Thermal Performance of Phase Change Material Based Heat Sink for Solar Photovoltaic Cooling

M. Senthil Kumar, K.R. Balasubramanian, Ajith Krishnan. R, L. Maheswari, N. Sivakumaran

Abstract: Solar photovoltaic panels can receive only eighty percent of total incident solar radiation. A small amount of incident energy is transformed into electrical energy based on the efficiency of the photovoltaic (PV) cell. The remaining energy leads to an increase in photovoltaic cell operating temperature which affects its life and power output. Cooling of PV panel is the best way to improve the efficiency either by passive or active cooling methods. PV cooling by Phase change materials (PCM) is the best effective technique. Paraffin wax is a non toxic material having high latent heat of fusion used for many thermal applications. In this study, paraffin wax is taken as phase change material in aluminum heat sink with fins. Using DSC, the melting point of paraffin wax is analysed. The flat plate heater is used instead of solar PV panel. Different wattages are used for the experiments. Different inclinations such as horizontal (0^0), vertical (90^0) and intermediate (45^0) were taken in to consideration. The melting starts at 50°C and complete melting occurs at a temperature around 60°C for the paraffin based heat sink. The heat sink surface temperatures, fin temperatures and PCM temperatures are measured. The transient temperature distribution of heat sink, PCM is analysed at different wattage inputs. The total thermal performance of this paraffin PCM based heat sink was analysed experimentally. This infers that the cooling of high temperature of PV panels can be done by using paraffin based PCM to increase the efficiency and life of the panels.

Key words: Photovoltaic cooling, Heat sink, Thermal performance, PCM

I. INTRODUCTION

In silicon photovoltaic cell panels, the elevated operating temperatures due to complete exposure to sunlight reduce the solar panel electrical efficiency. Presently, small part of solar energy incident (15 -20 %) on a PV panel only converted to electricity, remaining part will be changed into heat. It will be absorbed by the PV cell and increasing the temperature upto 80^0C. The electrical efficiency is decreased by 0.4–0.65% for each increased degree [1]. Many researchers conducted the experiments to remove the heat from PV panel surfaces and efficiency improvement. Lot of the research on PV cooling focus on natural or forced convection cooling, hydraulic cooling, refrigerant cooling and heat pipes[2][3][4][5][6]. The thermal regulation of PV panels includes two approaches, passive and active. In case of passive cooling, the rear of the panel is mounted with air channel or duct which conducts heat away by natural air flow. No external power is required for this passive cooling of PV panels. In case of active cooling method, heat removal by water or air using fans or pumps. PV cooling by active method increases heat dissipation, PV performance compared to the passive approach. Even though active method of PV cooling enhances heat dissipation the power usage and maintenance costs are more, which further reduces overall efficiency of PV panel system [7]. Recent times a phase change material (PCM) based PV panel cooling method have more attention by researchers. Such a PV-PCM panel absorbs the latent heat when the process of solid to liquid phase changes. Figure 1 shows a typical PV-PCM Panel. It has a conventional PV panel with aluminum heat sink container filled with PCM. The PV panel converts part of solar radiation into electricity. The remaining is converted into heat and entering into PCM container by the process of conduction. At the back side of the container, the heat may be removed by natural convection.

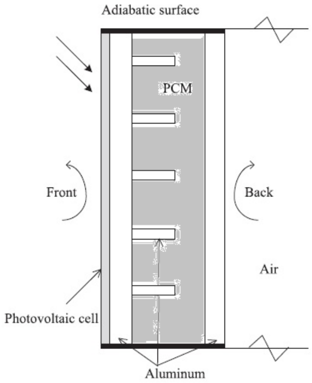

Figure 1 . Schematic of PV-PCM system

An investigation study has been conducted with PV/PCM by Huang. The PV-PCM system is compared numerically and experimentally with conventional air-cooling arrangement. The authors found ‘‘RT27’’ PCM with metal fins is suitable for the temperature rise of the PV panel in a PV-PCM system [8] [9]. The experimental tests by Hasan et al. pointed that the surface temperature of PV panel retained below 40°C for 6 hours when using PCMs [10]. Biwole, showed that the PV/PCM panel can able to maintain PV panel temperature less than 40°C for 80 min under solar radiation of 1000 W/m^2 [11]. Huang et al. conducted research on a PCM with air system have better results in heat transfer [12].

