Increasing Efficiency of Solar Water Heater with PCM Used As a Thermal Energy Storage

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Abstract— Solar energy using Phase Change Materials (PCMs) and utilizing this energy to heat water for domestic purposes during nighttime. 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). The water heater functions normally and supplies hot water during the day. The storage unit stores the heat in PCMs during the day supplies hot water during the night. Melting point, heat of fusion, density, heat capacity, thermal conductivity, compatibility with container and cost of production are the chief parameters for selection of phase change material. Phase change materials (PCMs) have the capability of storing heat (latent heat storage units) and phase transition point to the environment of the operating temperature. Developing efficient and inexpensive energy storage devices is as important as developing new sources of energy. Energy storage can reduce the time between energy supply and energy demand, thereby playing a vital role in energy conservation. Heat storage in phase change materials (PCM) has an advantage of compactness and heat supply at constant temperature.

Keywords: PCM, Thermal Energy Storage

I. INTRODUCTION

A. 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. 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.

B. Phase Change Materials (PCMs)

Phase change materials (PCMs) are "latent" thermal storage materials. They use chemical bonds to store and release heat. The thermal energy transfer occurs when a material changes from a solid to a liquid or from a liquid to a 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 solar heat. Unlike conventional (sensible) storage materials, when PCMs reach the temperature at which they change phase (their melting point) they absorb large amounts of heat without getting hotter. When the ambient temperature in the space around the PCM material drops, the PCM solidifies, releasing its stored latent heat. Heat storage in phase change has advantage of compactness, since the latent heat of most materials are large compared to their heat capacity over a temperature of order of 20 degrees. It has added advantage of heat supply at constant temperature. The various phase changes that can occur are melting, evaporation, lattice change etc. Phase change 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 substances. Over 20,000 compounds and/or mixtures have been considered in PCM, including single component systems, congruent mixtures, eutectics and peritectics. 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. The value of the latent heat is very important, because the higher latent heat results higher storable heat quantity. According these aspects we can choose from several materials. We have to mind the chemical properties, the thermal expansion and the aspects of safety. PCMs in the 50 to 1000 temperature range have been proposed to water heating and o-peak electrical heater applications. There are a large number of organic and inorganic phase change materials (PCM) that meet the required thermodynamic and kinetic criteria for operation in desired temperature of 0-1400 C but many of them cannot be used due to the problems of chemical stability, toxicity, corrosion, volume change, availability at reasonable cost, etc. Solid-solid PCMs absorb and release heat in the same manner as solid-liquid PCMs. 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.
II. CLASSIFICATION OF PCM

![Diagram of Phase Change Materials]

A. Latent heat storage materials

Phase change materials (PCMs) used in Latent Heat Thermal Storage (LHTS) devices should fulfill a number of requirements. Basically, a good PCM should have a melting point in the desired operating temperature range, high latent heat, congruent melting, and absence of supercooling during freezing. The various criteria that govern the selection of phase change storage materials are summarized in Table 1.1. Generally, salt hydrates and paraffin have been found suitable for low temperature applications and inorganic salts like fluorides, chlorides, hydroxides, nitrates, and carbonates for high temperatures.

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Substance (Mixtures)</th>
<th>Melting Point °C</th>
<th>Heat of Fusion kJ/kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>H₂O</td>
<td>0</td>
<td>335</td>
</tr>
<tr>
<td>2</td>
<td>Na₂SO₄.10H₂O + NaCl</td>
<td>13-18</td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td>Na₂SO₄.10H₂O + KCl</td>
<td>13-18</td>
<td>-</td>
</tr>
<tr>
<td>4</td>
<td>CaCl₂.6H₂O</td>
<td>30</td>
<td>161</td>
</tr>
<tr>
<td>5</td>
<td>Na₂SO₄.10H₂O</td>
<td>32</td>
<td>241</td>
</tr>
<tr>
<td>6</td>
<td>Paraffin wax</td>
<td>46</td>
<td>209</td>
</tr>
<tr>
<td>7</td>
<td>Na NO₃</td>
<td>310</td>
<td>173</td>
</tr>
<tr>
<td>8</td>
<td>NaOH</td>
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<td>159</td>
</tr>
<tr>
<td>9</td>
<td>LiF</td>
<td>845</td>
<td>1044</td>
</tr>
</tbody>
</table>

