ENHANCE EFFICIENCY OF PHASE CHANGE MATERIAL IN SOLAR THERMAL ENERGY STORAGE SYSTEM

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Abstract: Thermal energy storage systems are progressively in demand for lower or higher temperature thermal storage applications because of their low cost and simplicity. Latent heat storage method is among one of the effective ways of store thermal heat energy and provides higher storage density as compared other conventional methods. In our article, we report a new solar collector which is studied and using a phase change material (PCM) to enhance the efficiency and utilizing the energy to heat water system for residential area. The PCM (phase change material) added to the peak of the water tank provides elevated storage density and minimize the heat loss in the top layer. The experiment was conducted using a Solar Residential Hot Water (SRHW) storage tank of 70ltr water capacity and was circulated with pump. The heat was transferred from the panel to the tank containing waiting incorporated with PCM. The material incorporated with water undergoes phase change by absorbing the latent heat of the water. The systematic study was performed during charging and discharging process. The obtained result revealed that with having in cooperation of phase changing increase the efficiency of solar water heater from 49.21% to 54.76%. The storage tank was made completely insulated in an order to prevent heat loss.

***Keywords* - Phase changing material, heat storage system, flat plate collector, efficiency, latent heat**

I. INTRODUCTION

The energy consumption is increasing worldwide & environmental awareness headed to suggest requirement of renewable energy. Solar energy is among one of the renewable energy sources which can serve for numerous domestic and industrial applications. In general, solar energy is the conversion of solar radiation into heat form. Over the last decade a wide range research and development has been done in the field of solar energy technologies. India is among countries which receives good amount of sunlight throughout the year around 5 x10^{15} kWh per annum, thus one can invest in solar thermal technology like solar water heating [1]. The solar thermal technology consists of conventional natural circulation flat plate solar water heaters and conventional forced circulation flat plate solar water heaters which uses solar energy to convert and store in heat form. The most efficient way is considered to be the latent heat storage for storing thermal energy as it gives much higher storage density, with a minimum temperature difference between storing and releasing heat. Phase Changing Material (PCM) is attracting research for storing thermal energy in heating systems. The major positives of PCM are high energy storage density and isothermal behavior during the charging and discharging processes. Solar water heater in cooperated with phase change material (PCMs) has proven to be more efficient and thus the energy can be utilized to heat water system for residential purposes. Basically, system consists of two absorbing unit's i.e. a solar water heater and other a heat storage unit consisting of material. During the sun radiation time, the solar collector absorbs the heat from radiation and the water is heated due to the exchange of heat from the radiation to the water. Then, heated water transfers the absorbed heat to phase change materials (PCMs) and thus the materials stores the absorbed heat as in form of sensible heat and latent heat. During the non-availability of sunlight, the material tends release the heat to the water and thus increases the temperature of the water. The most effective way to control greenhouse effect is to use the excessive heat in the surrounding for thermal applications and it can be achieved with the use of PCMs for Greenhouse Heating. The PCMs are applied in various other applications ranging from heat and cold cargo space in buildings and protective clothing. Materials with adjustable melting point are the major necessity as the melting point is the most important criterion for considering it as PCM for passive solar applications [2]. In 2001, *Kumar et al.* [3] designed a heat storage setup for latent heat storage in an order for evaluation of the performance and study. He used box type collector known as solar collector for collecting hot water requirements. System consists of3 heat exchangers and paraffin wax was used as a storage material for storing heat and having melting temperature near about 54ºC. Similarly, in 2005, Canbazoglu *et al*. [4] developed and study a water heating system in relation to phase changing material and it was observed that the outlet temperature of the system with phase changing material was greater, by 6ºC, than the system without the material. In 2006, Shukla *et al.* designed two water heating system with paraffin wax [5]. The two systems were operated on the fully day cycle and they were found to be more efficient nearly about 45% and 60%. Wide range of phase changing materials can be used for latent heat storage applications, which includes salt hydrates, paraffin waxes, fatty acids, and sugar alcohols [6]. For use in domestic solar based water heating applications, paraffin wax show reliability and have the most important parameter which is the melting point. But, they also usually undergo high volumetric expansion ratios and low thermal conductivity values. With low thermal conductivity, the advancement of phase changing materials can overcome the problem of low conductivity because of the materials having large surface area to its volume ratios. In our article paraffin wax has been used as phase changing materials due to its availability and usage. The Paraffin waxes are generally cheaper and have moderate thermal energy storage density with low thermal conductivity.