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The numerical simulation using the Commercial CFD code (Fluent 6.3) conducted by Nehariet states that the temperature of the PV panel increases with the increase of inclination, and the small inclinations (lower than 45º) have a better cooling of this panel[13]. In this present experimental study, thermal performance of the PV-PCM based system is demonstrated experimentally using electric heater instead of solar panel of transferring heat to the PCM heat sink. The paraffin wax was used as the PCM in this research work and is targeted for a high temperature PV cooling. The back side of the PCM heat sink was covered by transparent acrylic sheet for melting visualization of PCM.

II. EXPERIMENTS

Experimental setup

A prototype PV-PCM based heat sink system was designed with flat plate heater instead for PV panels for simulating the heat flux. Figure 2 shows the detailed drawing of the heat sink with Paraffin wax PCM. Thermo physical properties of the paraffin wax are indicated in the Table 1.

Table.1. Thermo physical properties of paraffin wax [15]

Property	Value
Melting Point (°C)	51-57
Maximum Operating Temperature(°C)	90
Heat storage capacity (kJ/kg)	170
Specific heat capacity (kJ/kg·K)	2
Density (kg/l) Solid phase Liquid phase	 0.88 0.77
Thermal conductivity(W/m·K)	0.2
Corrosion to metallic container	No

T1 –T3 represent the thermocouple point holes for measuring heat sink surface temperature. T4-T9 represents the fin temperature measurement points and T10-T12 represent the PCM temperature measurement locations inside the heat sink. The experimental arrangement as shown in Figure.3 consists a flat plate heater, Paraffin wax based PCM heat sink with Aluminum fins, Autotransformer, Ammeter, Voltmeter, Data logger and a computer. Heat is supplied by the flat plate heater to the heat sink which simulate the effect of heating of PV panel. Power to the heater is supplied by the autotransformer where the current and voltage and current were measured by an ammeter and voltmeter connected in series and parallel in the circuit. The transient temperature from T1-T12 is monitored and recorded using a data logger (Keysight 34972A) and a computer. The different orientations of heat sink with PCM are shown in Figure 4, which includes horizontal, vertical and inclined orientations.

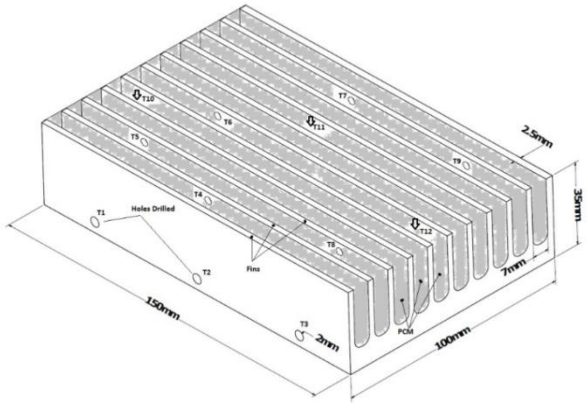

Figure 2: Heat Sink with PCM

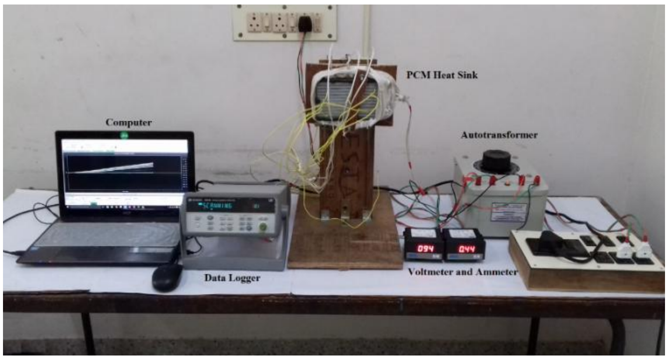

Figure3: Experimental facility photograph

Experimental procedure

The experimental procedure includes supplying the fixed power to plate heater using the autotransformer and hence observing the transient temperature of the heat sink. The heat loss from the plate heater is reduced using a silica aerogel insulation and glass wool tape wrapped around it. The experiments are conducted with two wattages of 30W and 45W.

