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Comparative study on photovoltaic cells performance using various types of PCMs

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Abstract. : Dependence the photovoltaic panel efficiency on its temperature during operation takes lots of concern for both developers and users. The passive thermal control for photovoltaic cells has been discussed from formal researches. Using phase change materials(PCMs)for thermal energy storage (TES) systems gained attention from engineers. Therefore, the current work experimentally studies the performance of PV cells using various types of PCMs (RT28HC, RT35HC and RT44HC).These PCMs are considered as thermal conductivity enhancer (TCE) for the surface of heated plate made from aluminum to simulate the PV solar cell. The results demonstrate that the highest reduction in the front surface temperature (FST) are 52.3%, 54.2% and 57.7% which occurred with the third configuration, heat flux of 820 W/m^2 and AL_2O_3 nanoparticles concentration of 0.77% for PCMs types RT35HC, RT28HC, and RT44HC, respectively at T_∞=20 ±1°C.

Keywords: PCM; Nanoparticles; Thermal conductivity enhancer; Photovoltaic cells; Heat sink; Heat storage capacity.

Nomenclature		Subscript	
A	area, m^2	E	enclosed
Conf.	configuration	R	root
FST	front surface temperature	PV	photovoltaic
H	fin height, mm	L	longitudinal
N	number of fins	T	transversal
PCM	phase change material		
Q	heat flux, W/m^2		
S	spacing		
T	temperature, ºC		
T	time, min		
TCE	thermal conductivity enhancer	Greek letters	
TES	thermal energy storage	∞	ambient
U	overall heat transfer coefficient, W/m^2.K	$\tau\alpha$	effective transmittance-absorptance of solar cell (optical efficiency)

1. INTRODUCTION

PCM with high heat storage capacity helps photovoltaic module to avoid increasing in temperature especially by fixing copper heat sinks at the rear surface of PV. Enhancement of PV temperature has convenient effect on their performance and duty life. Wei et al. (2017) showed experimentally the dependence of PV efficiency on its temperature during operation.

The measured average irradiance was 705 W/m^2, and the maximum value of irradiance was 1100W/m^2. The solar panel average temperature was 43.6°C with highest and lowest values of 53°C and 35°C, respectively.

Chandel et al.(2018)found that PCM technologies need to beoptimized in terms of its material use, the amount of material and its arrangement for it to be used in PV-panelsin terms of its material use.Hasan et al. (2017)evaluated the performance of energy saving (PV-PCM) system during the year in ahighly hot environment inUAE. A paraffin based PCM with melting range of 38–43 °C was integrated at the back of the PV panel and its cooling effectwas monitored. Their results indicated that the system enhanced the annual electrical energy of PV in a hot climatic condition by 5.9%. Browne et al. (2015) demonstrated that the PCM cost was expected to drop with increased interest in PV-PCM systems thus creating an optimal economic scenario. Idris et al. (2018) investigated experimentally the effect of two different PCM on heat sink and compared it with and without PCM of the heat sink.

Moreover, they studied the variation of PCM thickness and melting temperature for power ratings. Huang et al. (2004, 2006, 2011a, 2011b, 2011) introduced a different experimental and numerical studies on the integration of a suitable PCM with a PV panel to mitigate the panel temperature rise. The studies verified the likelihood and dominance of the PV–PCM system. The results demonstrated that the temperature rising of the system was reduced by about 30 °C when compared with the datum of a single flat aluminum plate.

Tao et al. (2015)presented a detailed review on the use of PCM for PV module thermal regulation and electrical efficiency improvement. Kaviarasu and Prakash(2016)provided a viewpoint of several types of PCM and selections of nanomaterial for incorporated PCMs.They stated that, despite the high latent heat storage advantage of PCMs, their low thermal property calls for the incorporation of nanomaterials.The results disclosed that, the high surface to volume ratio of nanoparticles tuned the properties of thermal base PCM. Sharma et al. (2017) presented a combined cooling solution of a passive type for Building-Integrated Concentrated Photovoltaics (BICPV). Their solution was incorporating micro-fins, (PCM) and Nanomaterial Enhanced PCM (n-PCM). The results displayed that there was a reduction in the average temperature at the center of the system of 10.7 °C when micro-fins with PCM was used and 12.5 °C when micro-fins with n-PCM was used.