II EXPERIMENTAL SETUP

In our experiment we designed and fabricated a solar water heating system at latitude of 23.7° N where the average solar radiation received was in the range of 3-4 kWh/m^2/day. As depicted in Figure 1, the flat-plate collector was tilted at an angle of 23ºtowards south facing, supported by a solid structure. Further, the Figure 2 shows a schematic diagram of the solar water heating system.

Figure 1. The experimental setup of the flat plate solar collector for solar thermal storage system

The performance solar based heating system generally depends upon the temperature distribution inside the collector which includes absorber plate, riser tubes and connecting pipe of a solar water heating system. A significant difference was noted between the cold and the hot water and thus due to the density difference, water in the riser tubes get heated and flows towards the storage tank. The tank incorporated with phase changing materials plays a vital role in improving the overall efficiency of the system. Here we provide an in detail to the phase changing materials.PCM can be broadly classified into four types namely solid–solid, solid–liquid, solid–gas and liquid–gas types [7]. Among all phase changing materials solid–solid type is considered to be decently good due its small volume change property, negligible sub-cooling, non-toxicity, high thermal efficiency and long service life. It also has some drawbacks like its costly and low thermal conductivity [8-9]. These materials further can be bifurcated into cross-linked polyethylene, calcium titanium and polyatomic alcohol [10]. Further, solid–liquid [11-12] can be bifurcated into three categories i.e. inorganic, organic and composite. Further on the basis of their properties inorganic and organic materials are further divided into fatty acid, hydrous salt and metal paraffin respectively. Phase changing materials (PCM) are generally found from two most common Organic and inorganic compounds. Among the both, organic PCMs possessive higher chemical stability, non-corrosive, high latent heat per unit weight with low vapor pressure and are much more compatible with most building materials. The major disadvantage found is to be flammability, high change in volume on phase change and low thermal conductivity. Whereas, in case of inorganic compounds they show non-flammable and high latent heat along with high thermal conductivity at low cost.

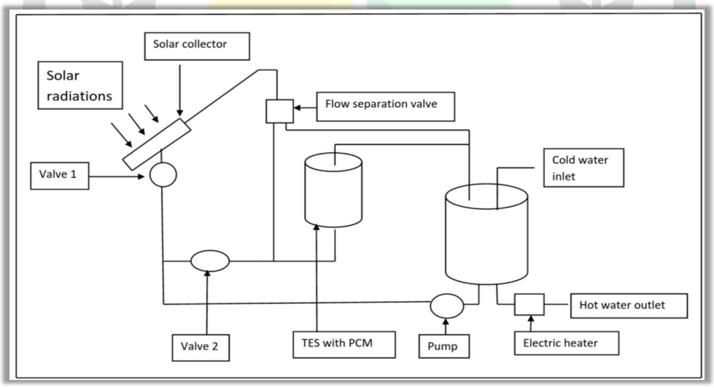

Figure 2. The schematic diagram of the solar based thermal storage system

However, they also have disadvantage of being among the corrosive materials and suffer from decomposition or sub cooling, which affects phase change properties. Our Experimental setup includes conventional solar based water heating systems consisting of a cylindrical circulating water tank which is consisting of PCM inside the tank along with the solar based flat plate collector. The water tank used of stainless had a capacity of 70ltrs with size of 60cm & 30 cm as length and width of the tank. The tank was insulated with 6cm glass wool along with an aluminium cladding. The phase changing materials used throughout the process was paraffin wax which was taken to be around 19kg. The mentioned amount was then significantly added to the 70ltrs of water to make a water-based solution. While in the charging process the material in cooperated solution was circulated through the inner tank and in the collector unit. During the process, the water gets absorbs with the solar radiated heat sensibly and thus leads to exchanges of heat with the phase changing material which is presented inside the storage phase changing material kept at the room temperature. Slowly, phase changing material heats up and it reaches a point of melting point of the material temperatures. In charging process, energy storage as Latent heat is achieved as the paraffin wax which melts at constant temperature (60±2°C). Once the melting is achieved, further heat addition makes the PCM to reach a superheat level, thereby again storing heat. Temperatures of the phase changing material and fluid were observed at the outlet point for every hour of the day. The phase changing materials gets charge during the day depending upon the customer usage of the system. While, charging process continues till the material and the fluid reaches thermal equilibrium. Once equilibrium is reach, discharging process begins batch wise process. During the experiment certain amount water was taken out for record purpose. The process was repeated for every interval of hours during which transfer of energy from the material occurred and it attains the temperature of 63°C.The temperature distributions of the solution (fluid containing PCM) in the water tank for an hour time interval were recorded during for both the processes.