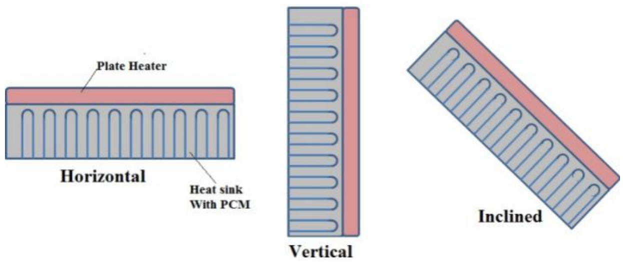

Figure4: Different positions of heat sink with PCM and plate heater assembly

III. RESULTS AND DISCUSSIONS

The PCM material used in this experiment is the paraffin wax, having a congealing point of 58-60°C. Figure 5 indicate the PV panel temperature distribution throughout a sunny day [14]. The temperature has reached up to 60-70°C during noon time. It is essential to cool the panel to reduce this high operating temperature. The paraffin PCM is a better option for high temperature PV cooling in the range of 55-65°C, since the congealing temperature of paraffin falls in the range of 58-60°C.

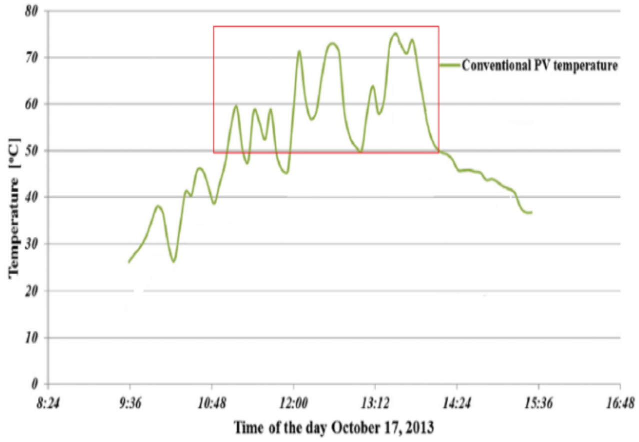

Figure 5.PV panel temperature in a sunny day [14]

The Figure 6 shows the heat flow variation with temperature of the paraffin sample tested. The onset observed at 52.4°C and peak at 65.2°C. The onset represents the starting of melting and peak represents the complete melting of the sample. The transient temperature distribution of the surface temperatures of heat sink (T1-T3), fin temperature (T4-T9) and PCM temperature (T10-T12) at heat inputs of 30W and 45W are shown in Figure 7 and Figure 8. For both different heat input cases, the temperature of PCM and heat sink observed to have a shift at 50°C. This seems to be the starting point of melting of paraffin. The DSC thermograph shows an onset of melting value of 52°C which is approximately close to the experimental results observed. Between the temperatures of 50 °C to 60°C, the entire melting of PCM happens. After that the temperature curve again attains its straight nature. The visualization of PCM melting observed through the acrylic window provided also confirms the same. The Figure 9 shows the PCM inside heat sink before and after melting during heating. The initial melting of the PCM is done by conduction, and then the PCM is melted due to the natural convection by the liquid. Since the heat sink size is small the effect of density variation and hence the natural convection effects are small.