Abdelrahman et al.(2019) investigated experimentally the use of PCM to augment the PV performance with fixing hollow copper cylindrical fins at the rear surface of Aluminum plate and submerged this system in tank of RT35HC. The results explored that enhancement in temperature reduction reached to 52.3% by adding the nanoparticles to RT35HC.Accordingly, hollow copper cylindrical fins, PCM and (nano-PCM) can be successfully used as a TCE to control the PV temperature and increase its efficiency.

Therefore, the present work introduces a comparative experimental study for three types of PCMs (RT28HC, RT35HC and RT44HC), which used individually pure to show their effects on FST behavior of PV panels. The effect of the PCM type at various heat flux is studied in the present work.

2. Experimental setup and procedures

The test section presented in Fig. 1 was established and built up by Abdelrahman et al. (2019)as a modeling system for PV panel. The test section is constructed from two aluminum surfaces, heating section, PCM tank and heat sink. The two aluminum surfaces have dimensions 220 *110 *4 mm, those have three grooves to fix the thermocouples to record surfaces temperature. The PCM tank is made from Perspex material and have 10 mm thickness, the depth of tank is 20 mm and its internal dimensions are 220 * 110 mm.Heat sink consists of hollow cylindrical fins made from copper and soldered to a copper sheet which is fixed to the rear aluminum surface. Three types of PCMs“RT28HC, RT35HC and RT44HC” are used in the present study. Table 1 represents the properties of the used PCMs. The applied voltage to the heating section is regulated by a voltage regulator to simulate the different applied heat fluxes of 279, 514 and 820 W/m^{2}in the simulated system.

Fig. 2 show the used heat sink configuration with staggered arrangement of fins at the rear aluminum surface after putting a conductive material to overcome the thermal contact resistance. the heat sink is constructed from hollow cylindrical copper fins with 20 mm height, 8 mm inner diameter and 2 mm thickness. These fins are soldered to a thin copper plate of 1 mm thickness. The used heat sink in the current work was the best configuration which recorded the highest reduction in FST among three different configurations as reported by Abdelrahman et al. (2019). There are other parameters are studied; heat fluxes and three types of PCM.

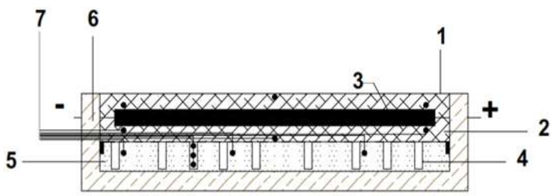
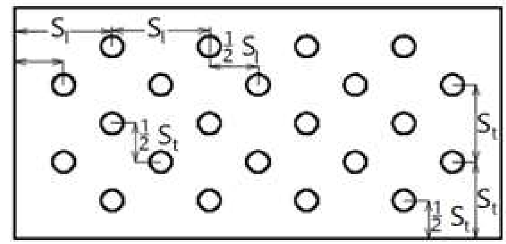


Fig. 1 A schematic drawing for test section(Abdelrahman et al. 2019)

1-Upper Al surface 2-Rear Al surface
3-Heating section 4- Heat sink
5- PCM 6- Tank
7- Thermocouples

Table 1: Thermo physical properties of RT28HC, RT35HC, RT44HC (Anon 2013)