III RESULTS AND DISCUSSION

3.1 Temperature Distributions (Charging and Discharging Process):

The temperature distribution of solution containing water and phase changing material was recorded at various time intervals for discharging and charging process. The collective heat stored and efficiency of system was deeply studied for both processes. It was observed that, temperature of water in the tank is increased along the time for charging process. But during discharging process, the temperature of water in the storage tank containing phase changing materials is reduced slowly. The temperature was measured at regular interval of 1 hour as shown in table 1 and table 2. At the final stage, the temperature of the water storage tank containing PCM was greater than ordinary system as shown in figure 3 and figure 4. The figure 3 shows the temperature distribution of the tank with and without PCM in the Charging Process while figure 4 shows the temperature distribution of the tank with and without PCM in the discharging process.

Table 1. The table shows cooling rates of water in the water tank with and without PCM (for charging time)

Charging without PCM		Charging with PCM	
Time(hrs)	Temperature of water(°c)	Time(hrs)	Temperature of water(°c)
0	27	0	36
9	32	9	39
10	37	10	43
11	44	11	46
12	50	12	50
13	57	13	56
14	61	14	59
15	63	15	61
16	65	16	63

Table 2. The table shows cooling rates of water in the water tank with and without PCM (for discharging time)

Cooling rates of water in SWH without PCM		Cooling rates of water in SWH with PCM	
Time(hrs)	Temperature(°C)	Time(hrs)	Temperature of water(°C)
0	65	0	63
4	62	3	61
6	58	6	59
8	55	9	56
10	51	10	53
12	48	12	49

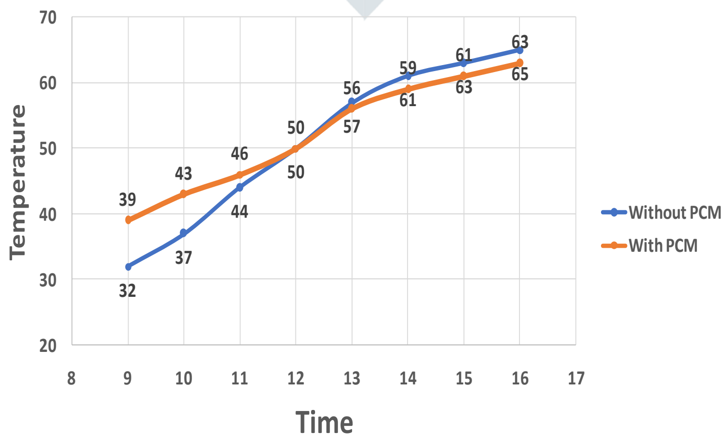

Figure 3. The plotted graph shows the temperature vs. time of the system with and without phase changing materials in Charging process.

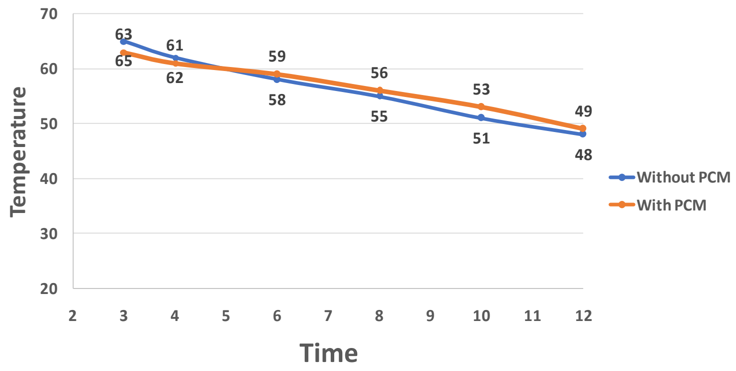

Figure 4. The plotted graph shows the temperature vs. time of the system with and without phase changing materials in Discharging process.

