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https://doi.org/10.5109/7160913

出版情報：Evergreen. 10 (4), pp.2583-2589, 2023-12. 九州大学グリーンテクノロジー研究教育センター
バージョン：

Thermal Regulation and Performance Improvement of Solar PV Panel Using PCM OM29

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(Received March 20, 2023; Revised December 18, 2023; accepted December 18, 2023).

Abstract: This study explores the performance of PV-PCM and PV-PCM-Water systems, which were constructed and subjected to comparative experimental analysis during the month of February. The PV-PCM systems incorporate PCM OM29 positioned behind the PV panel within an aluminum container, storing excess heat as latent heat and transitioning from a solid to a liquid state at a constant temperature. Furthermore, the PV-PCM-W system includes a heat exchanger arrangement within the same container, facilitating the circulation of water to harness the heat stored by the PCM for potential domestic heating applications. With PV-PCM and PV-PCM-W, the temperature of the PV decreased by 11°C at its peak and 6°C on average, and the voltage output was increased by 10 % approximately for both peak and average conditions. The gain in power output was about 10.5% and 8.5% for both conditions. Percentage gain in efficiency was found about 5.5 and 8.5, respectively. Also PV-PCM-Water systems showed around 8 °C increase in temperature for, which would be equivalent to total of 3348.4 kJ or 930 Wh/day. The experimental results obtained shows that a PCM based system is an effective way of regulating PV panel temperature and performance enhancement.

Keywords: Phase Change Material, PV-PCM system, PV/T-PCM system, Thermal Regulation

1. Introduction

India has the world's fastest-growing economy, averaging GDP 5.0%/year from 2015 to 2040[1)], which results in an average of 3.2%/year increase in net electricity generation. Till 2040, solar energy contribution in electricity generation is continuously increases and dominates other renewable energy sources[2)]. India committed at Paris in COP21 for achieving 40% non-fossil fuel based energy by 2030[3-4)]. Utilizing the solar energy for different applications are increasing progressively, i.e. solar air heater[5)], solar water heating system[6)], solar distiller[7)], solar AC system[8)], solar incubator[9)] etc.

Solar cells are made of semiconductors used to convert the solar radiation (or other electromagnetic radiation) emitting on it into electricity[10)]. The efficiency of solar cell is limited due to many losses occurring when energy conversion takes place, in which excess photon energy loss is our prime concern[11)]. It will increase the temperature of solar cell which reduces conversion efficiency due to reverse flow of ions. So cooling of PV panels is the solution for temperature regulation of solar cell. It gives optimum efficiency at standard test conditions (STC).

2. Literature Review

2.1 Effect of surface temperature on performance of PV panel

Many researchers bring into being the adverse effect of surface temperature of PV panel on power output and efficiency during their experimental and simulation work. Agarwal, A. et al. presented the effect of panel temperature on voltage and current output. The simulation results shows that the efficiency of the panel decreases as temperature increases. They suggested the use of PCM as passive cooling for PV[12)], Also Tiwari, G. N. et al. founds similar results[13)]. It is found that the increasing cell temperature of the PV module gives an adverse effect on the performance of that module. So, In the next section, we discuss how the performance was enhanced with the help of modification in PV panels by passive approach via thermal management.

2.2 PV Panel Cooling Techniques

Thermal management or regulation or cooling of PV panels are broadly classified on the basis of external electric power used or not used. There are of mainly two types, i.e. Active cooling and Passive cooling. Active cooling used the external electric power like for forced flow of air or water requires fan and pump respectively.

But passive cooling need not to require any external electric power. Fig. 1.6. shows the different PV panel cooling techniques used[14-16].

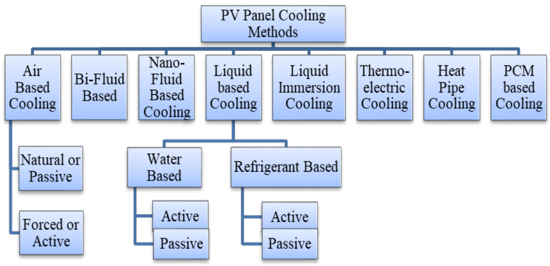

Fig. 1. 6. Different types of PV panel cooling techniques

The experimental and simulation results with pros and cons of different types of thermal management techniques reviewed and suggested that PCM has good potential for cooling purpose but still need to explore on solidification and melting process[17-18].

