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Experimental Investigation of Solar Thermal Flat Plate Collector with and without PCM

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ABSTRACT: This experimental investigation has been made to find out the possibilities of utilizing PCM inside the solar thermal flat plate collector to act as short term energy storage media and thus improve the performance and utility of SWHS. Two significantly different configurations of flat plate collector (FPC) were developed, one was conventional FPC i.e. without PCM another was a novel kind of FPC having tube in tube type risers, the outer tubes contains water and the inner tubes which are sealed from both end contains PCM. It is well recognized fact that the thermal conductivity of PCM is comparatively low than that of water. So, if placed in outer tube, the PCM may act as thermal resistance to the heat, flowing from absorber plate to water. Hence it was decided to use PCM inside the solar thermal flat plate collector in such a manner that the heat flowing from absorber plate will first come in contact with water and then subsequently with PCM. Two PCMs both organic non- paraffin's with different melting temperature and latent heat of fusion were used in the experimental investigation. OM55. During phase II of experimentation maximum improvement achieved in the instantaneous efficiency of solar thermal FPC by incorporating PCM in it, in comparison to that of solar thermal FPC without PCM for evening hours was 16.9% and 20.4% for first two days while using PCM-OM48 and 16.0% and 15% for another two days while using PCM-OM55.

KEYWORDS: flat plate, collector, pcmom-48, pcmom-55

I.INTRODUCTION

Conversion of solar energy into thermal energy is easiest and most used method. As mentioned by Sadhish Kumar and Balusamy (2014), the efficiency of solar conversion is around 70% in contrast of solar electrical direct conversion systems which has an efficiency of only 17%. Further solar water heating is one of the most popular solar thermal systems and accounts for 80% of the solar thermal market worldwide. Augmenting to this, as reported by Veerabonia and Ratnam(2012), another fact is that about 30-40% of a family's electricity bill is devoted to hot water usage. Sun heat systems can save the individual family from 70 to 90% of the total amount spent on the electricity used for heating water. SWHS are becoming widespread and are now contributing significantly to both domestic and individual sectors in several countries. SWHS is a device that makes the available thermal energy of the incident solar radiation for use in various applications by heating the water. Hot water is essential both in industries and domestic applications. Phase change materials (PCMs) are "latent" heat storage materials. The thermal energy transfer occurs when a material changes from solid to liquid, or liquid to 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 heat. Unlike conventional (sensible) storage materials, PCM absorbs and release heat at a nearly constant temperature. several studies have been carried out by incorporating PCM inside solar thermal collectors of significantly different design and configuration and by doing so improved performance and utility of solar water heating systems was reported by various authors. Taking consideration of the experimental research done by Kurklu et al. (2002), Thaib et al. (2014) and Gond et al. (2012), it can be seen that PCM was utilized inside solar thermal collector in such a way that the heat flows from absorber plate to PCM first, which was in sudden contact with absorber plate and then ultimately from PCM to water. It is well recognised fact that the thermal conductivity of PCM's is comparatively low than that of water. So, in this way PCM may as thermal resistance to the heat, flowing from absorber plate to water. Hence it was decided to use PCM inside the solar thermal flat plate collector in and then subsequently with PCM. This new

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configuration of solar thermal flat plate collector containing PCM proposed here has never been examined earlier. Therefore, it has been decided to carry out experimental investigation with this new kind of solar thermal FPC incorporating PCM inside it. Keeping in view all the above discussed matter, a consensus has been made to carry out the present research entitled experimental investigation of solar thermal flat plate collector with and without PCM'.