Description	RT28HC	RT35HC	RT44HC
Melting area	27–29°C	34–36°C	41–44°C
Main peak	28°C	35°C	43°C
Congealing area	29–27°C	36–34°C	44–40°C
Main peak	27°C	35°C	43°C
Heat storage capacity ± 7.5% Combination of latent and sensible heat in a range of 21°C to 36°C	245 kJ/kg 67 Wh/kg	240 kJ/kg 67 Wh/kg	255 kJ/kg 71 Wh/kg
Specific heat capacity	2 kJ/kg K	2 kJ/kg K	2 kJ/kg K
Density solid at 15°C	0.88 kg/l	0.77 kg/l	0.78 kg/l
Density liquid at 40°C	0.77 kg/l	0.67 kg/l	0.76 kg/l
Heat conductivity (both phases)	0.2 W/m K	0.2 W/m K	0.2 W/m K
Volume expansion	12.5 %	12 %	12.5 %
Flash point (PCM)	165 °C	177 °C	186 °C
Max. operation temperature	50 °C	70 °C	70 °C



S_l, mm	S_t, mm	N	h, mm	A_R, %	A_e, %
44	36.7	22	20	2.57	7.14

Fig. 2 Fins heat sink configurations (Configuration no. 3: 22 fins).

As introduced before by Abdelrahman et al. (2019), six thermcouples of k-type are distributed on both upper and lower aluminum plates, three on each side, to measure the front and rear surface temperatures. Also, as presented in Fig. 3, three thermocouples are locatedinside the PCM container with heat sink which repeated vertically in three levels.

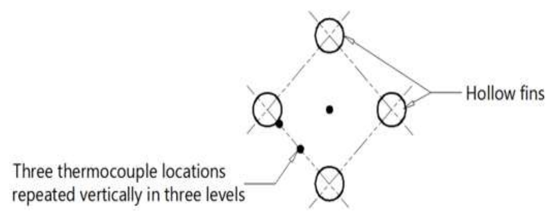


Fig. 3 Thermocouples positions inside PCM tank with heat sink fins

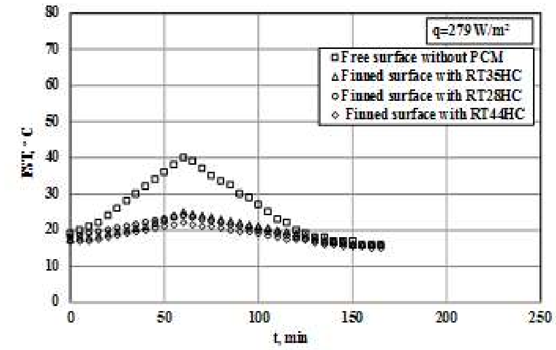
3. Results and discussion

The experimental setup has been validated with Huang et al. (2006) as introduced before by Abdelrahman et al. (2019) and a worthy agreement with the former study shows the assurance in the experimental test rig and the measuring techniques. Furthermore, Abdelrahman et al. (2019) results revealed that, the FST increases as the heat flux increases and ahighertemperatureof74.5°C was obtained at the highestheatfluxof820W/m^{2}after75min.

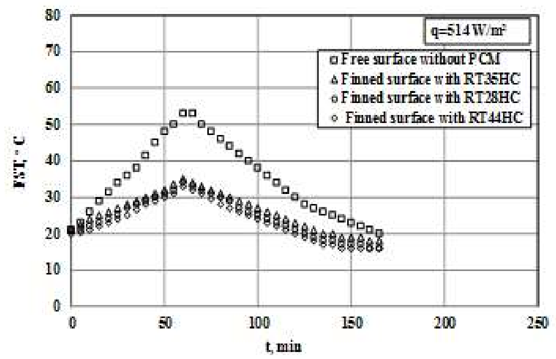
In the current study ;PCM type and heat flux are experimentally investigated, and the results are presented below to show their effect on the FST.

The used heat sink, finned surface, in the current work was the best configuration which recorded the highest reduction in FST among three different configurations as reported by Abdelrahman et al. (2019). Fig. 5 reveals that for a fixed heat flux, the PCM type influences the FST.