2.3 PV-PCM System

Many researchers modified the simple PV module by incorporating PCM at back side in a box. They compare operating data for a modified PV-PCM system with Reference PV. Some of these research work is summarize in table1.

Table 1 Comparative Literature Review of PV-PCM systems

Reference	PCM Used with melting temperature (°C)	Results Obtained		Comments/Suggestions/Conclusions
		Thermal regulation	Voltage & Power Output / Efficiency	
19)	Paraffin (42-44), RT22 and Ceresin (61-78)	7 K for 5 hours	NA	2 cm thick Paraffin with water cooling suggested
20)	paraffin wax (46.7), beeswax (51)	maintained temperature below ref. PV panel	Efficiency for without PCM is 6.1- 6.5 % and with PCM is 7.0- 7.8 %	Beeswax has shows better heat absorbing capacity
21)	Inorganic glauber salt (32)	Surface temperature is reduced by 8 °C	Electrical efficiency is increases by 10 %	Suggested east orientation in hot and humid location
22)	RT22 (20-23) and Ceresine(61-78)	temperature of both modules equal to 55 °C	Eff. 10.5/10.8% (M1), 10.15/10.6% (M2)	Due to very thin layer of PCM, desired effect was not achieved
23)	RT42	average drop of 6 °C (April) compared to 2.3 °C (June)	electrical energy capitulate by 5.9% annualy	In peak hot and cold months, PCM provides less cooling
24)	RT35	temperature reduced by 10°C, remains constant for 4–6 hours	conversion efficiency increases	validate results by comparing it with other researchers findings
25)	Coconut Oil, Crude Palm Oil (CPO)	Max. of 9.6°C for 102 mm thickness	% increase in average power and efficiency was 23.8%and 29.3% respectively	80 mm thick CPO has suggested
26)	RT42	Avg. red. PCM is 9.6 °C (13.8%) & with n-PCM is 11.3 °C (16.2%)	gives 15.15 GW increment in electrical output	n-PCM founds effective
27)	RT27	reduced by 15 °C for12-fin configuration	improved max. electrical conversion efficiency of 5.39%	LHTES approach was used
28)	paraffin wax RT40	reduction of 19 °C	Overall net efficiency increased by 12.97%	Arrangement with 30 mm thick PCM infused was suggested

It is concluded from above table that PCM inclusion behind the PV panel shows positive results for temperature regulation and performance improvement. All researchers suggested the use of PCM via passive cooling technique is better option with compare to active cooling techniques.

2.4 PV/T-PCM System

A comparative literature review, shown in table 2, has been made on the basis of different parameters like PCM used, temperature regulation, voltage & power output, efficiency gained, working fluid and their heat gained.

Table 2 Comparative Literature Review of PV/T-PCM systems

References	PCM melting temperature (°C)	Results Obtained			Comments / Suggestions
		Temperature regulation	Voltage & Power Output / Efficiency	Heat gained / Temperature gain by working fluid	
29)	capric acid (30.1)	maximum backplane temperature difference is 15.8 °C	power output difference is 7.4 W	Avg. water temp. in incorprated tank of PVT and PVT-PCM is 42.4°C and 40.3 °C	PVT-PCM system make significance for performance improvement
30)	RT-30	max. reduction is 47% & 53 % for PVT & PVT-PCM	average increment in Voc is 21.27% & 32.5% for PVT & PVT-CM	NA	average electrical efficiency gain is 230% & 300 % for PVT & PVT-PCM
31)	C-P acid (17-22)	NA	thermal efficiency is 20-25% for PVT-PCM	PV/T-PCM system can transfer heat 28 % longer than that of the PVT	PVT-PCM efficiency increases by 3.9 %
32)	RT42	peak front surface temperature drop is 9°C, while the average drop is 5°C	gain in electrical conversion efficiency by ~1.3%	water temperature increase of 9 °C, circulating water extracted 521 Wh/day thermal energy	PV/T-PCM system gives better performance compare to other systems

All experimental and simulation results proven that modified PV-PCM system is acceptable for better cooling with higher conversion or efficiency. Also PV/T-PCM systems can be used to increase thermal efficiency.