II. MATERIALS AND METHODS

Experimental set up was designed, fabricated and used for carrying out the present experimental investigation. Photographic view of experimental set up i.e. SWHS with and without PCM is shown in Fig. 4.1. Both the SWHS resembles with each other in all aspects other than one, which is FPC configuration. The other components which constitute the SWHS are storage tank and plumbing circuit. An active temperature measurement system was employed to measure the temperature of water in both the setups during the working cycle of system. And to measure mass flow rate of water trace injection method was used for both setups. All the experimentally measured data was recorded manually, which was further utilised to compute important factors for comprising SWHS i.e. profile of water temperature at the inlet / outlet of FPC and instantaneous efficiency. Experimental investigation was carried out in two phases, in first phase experiment was conducted in the month of January and in second phase experiment was conducted in the month of May. In both of the phases experimental investigation was carried out for four days, for first two days PCM-OM48 was incorporated in solar thermal FPC with PCM, Both the SWHS i.e. with PCM and without PCM were made to run and thus experimental data was recorded. In similar fashion experimental investigation was carried out for another two consecutive days while using PCM-OM55 instead of PCM-OM48 which was previously used, Again both the SWHS i.e. with PCM and without PCM were made to run and thus experimental data was recorded. All the components of both SWHS (i.e. with and without PCM) constituting experimental setup were placed in appropriate position so that the proper working condition should prevail. Both the setups were filled with water up to certain suitable level to carry out continuous thermo-syphon flow without any interruption. Temperature of water at the inlet and outlet of solar thermal FPC for both the experimental setups was measured with the help of thermocouples at regular intervals of time and then recorded manually for further utilization in calculations. Intensity of solar radiation falling at flat surface of solar thermal FPC inclined at an angle of approximately 31° to horizontal was measured with digital pyranometer at regular interval and recorded manually for further use in calculations. Velocity of flowing water in both the experimental setups was measured with dye trace injection method and recorded manually. The measured value of velocity of water was then utilized to compare the mass flow rate of water. Experimental investigation by incorporating PCM-OM48 as phase change material in solar thermal FPC with PCM was carried out for two consecutive days. Experimental data was recorded for both the setups (i.e. with and without PCM) and then conveniently utilized to compute the instantaneous efficiency of both solar thermal FPCs. In the similar fashion experimental investigation was carried out for another two consecutive days while using PCM-OM55 instead of PCM-OM48 which was previously used. Experimental data was recorded for both the setups (i.e. with and without PCM) and then conveniently utilized to compute the instantaneous efficiency of both solar thermal FPCs.

III. DATA REDUCTION

To calculate the mass flow rate (\dot{m}) of water (HTF), below mentioned equation was used as reported by Ong (1974).

$$\dot{m} = \rho A V$$

A = Area of cross section of pipe carrying water in m^2 .

V = Velocity of water in m/sec.

ρ = Density of water equals to 1000 kg/m^3 .

To calculate the instantaneous efficiency (η) of the solar thermal FPC below mentioned equation was used as reported by Kurklu et al. (2002).

$$\eta = \frac{\dot{m} c_p \Delta T}{I A_c}$$

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A_c = Collector area in m^2 .

C_p = Specific heat of water in $J/Kg-^{\circ}C$.

I = Solar radiation intensity in W/m^2 .

\dot{m} = Mass flow rate in Kg/sec .

ΔT = Temperature difference of water across the FPC in $^{\circ}C$.

IV.RESULTS AND DISCUSSION

By incorporating PCM-OM48 as phase change material, having melting temperature of $48^{\circ}C$ and latent heat $275 KJ/Kg$, the inlet/outlet water temperature variation of both the solar thermal FPCs i.e. with and without PCM was investigated for two consecutive days. Fig.1 and Fig.2 depicts the temperature variation recorded at the inlet and outlet of both the solar thermal FPCs i.e. with and without recorded at the inlet and outlet of both the solar thermal FPCs i.e. with and without PCM with respect to time. It can be observed from Fig.1 and Fig.2 that the outlet water temperature of both the solar thermal FPCs i.e. with and without PCM remains quite close to each other almost throughout the day except during evening hours. It can also be observed from Fig.1 and Fig.2 that at the evening hours near to the sunset time, the outlet water temperature of solar thermal FPC without PCM falls more rapidly than that of solar thermal FPC with PCM. In the evening hours when solar incident radiation intensity decreases, the outlet water temperature of both the solar thermal FPCs gradually decreases altogether until the temperature of water reaches to the phase transition temperature of PCM. Afterwards when the phase transition temperature of PCM is reached the outlet water temperature of solar thermal FPC with PCM becomes stable for short while and decreases gradually whereas contrary to this the outlet water temperature of solar thermal FPC without PCM goes on decreasing rapidly. The credit of maintaining the outlet water temperature of solar thermal FPC incorporated with PCM considerably higher than that of solar thermal FPC without PCM during evening hours goes to the PCM. PCM absorbs sensible and latent heat during day time and changes its phase from solid to liquid. During evening hours PCM changes its phase from liquid to solid and thus releases sensible and latent heat to surrounding water. This sensible and latent heat is now utilised to maintain the outlet water temperature of solar thermal FPC with PCM sufficiently above the outlet water temperature of solar thermal FPC without PCM. Thus for nearly one hour or so the outlet water temperature of solar thermal FPC with PCM can be maintained about $10^{\circ}C$ higher than that of the solar thermal FPC without PCM at evening time by incorporating PCM inside the riser tubes of solar thermal FPC. Also it can be observed from Fig.1 and Fig.2 that the value of maximum temperature of water at the outlet of both the solar thermal FPCs i.e. with and without PCM is nearly equal.