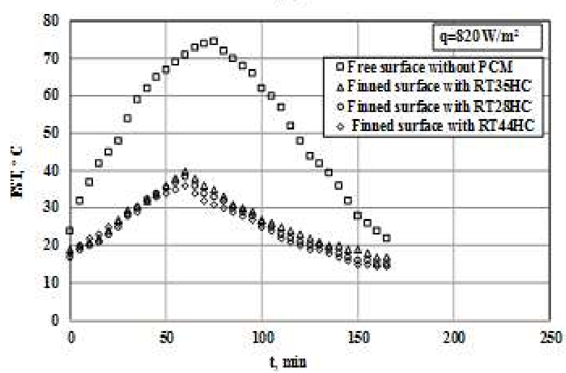
Fig.4 represents the effect of PCM type on FST at T_∞=21°C at three heat fluxes of 279, 514 and 820 W/m^2.



(a)



(b)



(c)

Fig. 4Effect of used PCMs on FST at T_∞=21°C

(a) q=279 W/m^2, (b) q=514 W/m^2

and (c) q=820 W/m^2.

Fig.5shows the consequence of three used types of PCMs on the peak FST, at the end of charging mode. The figure represents the collective effect of the PCM type with finned surface at three heat fluxes of 279, 514 and 820 W/m^2. The figure shows that finned surface with RT44HC has the lowest values of FST when compared with free surface without PCM and finned surface with the other two PCMs at all tested heat fluxes. Moreover, the finned surface with RT35HCrecords higher values of FST when compared the other two PCMs at all tested heat fluxes.

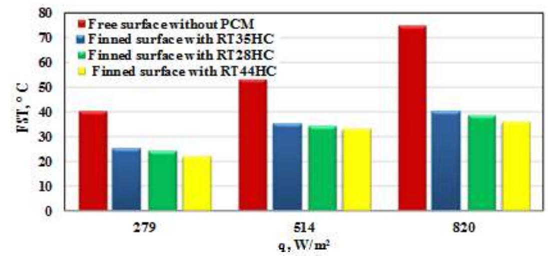


Fig. 5Effect of PCM type on the peak FST at different heat fluxes.

Fig. 6 represents the whole enhancements of finned surface with the three types of PCMs compared to the free surface without PCM. The results show that RT44HC has the highest enhancement compared to the other two PCMs at all heat fluxes. Generally, the achieved enhancement is due to the combined effect of finned surface configuration and PCM. Also, the high heat storage capacity and latent and sensible heat combination of RT44HC lead it to have the best performance compared to the other two PCMs.

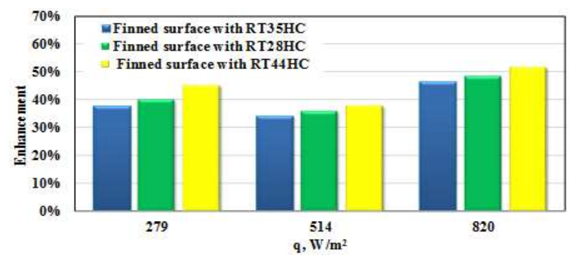


Fig. 6Enhancement percentages of FST compared to the free surface without PCM at different PCM types and heat fluxes.

4. Conclusions

The present work introduces a study on passive thermal control of photovoltaic cells and comparing different types of PCMs (RT35HC, RT28HC and RT44HC) at different heat fluxes around the year of 820, 514 and 279 W/m^2 to predict and compare the thermal performance of aluminum heated plate simulating PV solar cell. Experiments are conducted, and the results are obtained to reach to steady state. The foremost conclusions of the present experimental work are:

- Using PCM reduces the surface temperature of the PV system, and consequently leads to enhancing its performance.
- The highest reductions in the FST are 46.3%, 48.3% and 51.7% which occurred at heat flux of 820 W/m^{2}for finned surface with PCMs typesRT35HC, RT28HC, and RT44HC, respectively.
- Using PCM reduce the FST of the simulated PV cells which means that during life time of photovoltaic cell will be increased.

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