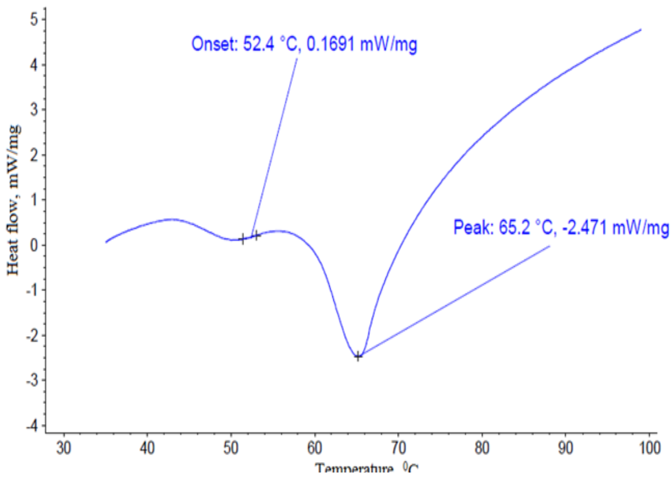

Figure 6: DSC heating thermogram of paraffin

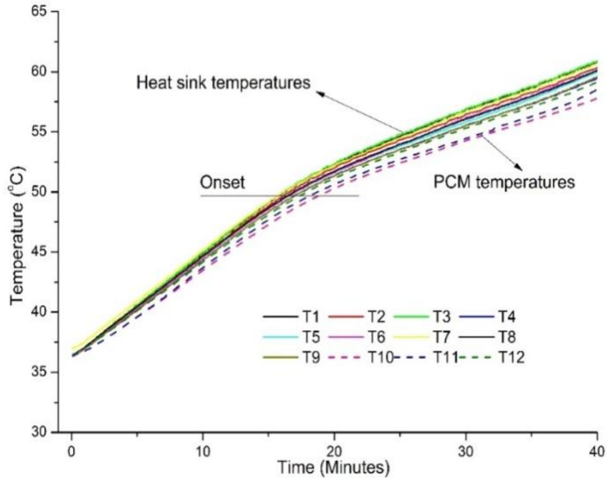

Figure 7: Transient temperature distribution curve for 30W at vertical position

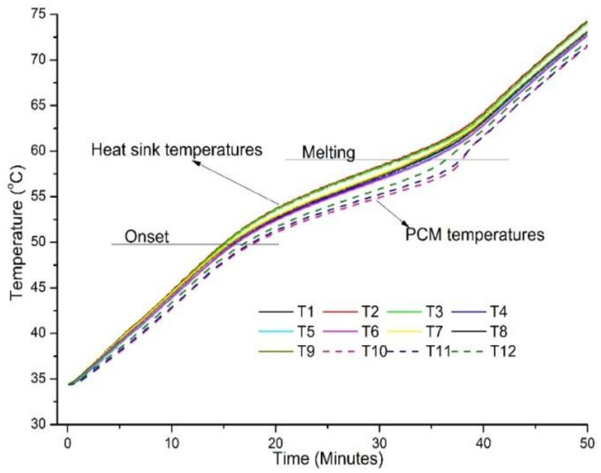

Figure 8: Transient temperature distribution curves for 45W at vertical position

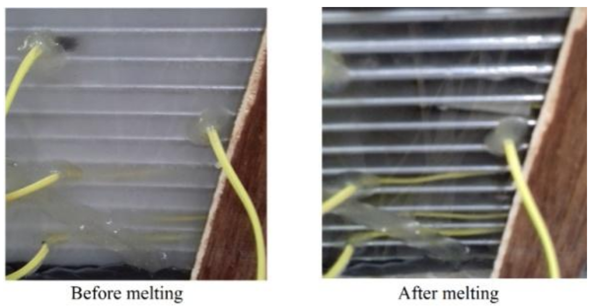

Figure 9: PCM before and after melting during experiment

IV. CONCLUSION

This experiment is conducted using flat plate heater instead of solar PV panel with different wattages. The onset of melting value of 52°C is analysed with DSC. The PCM heat sink is manufactured and experimented with a flat plate heater as a heating source. The transient temperature readings taken during the experiment shows that the paraffin PCM starts melting at a temperature of approximately 50°C and the complete melting happens at a temperature of 60°C.The transient temperature distribution of the heat sink and PCM were compared with 30W and 45W input wattages.

The phase change material based heat sink thermal performance for photovoltaic cooling is successfully demonstrated. From this research work, it is observed that paraffin based PCM is best material for cooling solar PV panels at high temperatures. The future work may be conducted using solar PV panels in outdoor conditions.

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