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PERFORMANCE ANALYSIS OF SOLAR WATER HEATER INTEGRATED WITH SODIUM ACETATE TRIHYDRATE AS PHASE CHANGE MATERIAL

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Abstract

The Solar Water Heater (SWH) has an important place among solar heating collectors due to the fact that construction of the water heater requires less material than others. The Solar water heater may be used for space heating and drying. The main objectives of this paper are to increase the efficiency of flat plate collector solar water heater. The efficiency of Solar Water Heater is increased with decreasing, the thermal losses. To overcome the high thermal losses due to conduction, convection and radiation in the flat plate collector, PCM materials are used. To improve the efficiency of the flat plate collector, it is integrated with the Sodium Acetate Trihydrate as PCM. To enhance the heating rate of the solar water heater, the PCM is integrated and stored directly in flat plate collector. The performance of the flat plate collector is measured with and without using PCM. The Experimental result were taken for the area of 0.42 m^2. The efficiency of the flat plate collector is increased up to 5 to 7% while compared to with and without using PCM.

Keywords: Solar water heater, Flat plate collector, Thermal energy storage, Latent heat storage, Phase change material, Encapsulation

1. INTRODUCTION

Solar water heating (SWH), one of the most popular solar thermal systems, it accounts for 80% of the solar thermal market worldwide (Philibert C 2006, Boyle G 2004). Over the past few decades, SWH have gained wide applications in the building sector all over the world (Zhai XQ, Wang RZ 2008). However, the systems have been identified with a number of technical problems becoming the barriers to their promotions, e.g., low efficiency in cold climate, high heat losses during night and poor solar harvesting capability, as well as the economic barriers, e.g., high cost in some regions. Phase change material (PCM) is a kind of latent energy storage material by undergoing an isothermal or near isothermal phase transformation, which has attracted considerable attentions due to the high energy storage density and compactness of the material (Abhat A 1983, Region A.F 2008).

Solar domestic hot water (SDHW) systems can be designed in many ways and manufactured with a variety of techniques. Conventional SDHW systems consist generally of solar collector(s) connected to a thermal storage tank via suitable piping. The storage system differs from the conventional one by the integration of the collector and storage tank into a single piece of equipment.

Solar thermal energy had been traditionally stored in the form of sensible heat by raising the temperature of water for later use. Despite the obvious simplicity of such storage methods, they are inefficient as their storage capacities are limited. In contrast, solar thermal energy can be stored in the form of latent heat by using suitable Phase Change Materials (PCMs), which can offer high storage capacity per unit volume and per unit mass. A PCM is a material that stores or supplies heat at its melting/solidification temperature using its high thermal energy storage density per unit volume by its latent heat, which is higher than the sensible heat (I. Dincer 1999). It is possible to use the latent heat of solid–gas, solid–liquid and liquid–gas transformation; however, only the solid–liquid transformation is used due to its lower volume variation (L.F Cabeza 2006).

Phase change materials was integrated in solar heating systems using various manufacturing techniques. Some of these techniques are a storage water heater containing a layer of PCM-filled capsules to get hot water during off-sunshine hours (J. Prakash 1985).

2. FLAT PLATE COLLECTORS

Numerous innovative investigations have been done to modify the basic design of flat plate solar collector to increase its thermal performance. PCMs have been a dedicated motivation to tap the promising outcomes in thermal stability and performance. PCM stabilizes the intermittent temperature fluctuations as well as extends the operating hours. Domestic flat plate solar water heating system can be incorporated with PCM in three ways: (a) under the collector absorber plate, (b) concentric to the flow line (Malvi et al., in press), or (c) a separate thermal energy storage unit (Eames and Adref, 2002; El Qarnia, 2009; Kaygusuz, 1995; Nallusamy et al., 2007). In this study, we compile and analyze innovative approaches in the literature to incorporate PCM inside solar collectors.

Integrating PCM with flat plate solar collector has been the oldest technique to enhance its thermal performance. (Boy et al. 1987) first investigated integrating phase change material in a combined solar collector storage in 1987. Scarcely, other investigations were performed in later years, until Rabin et al. (1995) who studied another conceptual design with liquid and solid PCM layers. They used eutectic mixture of salt hydrates at PCM on a layer of stationary heat transfer liquid (SHTL) containing the heat exchanger. Their theoretical study suggested a PCM thickness of 30–65mm for heating greenhouses. Their experimental study reported that two third of the solar radiation that falls on the collector can be stored. In (2006, Mettawee and Assassa 2006) experimentally investigated a completely new compact design of PCM solar collector with $1m^2$ effective area. They tested a 1.3m length collector fixed at 318 K with a single water pipe at a specified central location to maximize heat intake from the surroundings filled with PCM (paraffin wax). They found that the heat gain increased with increase in mass flow rate of heat transfer fluid (HTF)-water; and that decreases over the time due to the low thermal conductivity of the PCM. They also concluded that the initial heat transfer is primarily through conduction and later through convection (within the PCM layers).

