➢ Hence, amount of heat required to carry out the above transition(Q)

$= m_{water} \times (T_f - T_i) \times C_v$

$= 10 \times 25 \times 4.187$

$= 1046.75$ kJ

Hence, amount of energy needs to be stored = 1046.7 kJ

- Estimating Required amount of PCM

Amount of energy to be stored (Q_1)

$= 1046.75$ kJ

Hence mass of PCM to be incorporated, m_{pcm}

$= Q_1$ / (Latent heat)

$= 1046.45/206$

$= 5.0816$ kg.

Hence approximately 5.1 kg of PCM needs to be incorporated in the heat exchanger.

- Selection of heat exchanger for energy storage unit

The simplest sort of heat exchanger is a tube in shell design. This kind of exchanger makes it simple to incorporate PCMs. The heat transfer fluid (HTF), in this case water, flows from the inner tube of the heat exchanger, which contains the PCM.

- Dimensions of Energy storage unit
- ➢ Assume no of energy storage pipes to be used

(n) = 7

- ➢ Mass of PCM in each unit

$= m_{pcm} / n$

$= 5.0813/7$

$= 0.7259$ kg

- ➢ Volume of PCM to be used (V_{pcm})

$= M_{pcm}/\text{unit} \times \dot{\rho}_{pcm}$

$= 0.7259 \times 789$

$= 0.00092002\ m^3$

- Cross sectional area of outer portion of heat exchanger(A_2)

  $= V_{pcm} / l$

  $= 0.00092002/0.5$

  $= 0.00184005\ m^2$
- Material of Inner Piper

  Copper being best suited for heat transfer with heat transfer rate of is selected
- Considering standard diameter of Inner Pipe(d_1)

  $=0.019$ m
- Standard outer diameter of copper inner pipe (d_2)

  $=0.022$ m
- Cross sectional area of the inner pipe (A_1)

  $=1.5393 \times 10^{-5}\ m^2$
- Material of outer Pipe

  Considering the purpose of insulation PVC is selected as it prevents the melted wax to solidify after charging.
- the internal diameter of outer pipe (D_1)

  $= 1/4 \times ((A_1+A_2)/\pi)^{½}$

  $= 0.05$ m
- Outer diameter for PVC outer pipe (D_2)

  $= 0.053$ m

- Placement of heat exchanger in energy storage device

- Clearance between two heat exchanging units(C)

From standard chart minimum clearance

$= 0.25xD_2$

$=0.013$ m

As this is minimum condition it was adjusted to 0.625" in CAD

- Pitch $= D_2 + C$

  $= 0.053 + 0.013$

  $= 0.066$ m

b) *Area Estimation of Collector*

- Total Area of Collector (A_c)

  $= [(\text{quantity of water} \times C_v) + Gt] / 100$

  $= [(10 \times 4.187) + 5.8] / 100$

  $= 0.48\ m^2$

5. MANUFACTURING AND ASSEMBLY OF MODEL

The scale model manufactured for solar water heating setup with PCM is shown in Fig-2.

Fig-2: Scale model of solar water heating setup with PCM heat exchanger

To assess the effectiveness of a solar water heater, it is necessary to compute its thermal efficiency, which represents the proportion of the energy input from solar radiation to the power output in terms of the resulting water temperature. This calculation is crucial for evaluating the performance of the solar water heater. By measuring the inlet water temperature 25.3°C and formerly implementing the temperature readings in the calculation, the efficiency is calculated as:

A sample efficiency calculation of Day1 at 9.00am:

Energy Input with PCM at (Q_{in})

$= Ac \times Gt$

$= 0.48 \times 5.71$

$= 2.7408$ kW

Energy Output with PCM (Q_{out})

$= (m \times Cp \times \Delta T)/1000$

$= (10 \times 4.2 \times 8.2)/1000$

$= 0.3444$ kW

Efficiency with PCM (η)

$= Q_{out} / Q_{in}$

$= 0.3444 / 2.7408$

$= 0.1257$

$= 12.57\%$

6. RESULTS AND DISCUSSION

The results of the experimental work, provide a comprehensive comparison of a solar water heating setup without PCM and with PCM.

Table-2: Results of experimental work

Parameters	Without PCM	With PCM
Temperature of Input Water in Morning (9.00 Hours)	25°C	25°C
Temperature of Output Water in Evening (21.00 Hours)	32°C	42°C
Temperature Difference After 12 Hours	7°C	17°C
Avg. Efficiency	**12.26 %**	**25.97 %**

The comparison as done in Table-2 is based on various temperature and efficiency measurements over a specific period of time. To simplify the experimentation and calculation process, the prototype model was used to collect data for a shorter period. However, the results obtained can be used as a basis for actual solar water heating systems, as the proportion of results might be similar. It can be found that increasing the quantity of PCM and the capacity of the plant tends to increase the efficiency and temperature difference.

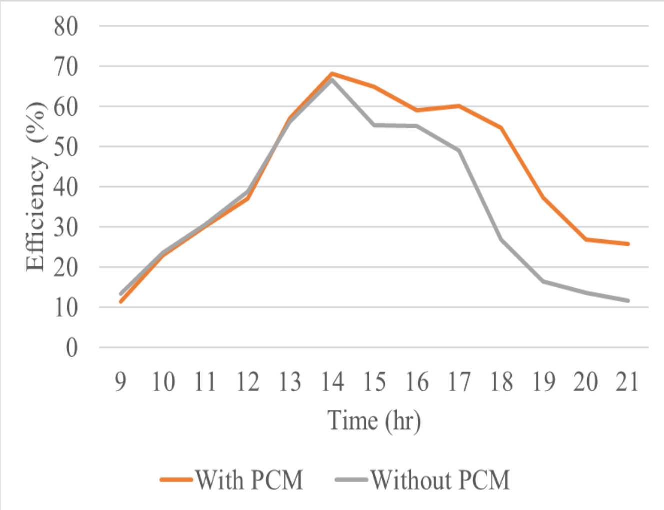

Chart-1: Hourly efficiency graph for solar water heating setup with and without PCM

The Chart-1 demonstrates that the setup with PCM is better at preserving the temperature for a longer duration and reducing heat loss, in comparison to the solar water heating setup without PCM.

7. CONCLUSIONS

Integrating PCM in solar water heating systems is of great benefit. With appropriate parameter selection and integration of a PCM in the heat exchanger of a solar water heating system, hot water can be maintained with a consistent temperature near the melting temperature of the PCM for an extended period of time. It was found that the PCM based solar water heating setup have high potential to replace solar water heating setup without PCM to enhance the thermal efficiency of solar water heating setup.

Based on the experimental work carried out, following conclusions are drawn:

- Fully refined paraffin wax has a suitable transition temperature range of 45 to 55°C and a relatively high latent heat of 206 kJ/kg. In addition, it does not exhibit any sub-cooling. Utilization of PCM with lower melting temperature is beneficial to enhance energy performance of the solar water heating setup.
- The cost to incorporate the system is economical with a moderate installation cost of the unit and a very low maintaining cost made this kind of solar water heating so efficient.
- A functional prototype model was created that effectively retained the temperature of heated water for a longer duration compared to a solar water heating setup without PCM.
- The prototype model of a solar water heating setup was able to achieve a 10 % increase in efficiency by integrating a PCM setup.

A collector-storage water heating system is extremely endorsed for low/medium temperature applications as they can store solar energy in the form of latent heat during daytime and can provide heat at night time or unavailability of sun radiation to produce hot water.

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