3.2 Efficiency Calculations

Efficiency calculation of Solar based water Heater without using phase changing material:
The parameters for calculating the efficiency of solar water heater without PCM are shown in Table 3.

Table 3: The table shows the various parameters of the solar water heater without phase changing materials (PCM).

Parameters for solar water heater without PCM		
	Symbol	Value
Volume of fluid	V	70litres
Starting Temperature	T_i	26ºC
Heat radiated	P_{in}	3390 Watts
Time	T	6hrs
Final Temperature of water	T_f	65ºC

Calculating the efficiency of solar based water heater storage system without using phase changing materials
Now, in an order to derive and calculate the efficiency of the solar based water heater carrying the phase change materials, we incorporated 19 kg PCM (Paraffin Wax) in water tank. We calculated the cooling rate of water in the water tank by adding PCM and heating water for 6 Hrs. The various parameters required to calculate the efficiency of solar based water heater system incorporation with phase change materials are shown in Table 4.

Table 4: The table shows the various parameters of the solar water heater with phase changing materials (PCM).

Parameters for solar water heater with PCM		
	Symbol	Value
Volume of fluid	V	70litres
Starting Temperature	T_i	30ºC
Heat radiated	P_{in}	5000 Watts
Time	t	6hrs
Final Temperature of water	T_f	68ºC

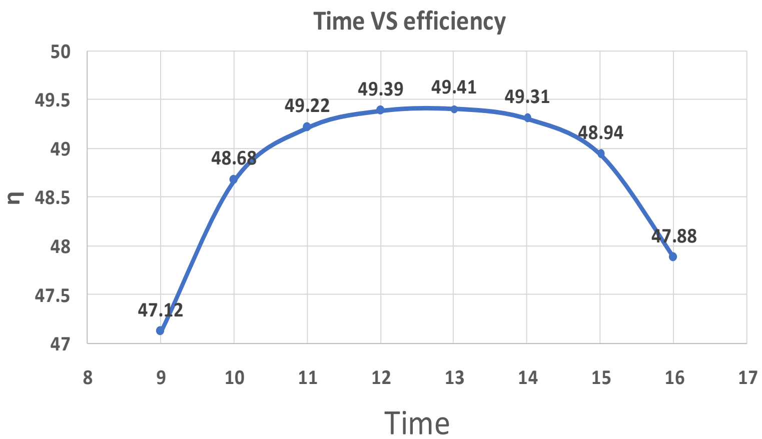

Figure 5. The plotted graph shows the calculated efficiency of solar water heater.

Therefore, the heat energy stored in the solar based water heating system with using the PCM becomes 3712.04 kJ and the efficiency becomes 54.76%. Fig. 6 shows the Heat energy stored in kJ without using PCM and also With PCM. From Table 5 it is clearly shown that by using PCM heat energy stored is greater than without using PCM in solar water heater.

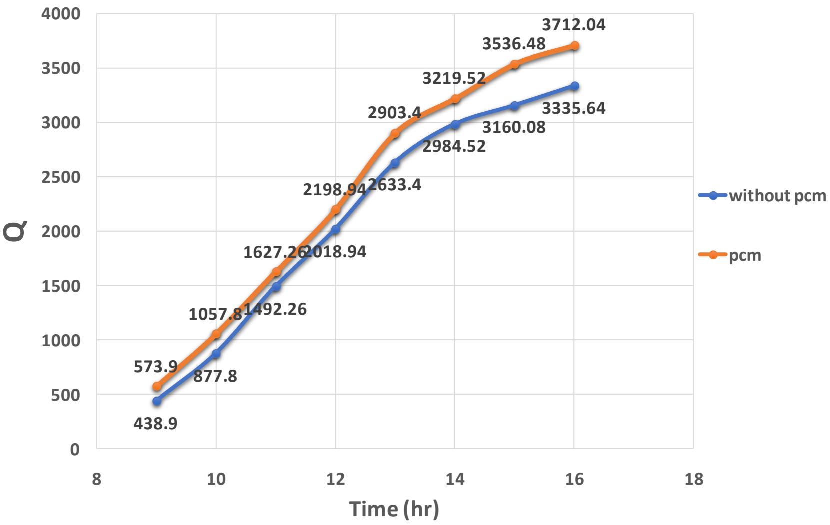

Figure 6. The plotted graph shows Heat Storage vs. Time for solution without and with phase changing material