3. THERMAL ENERGY STORAGE (TES)

Thermal Energy Storage (TES) plays an important role in energy conservation. The most important advantage of thermal energy storage is that the stored energy can be utilized later as and when required (I.Dincer 1996). Economical and safe energy storage technology has high potential in solar thermal applications such as water and space heating, air conditioning, waste heat recovery etc. This type of storage is more attractive for reducing the gap between the supply and demand of energy (K.Kaygusuz 1999). The demand for energy is high when the solar radiation is unavailable or poor i.e. during night and/or cloudy days. Thermal energy can be stored either in the form of sensible heat or latent heat or combination of these.

3.1 Sensible heat storage (SHS)

The sensible heat of a solid or liquid allows to store thermal energy by raising its temperature until the phase change process initiates. The amount of stored thermal energy depends on the specific heat of the medium, temperature change and the mass of storage material as shown in the following equation.

$$Q = mc_p\,(T2 - T1) \qquad (1)$$

Examples for this type of energy storage are rock, glass wool, water, sand etc (A.Sharma 2009). As the sensible heat storage system occupies substantial volumetric space and its thermal energy storage efficiency is significantly lower, this type of storage is not focused in rest part of this paper.

3.2 Latent heat storage (LHS)

Latent heat storage refers to the storage or release of thermal energy during its phase change. When a solid Latent Heat Storage Material (LHSM) is heated, it's sensible heat increases until it reaches the melting point. From the initiation of melting to the completion of melting the significant amount of heat is stored in the form of latent heat. In contrast, the latent heat is released when a heated LHSM is cooled from the initiation to its completion of solidification process. For a given volume the latent heat storage is significantly higher than that of sensible heat storage. Latent heat provides substantially high energy storage density and maintains small temperature difference between the storage and release of heat (M.M. Farid 2004). LHSMs can be of the form Solid–Solid (S–S), Solid–Liquid (S–L), Solid–Gas (S–G) and Liquid–Gas (L–G) based on the transformation type. In a S–S LHSM, the material undergoes phase transformation from one solid state to other. Among S–S, S–L, S–G and L–G phase change materials S–S and S–L are preferred due to smaller volume change (Z.Wang 2015). Also, S–G and L–G LHSMs require compression to revert back from gaseous phase to either solid or liquid phases. This phase transformation requires additional energy thus it reduces the storage efficiency. For this reason, solid–gas and liquid-gas based LHSMs have not gained more attention for their commercial application. It may be noted that the present study will be restricted to Solid–Liquid phase change materials. The amount of thermal energy stored in the form of latent heat can be determined by the following equation

$$Q = m\Delta H \qquad (2)$$

Typical examples of such materials are paraffin compounds, fatty acids, salt hydrates and eutectics. (Barreneche et al 2015) provided a detailed database on LHSMs for low temperature thermal energy storage applications. It was mentioned that the latent heat of fusion is one of the most important parameters in the selection of the best LHSM.

4. PHASE CHANGE MATERIALS

The main property of phase change materials is the storage of heat energy in a latent form, leading to greater heat storage capacity per unit volume than that of conventional solar water heater materials. When the ambient temperature increases, the chemical bonds of materials will break up where by materials will change from solid to liquid. This phase change is an endothermic process and as a result will absorb heat. As the ambient temperature drops again the PCM will return to the solid state and give off the absorbs the heat shown in fig 1. This cycle stabilizes the interior temperature cuts off-peak cooling load and decrease heating loads, not by affecting the thermal resistance of the solar water heater envelope but by influencing the (surface) temperature. A phase change materials (PCM) is a substance with a high heat of fusion which, melting and solidifying at a certain temperature, is capable of storing and releasing large amount of energy. Heat is absorbed or released when the material change from solid to liquid and vice versa.

Including such phase change materials in solar water heater constructions, some specific thermal, physical, kinetic and chemical properties are desired:

- From a thermal point of view, a suitable phase change temperature range, a high latent heat of fusion and a good heat transfer towards the PCMs are desired. The desired phase change temperature will depend on climatic conditions and the desired comport temperature.
- From a physical point of view, a high density and small volume change at the phase change are desired for easy incorporation in existing solar water heater materials or structures.
- From a kinetic point of view, no sub cooling and a sufficient crystallization rate are desired to make optional use of the properties and possibilities of PCMs. Super cooling, i.e. the process of lowering the temperature of a liquid below its freezing point without becoming a solid, could strongly affect the performance of the PCMs based on the chosen suitable phase change temperature by influencing this temperature.
- From a chemical point of view, a long term chemical stability of the PCM despite, compatibility with construction materials, non-toxicity and no fire hazard is desired.
- The melting temperature of the PCM should be in the range of operating temperature.
- High thermal conductivity.
- High density.
- Low volume change during phase change.
- Less corrosion effect to the construction materials.
- Low degradation, easily available & cost effective.