Table 1.1. List of some phase change substances and their properties

III. PARAFFINS

Paraffin is safe, reliable, predictable, less expensive and non-corrosive. The paraffins are waxes at room temperature. 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. Paraffin’s qualify as heat-of-fusion storage materials due to their availability in large temperature range and their reasonably high heat of fusion. Due to cost consideration, only technical grade paraffin may be used as PCMs in latent heat stores. Paraffins like other mineral oil products are complicated mixtures of several organic compounds and contain one major component called alkenes. The desirable characteristics that make them suitable to be used as PCMs are:

1. Congruent melting
2. Good nucleating properties

Advantages

1. Freeze without much supercooling.
2. Ability to melt congruently.
3. Self nucleating properties.
4. Compatibility with conventional material of construction.
5. No segregation.
7. High heat of fusion.
8. Safe and non-reactive.
9. Recyclable

Disadvantages

1. Low thermal conductivity in their solid state. High heat transfer rates are required during the freezing cycle.
2. Volumetric latent heat storage capacity is low.
3. Flammable. This can be easily alleviated by a proper container.
4. To obtain reliable phase change points, most manufacturers use technical grade paraffin which are essentially paraffin mixture(s) and are completely refined of oil, resulting in high costs.

Fig. 2: Photographic view of Paraffin wax plate

IV. SOLAR WATER HEATER

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 unshaded, 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. 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. Solar water heater is getting popularity, since they are relatively inexpensive and simple to fabricate and maintain. 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. The PCM for a solar water heater and concluded that the efficiency of the system and the outlet water temperature during the evening hours increases with the increase in the thermal conductivity of the solid-liquid phases of the materials. Hot water can be obtained throughout the day if water pipes are placed near the surface of the storage material.

The outlet water temperature curve becomes flat if the pipes are placed near the bottom of the storage material. Water heater containing a layer of PCM filled capsules at the bottom (Fig. 3).

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. The energy is released by the PCM on changing its phases from liquid to solid.

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. 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. The stored energy can be used for pre-heating the cold incoming water.
storing heat sensibly. The charging process continues till the PCM and the water attain thermal equilibrium. Temperatures of the PCM and water at the outlet are recorded at intervals of 3 hours. The PCM is charged through the day, whenever hot water is not demanded by the user. The discharging process used is termed as batch wise process. In this method, a certain quantity of hot water is withdrawn from the water tank and readings are taken. This is then repeated for intervals of 3 hours, in which time transfer of energy from the PCM would have occurred. This procedure is continued till PCM reaches a temperature of 56°C. PCM storage for a water heater by incorporating the effect of water flow through a parallel plate placed at the solid-liquid interface. In order to reduce the night heat losses from the exposed surface, a provision of covering the system by movable insulation was made.

VI. RESULTS AND DISCUSSION

The temperature distributions of water and the PCM in the water tank for different time intervals are recorded during charging and discharging processes. The cumulative heat stored and system efficiency of process is studied in detail during the discharging process.

A. Charging Process

1) Instantaneous heat stored

Fig 6 graphically represents the instantaneous heat stored in the storage tank during the charging process of PCM. This is estimated based on the instantaneous inlet and outlet temperatures of the water. It is observed that during the initial period of charging the heat stored is high, but decreases there on end. During the phase change period of PCM, the drop in heat stored is less drastic, almost a constant. This is a major advantage of the PCM system where a uniform rate of charging and discharging is possible for a longer period, which will be useful for practical applications.

B. System Efficiency

System efficiency is defined as the ratio of the amount of energy stored by the water tank to the heat energy available from solar radiation. The system efficiency of the SWH with & without PCM is as shown. It is seen that the system efficiency increases with time during the sensible heating of solid PCM, remains nearly constant during phase change period and then further increases during sensible heating of liquid PCM.

C. Temperature histories of water and PCM

<table>
<thead>
<tr>
<th>Time elapsed (hrs)</th>
<th>Temperature of water0C</th>
<th>Time elapsed (hrs)</th>
<th>Temperature of water0C</th>
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<tbody>
<tr>
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<tr>
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<td>68</td>
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</table>

Table 2 Charging process

The graphical representation is as follows:
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Fig. 9: Charging process in SWH

D. Discharging process

Fig. 10: Discharging process in SWH

VII. CONCLUSIONS

A solar thermal energy storage system using phase change material (Paraffin Wax) has been proposed that can overcome the time mismatch between solar availability and demand. The use of PCM in solar water heater helps to reduce cooling rate of water, thus it enhance the maximum utilization of solar energy and hence improves efficiency of system. With using PCM material efficiency & heat capacity of solar water heater increases at reduced initial heating rate because PCM take heat to get heated. As PCM based solar water heater store maximum solar energy, it reduces the size of tank and hence can reduce cost of Solar Water Heater.

REFERENCES