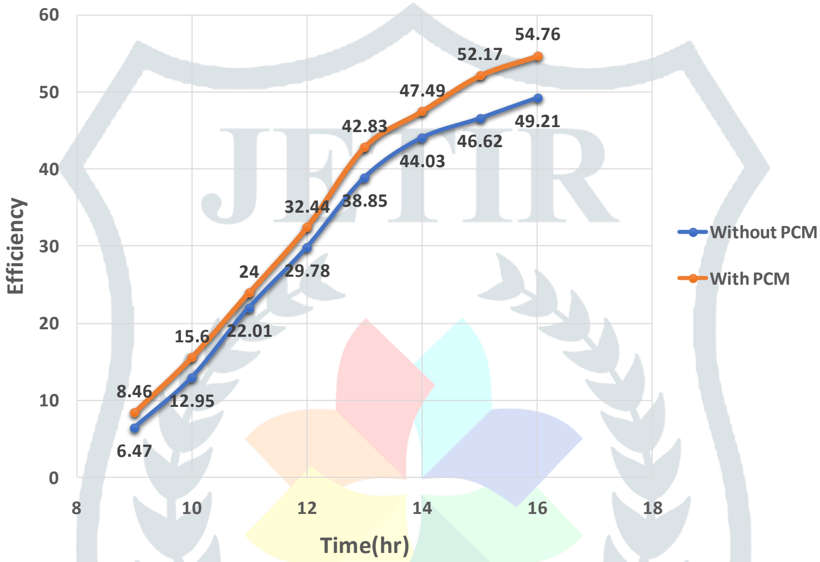

Figure 7. The plotted graph shows increment in the Efficiency along the time for solution without and with phase changing material.

From Table 6 it is clearly shown that by using PCM the efficiency is greater than without using PCM in solar water heater as compared to the one without using phase changing material.

Table 5. The table shows efficiency of solar water system with and without PCM.

Time (HH:MM)	Heat store without PCM (KJ)	Heat store with PCM (KJ)
09:00	438.9	573.9
10:00	877.8	1057.8
11:00	1492.26	1627.26
12:00	2018.94	2198.94
13:00	2633.4	2903.4
14:00	2984.52	3219.52
15:00	3160.08	3536.48
16:00	3335.64	3712.04

Table 6. The table shows efficiency of solar based water system with and without PCM.

Time	efficiency without PCM (KJ)	Heat store with PCM (KJ)
09:00	6.47 %	8.46 %
10:00	12.95 %	15.60 %
11:00	22.01 %	24.00 %
12:00	29.78 %	32.44 %
13:00	38.85 %	42.83 %
14:00	44.03 %	46.02 %
15:00	46.62 %	52.17 %
16:00	49.21 %	54.76 %

Figure 7 shows the Efficiency of the solar based water heater in % without using phase changing materials and also with PCM.

IV CONCLUSIONS

The incorporation of phase changing materials in the solar water heating system certainly helps in reducing cooling rate of fluid and enhances the utilization of sun radiated energy. Thus, it proves to be an efficient system. In our reported work with PCM, efficiency of solar water heater is increased from 49.21% to 54.76% along with enhancement in heat storage which enhances from 3335.64 kJ to 3712.04 kJ. PCM tends to heat it up from the solar energy and thus using renewable energy, it increases the efficiency and heat capacity of solar water heater. Along, the increment in the efficiency it also provides an advantage for the reduction of storage size tank which eventually reduces cost of Solar Water Heater. In future this work will help to test other materials of PCM along the system to enhance the efficiency of the system with novel designs for solar based water heating systems to store the thermal energy very effectively.

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