3. Material Selection

3.1 Phase Change Material

Certain substances changes its phase at a particular phase transition temperature and offer significant heat interaction within a narrow temperature range, these are called as PCM. PCM is mainly classified into three types i.e. organic, sugar alcohols, fatty acids, slat hydrates, inorganic and eutectic as shown in Fig.2.

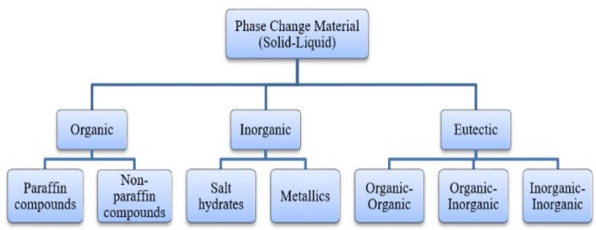

Fig. 2: Classification of PCM

3.2 PCM Selection Criteria

It is difficult to choose a most favorable PCM for a particular application. Each type of PCM having some advantages as well as some disadvantages. With the help of PCM properties and literature review, it is found that organic PCMs are more advantageous than inorganic PCMs. As organic PCM contains high latent heat, chemically stable, negligible sub-cooling, without phase segregation, safe and reliable. A solar PV panel operates under standard test conditions (STC) gives maximum performance. So, the operating temperature of solar cell must be nearest to 25 °C. Also the phase transition temperature of PCM must be tuned with ambient temperature otherwise PCM doesn't perform repetitively charging and discharging process. Also it should be below or near by maximum ambient temperature to avoid melting of PCM by Tamb. alone. So, select the PCM with melt temperature of 29 °C for an ambient temperature range of 22-29 °C.

4. Experimental Setup Design

Fig.3 shows the complete prototype system overview of an experimental setup and fig.4 shows panel modification.

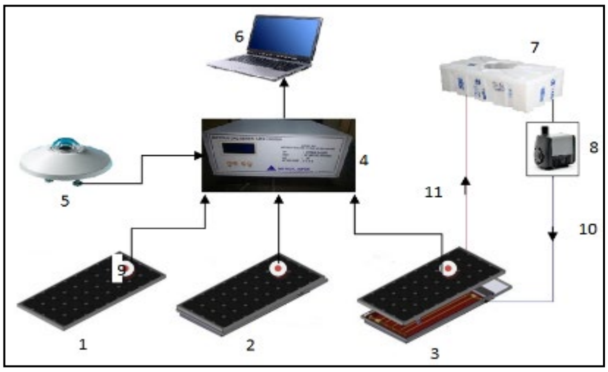

Fig. 3: Experimental setup prototype consists: 1-PV-Reference system, 2-PV-PCM system, 3-PV-PCM-Water system, 4-Data logger, 5-Pyranometer, 6-Host computer, 7-Water tank, 8-Water pump, 9-Thermocouple, 10-Water flow from tank to PV (cold) and 10- Water flow from PV to tank (hot)

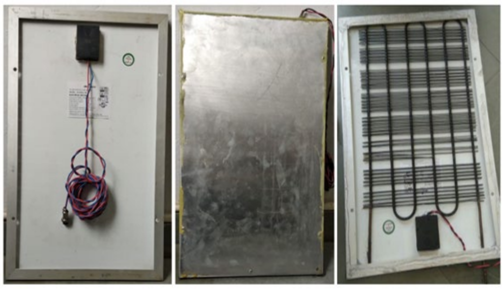

Fig. 4: . ref. PV(Left), PV-PCM (middle) & PV-PCM-W(Right) system

5. Result and Discussion

5.1 Solar Radiation Intensity (G)

During the three days of the experiment, Fig. 5 shows the global solar radiation intensity (G). The average solar radiation intensity for three consecutive days are found to be 441 W/m^2, 451 W/m^2 and 468 W/m^2 respectively.