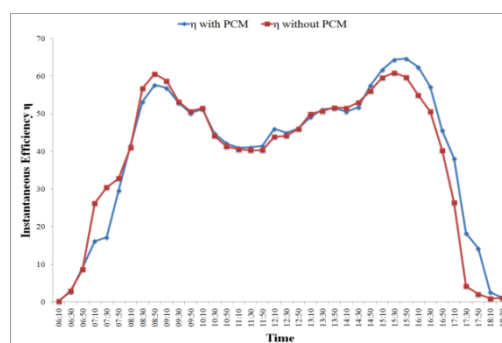


Fig.1. Variation of instantaneous efficiency of solar thermal FPC with and without PCM (OM-55) on 1st day.

The maximum temperature of water recorded at the outlet of solar thermal FPC with PCM and solar thermal FPC without PCM is $83^{\circ}C$ and $80^{\circ}C$ respectively for 1st day and the same is recorded as $88.1^{\circ}C$ and $87^{\circ}C$ respectively for 2nd day. Thus no significant effect of incorporating PCM inside the solar thermal FPC was found on the maximum temperature of water at the outlet of collector. Further it can be observed from Fig.1 and Fig.2 that the inlet water temperature of both the solar thermal FPCs i.e. with and without PCM remains almost equal throughout the day.

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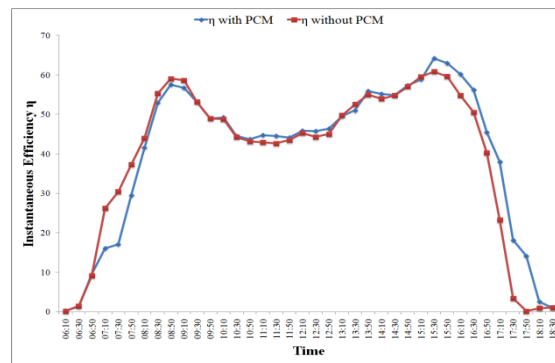


Fig.2. Variation of instantaneous efficiency of solar thermal FPC with and without PCM (OM-55) on 2nd day.

V. CONCLUSION

Incorporating PCM inside the riser tubes of a solar thermal FPC to act as short term thermal energy storage media is satisfactory and useful in improving its instantaneous efficiency at evening hours. By incorporating PCM inside the solar thermal FPC the outlet water temperature of solar thermal FPC with PCM can be maintained nearly 10°C higher than that of solar thermal FPC without PCM at evening hours, thus degree of hotness of water can be maintained for longer duration of time. Maximum improvement achieved in the instantaneous efficiency of solar thermal FPC by incorporating PCM in it, in comparison to that of solar thermal FPC without PCM for evening hours during phase I of experimentation was 14.5% and 15% for first two days while using PCM-OM48 and 16% and 11.5% for another two days while using PCM-OM55 and during phase II of experimentation was 16.9% and 20.4% for first two days while using PCM-OM48 and 16.0% and 15% for another two days while using PCM-OM55.

VI. FUTURE SCOPE OF WORK

Although the results of the present experimental investigation gives vivid view of improvement in the instantaneous efficiency of solar thermal FPC by incorporating PCM inside the riser tubes of collector at evening hours in comparison to the without PCM solar thermal FPC. But yet, to maximize the benefits of using PCM with SWHS by incorporating PCM into the solar thermal FPCs, research must be further carried out while considering some factors like Phase transition temperature of PCM, Latent heat of fusion PCM possesses, Quantity of PCM utilized inside the collector and adequately compatible material for inner tube of riser containing PCM.

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