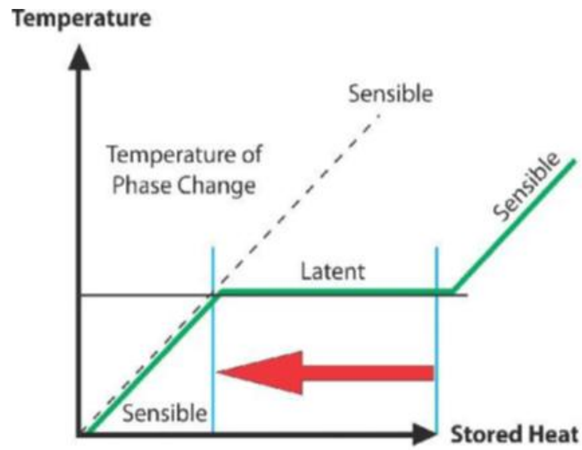

Figure: 1 The graph of sensible and latent heat of water

5. EXPERIMENTAL SETUP

5.1 Flat plate collector

The collector was designed of a rectangle shape of dimension 70×60 cm and width 15 cm, in such a way that fluid can flows from the inlet to outlet through the pipe with longer is 5.9 m, designed as Zig Zag pattern as shown in Fig.2 shows schematic of the flat plate collector. The absorber collector was insulation to decrease the heat loss by conduction through the collector, Polystyrene of thickness 2 cm was used to insulate the wall of inner collector faces, this face covered by aluminum foil sheet in order to increases heat absorber by the pipe because the aluminum foil sheet is a good reflector. The copper pipe of diameter 8mm is used to flow the water inside the collector. The absorbed collector was covered with a transparent glass of thickness 2mm to absorb the maximum amount of incident radiation. The inlet pipe connected with flow meter device, thermocouple, and controlling valve to control the volume flow rate, the outlet pipe insulation and supplier by thermocouple to measure the temperature outlet of the water. Measuring range: The water flow rate was selected (0.12–0.21 L/min). The experimental setup layout shown in fig.3.

Figure: 2 Solar water heater

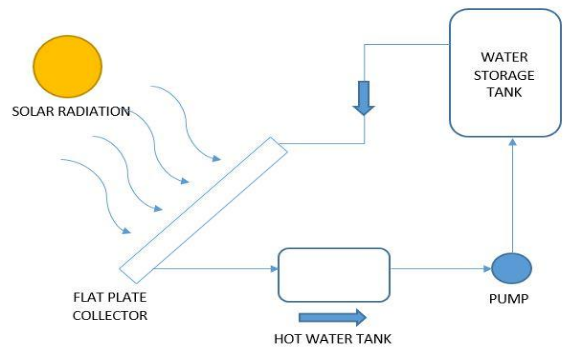

Figure: 3 Layout of solar water heater

5.2 Phase change material – Sodium Acetate Trihydrade ($C_2H_9NAO_5$)

The Sodium Acetate Trihydrate phase change material are especially interesting since they demonstrate high latent of fusion, high thermal conductivity, low flammability, and facilitate the use of buildings as compared to organic PCMs. The thermo physical properties of Sodium Acetate Trihydrate is find for use the differential scanning calorimeter and hydrometer.

Properties of the PCM	Value
Melting point	58°C
Specific heat 1.Solid 2.Liquid	 2.79 KJ/Kg K 2.1 KJ/Kg K
Latent heat of fusion	252 kJ/kg
Density	1.45 g/cm^3
Thermal conductivity 1.Solid 2.Liquid	0.7 W/m K

Table: 1 Properties of PCM

Its water content was determined by drying the material in a vacuum oven at 1500C and them weighing it before and after drying. Sodium Acetate Trihydrate ($C_2H_9NaO_5$) was used only as seed crystals. In some experiments ($C_2H_9NaO_5$) crystals were crushed in order to achieve seeds of a high nucleating capability. Other chemicals used were of pro analysis quality. Salt solutions of Sodium Acetate Trihydrate of varying concentration were prepared by mixing ($C_2H_9NaO_5$) with water or ($C_2H_9NaO_5$).