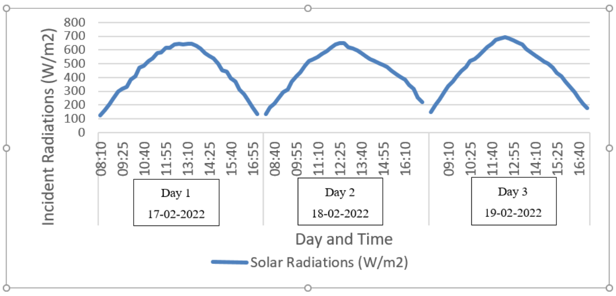

Fig. 5: The measured solar irradiance(G) data for consecutive three days

5.2 Temperature Drop

According to Figure 6, we can observe that at the commencement of the experiment, the ambient temperature stood at 18°C. Over the course of day 1, the temperature consistently rose to a peak of 29°C, maintaining a steady increase until 15:55. An analysis of the data also reveals that throughout this period, the ambient temperature remained lower than the phase change material's melting point of 29°C. This data illustrates that the prevailing ambient conditions alone are insufficient to trigger the melting of the phase change material.

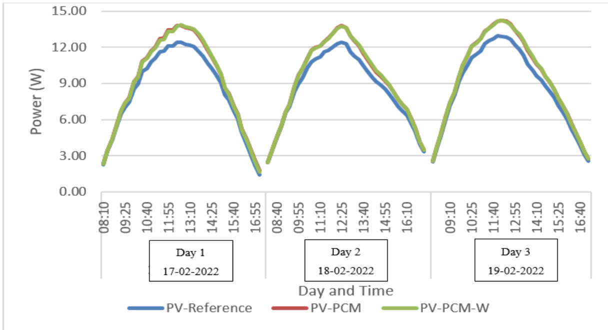

Fig. 6: Recorder temperature during identified days for various arrangements of PV panel

5.3 Variation in PV Output

The temperature decline noted in section 5.2 is seen to benefit the PV voltage, but it adversely affects the current, mainly due to decreased charge mobility. This pattern is elaborated upon in Figure 7, where it becomes clear that both PV-PCM and PV-PCM-W consistently maintained high V_{OC} values with respect to the reference PV.

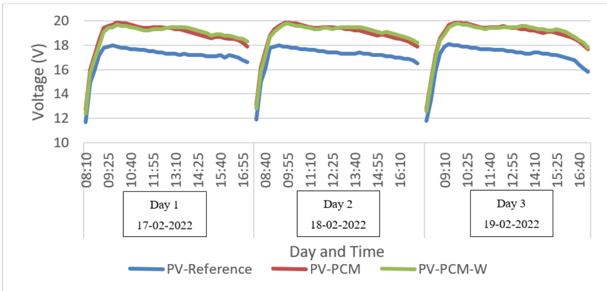

Fig. 7: Open Circuit Voltage (VOC) measurements for ref. PV, PV-PCM & PV-PCM-W

Figure 8 shows I_{SC} values with minimal differences observed among the three systems, except over the peak point. Notably, the ref. PV registered slightly high current with respect to the PV-PCM and PV-PCM-W, attributed to its higher operating temperature.

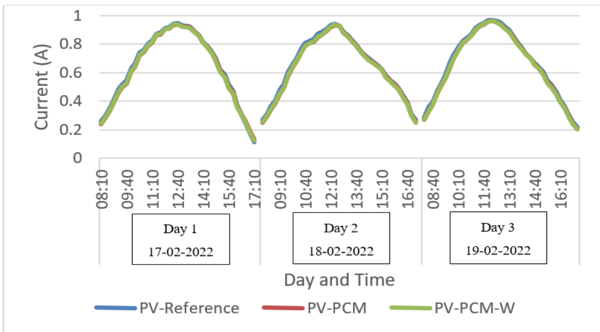

Fig. 8: Short circuit current measurements for identified days

The effect of temperature regulation on power output is plotted in Fig. 9. The PV-PCM and PV-PCM-W systems produces more power than reference PV panel.