5.3 Encapsulation – Aluminum Material

Aluminum foil is an important material in laminates and has wide application in food packaging. Its barrier function against the migration of moisture, oxygen and other gases, and volatile aroma, as well as against the impact of light is generally higher than any plastic laminate material. Therefore, aluminum foil is used in the laminates when insufficient barrier properties are the limiting factor for shelf-life stability of food. The barrier properties of aluminum coated plastic laminates, which can offer an alternative to aluminum foil laminates, are somewhat less efficient. Application of encapsulation of phase change materials is to avoiding the chemical reaction between PCM and environment elements, easy handled and reduce the leakages during the melting operation. Foil is a very thin sheet of rolled aluminum supplied in its pure form 'commercial purity' or in a variety of alloys and tempers which give a wide choice of tensile properties.

The dimensions of the aluminum pouch are

Length = 15 cm

Breath = 8.5 cm

Thickness = 0.05 cm

Figure: 4 Aluminum pouch

The thickness of foil ranges from the thinnest currently produced commercially at about 0.0065 mm (or 6.5 µm) to the defined upper limit of 0.2 mm (or 200 µm).

Property of aluminium	**Values**
Specific gravity	2.7
Weight	At 6.35 µm foil weighs 17.2 g/m2
Melting point	660°C
Thermal conductivity	235 W/m.K
Thickness	0.2mm (or 200 µm and below)

Table: 2 Properties of aluminum foil pouch

6. RESULTS AND DISCUSSION

The experiments were carried in a rectangular solar flat plate collector with aluminum absorber corrugated plate of 0.42 m^2 area and 0.5 mm thickness. The experiments consist of 2.5 Kgs of PCM storage along with aluminum absorber plate. The materials used along with flat plate absorber plate were black coating of corrugated sheet. The whole experimental setup was placed in Govt. College of Engineering, Salem on 17-10-2018 to 20-10-2018. The experiment was started at 9.30am, and took the readings for every one hour from 10.00 am until 5.00 pm. The parameters which measured from the rectangular solar still were, solar radiation (Ir), Ambient Temperature (Ta), Inlet and Outlet water temperature (T_i) & (T_o). In the case of experiment which is using Flat Plate collector. Each temperature was found using thermometer. As comparing below two graphs there is gradual deference in the inlet and outlet temperature with & without using PCM as shown in fig.5 & fig.6 its concluded that by using of PCM can stored more heat energy and can liberate up to 2 hours after sun set or less radiation hours.

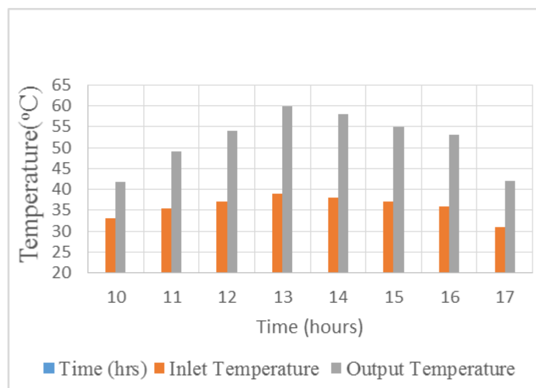

Figure: 5 Time Based Reading Inlet Temperature Vs Outlet Temperature without PCM

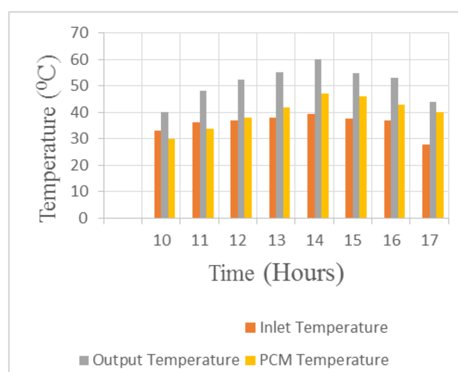

Figure: 6 Time Based Reading Inlet Temperature Vs Outlet Temperature with PCM

7. CONCLUSIONS

From the present work it is concluded that the thermal losses in the flat plate collector is reduced by using the PCM of Sodium Acetate Trihydrate. In this study solar water heater integrated with flat plate collector with and without Sodium Acetate Trihydrate, adding in the collector are investigated experimentally. It includes distribution of temperature, temperature difference between the Inlet and Outlet of the collector. The comparative the reading was taken with and without PCM. The large amount of water is heated between 1.00 pm and 2.00 pm which is about 60 to 65°C. The maximum amount of solar radiation collected by on 17-10-2018 day was 882 W/m^2 at 1.00 pm to 2.00 pm. After the sunset (4.00pm) or when Radiation is less the PCM starts discharging up to 2hrs. The efficiency of the collector is increased by 5 to 7% while compared to with and without PCM.

8. FUTURE WORK

The Future work will be based on the solar water heater with the composite PCM in the flat plate collector. It includes the preparation and analysis of the composite PCM. A comparative study will be carried out with the single-Phase Change Material and the Composite PCMs.

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