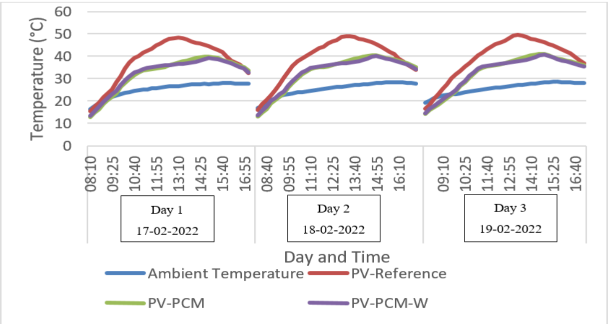

Fig. 9: Power produced by ref. PV, PV-PCM & PV-PCM-W

So inclusion of PCM behind the PV panel produces more power than simple PV panel. In next section, effect of thermal regulation on conversion efficiency can be elaborated with the help of experimental data.

5.4 Improvement in PV Efficiency

The calculated efficiency is plotted which is shown in Fig. 10. The efficiency of PV-PCM & PV-PCM-W always remains over the reference PV panel. The PCM modified panels shown an improvement in efficiency compare to that for PV without PCM.

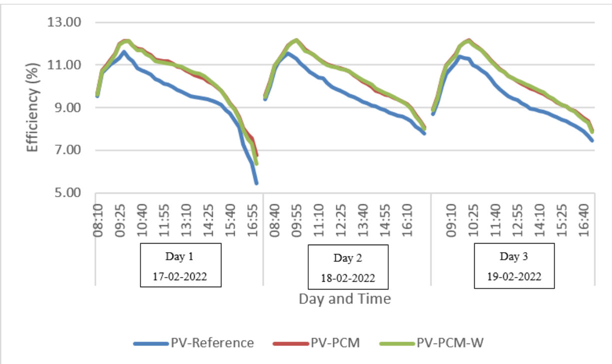

Fig. 10: Efficiency for ref. PV, PV-PCM & PV-PCM-W

5.4 Heat Gain by Water

The heat gain was calculated with following sensible heat gain equation. For this work, ρw is taken as 1000 kg/m3, Vw is 100 L, cpw is 4185.5 J/kgK and (Twi - Twf) is 8 K, we get Qw is 3348400 J. The calculation reveals that 930 Wh/day of thermal energy was stored in the water.

6. Conclusion

It is found that the PV-PCM & PV-PCM-W systems maintain the surface temperature below reference PV panels temperature for whole day. The temperature drop was found to be approximately 11°C at its peak and 6°C on average. The decreasing surface temperature has shown a positive effect on VOC and negative effect on ISC. With respect to PV only, the PV-PCM and PV-PCM-W systems maintained a high VOC.. There is an about 10 % yielding in voltage gain were reported for both at peak and an average data. The ISC shown negligible difference among the three systems other than at peak values where the reference PV panel has slightly higher values compare with other arrangements.

The increase in power output has been reported for both the modified panels as compared to the simple PV panel. The peak and average percentage gain in power output is founds to be about 10.5% and 8.5% respectively. The promising results for improvement in efficiency were found. The efficiency of PV-PCM & PV-PCM-W system is seen higher with respect to the ref PV panel. The peak and average percentage gain in efficiency is found nearly about 5.5% and 8.5% respectively. The PV-PCM-W system is showing an extra advantage over the other two systems. The circulated water extracts the stored thermal energy in the PCM and shows a 8 °C temperature gain. This would be equivalent to total of 3348.4 kJ or 930 Wh/day.

Nomenclature

PV	Photovoltaic
PCM	Phase change material
PV/T	Photovoltaic Thermal

Greek symbols

η	efficiency

Subscripts

Wh	Watt-hour

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