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Cooling enhancement of photovoltaic cell via the use of phase change materials in a different designed container shape

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Abstract. During the electricity generation of photovoltaic (PV) cells, large fraction of solar radiation gets converted into heat which raises the temperature and decreases the electrical efficiency. In order to reduce the heat accumulation, there are several methods that can be applied to cooling the solar panel. One of the simple and efficient approaches is to use the phase change materials (PCM) as a heat absorber. This research is the designed and constructed a housing container for filling up palm wax that is used as a PCM. The designed PCM containers are groove type, tube type, and fin type. Experiment was to compare the PV cell that installed the designed with PCM (test module) and with non-installed PCM containers (reference module). Exposure time for solar radiation is carried out from 9:00 AM to 5:00 PM at an atmospheric condition in Khon Kaen, Province of Thailand (latitude, 16° 25' 50" N and longitude, 102° 37' 0" E). Results showed that when the time is at 11:00 AM to 1:00 PM, solar radiation yield the most constant value. It was found that the designed fin type achieved the most outstanding heat reduction when compare with other designed prototype. The designed fin type has also reduced an average temperature by 6.167 ℃ and the average electrical efficiency is increased by 4.858 per cent.

1. Introduction

PV cell is one of the economically feasible renewable technologies for electricity generation. Heated PV cell causes drop of electrical voltage and decreases the electrical power at 0.65% per 1 ℃ [1]. It was also reported that, the heat in the PV cell causes the electrical power to decrease by 0.8 % per 1 ℃ [2] [3]. S. Sargunanathan [4] studied about the cooling method. There are 6 cooling methods used, they are Heat Pipe, Passive Cooling, Active Cooling, Liquid Immersion, Bionic and Additional PCM layer. The PCM method is another approach that many researchers have carried out an investigation. Literature review as shown in Table 1.

It can be seen from literatures that using the PCM method can lowered the temperature that accumulated on solar PV. This research is the designed and constructed the PCM container. The designed PCM containers are groove type, tube type, and fin type. The experiment was to compare between PV cell that is installed the PCM (test module) with non-installed PCM containers (reference module) and carried out during 9:00 AM to 5:00 PM at an atmospheric conditions in Khon Kaen Province of Thailand (latitude, 16° 25' 50" N and longitude, 102° 37' 0" E). The temperature measurements are measured at the front surface of the PV panel and electrical parameters as well as solar radiation were recorded every 3 minutes.

Table 1. Literature review.

Authors	Method	Results
A. Sweidan [5]	Water pipe were installed at the backside of solar panel and connects a water pipe to the PCM tank	The electrical power is increased by 4 kW
S. harma [6]	Rubitherm 42 (RT42) was used as a PCM and installed them in a box at the back side of solar panel	The temperature was decreased by 3.8 °C and the electrical efficiency was increased by 7.7 per cent
T. Cui [7]	PCM box and a Fresnel lens for combining the solar light.	The electrical efficiency increases by 12.74 per cent
F. Hachem [8]	They have made the combined PCM container, the combined PCM container attribute to 70 per cent of PCM total mass. The material of container was inserted with copper 20 per cent and graphite 10 per cent of space used	The temperature was found to decrease by 6.3 °C and the electrical power increases by 5.8 per cent.
C. J. Ho [9]	Two layers of PCM with different melting points were employed	The electrical efficiency increases by 2.1 per cent.
R. Stropnik [10]	Rubitherm (RT28) PCM box were installed at the back side	The temperature was decrease by 35.6 °C and the electrical efficiency increases by 7.3 per cent (average of 1 year)
S. Khanna [11]	Simulated the temperature inside of the PCM box by ANSYS Fluent	The temperature is decreased by 6.9 °C and the electrical efficiency increases by 0.9 per cent.
A. Hasan [12]	Installation of the paraffin box at the back side of the solar panel	The electrical power increases up to 5.9 per cent

2. Methodology

2.1. PCM container

The PCM container is designed with the goal of increasing the surface area and to maximize the heat exchange media. The PCM containers were made by stainless steel for filling up the PCM (palm wax) of 3 kilograms. The surface areas of container are, groove type (4,158.8 cm^2), tube type (4,346.8 cm^2) and fin type (5,402 cm^2). The groove type dimension is 370 x 310 x 42 mm. The width of the fin is at 30 mm with 8 containers in rows as shown in Figure 1. The tube type dimension is 370 x 310 x 47 mm. It is buried with stainless steel pipes inside the container. The diameter is 20 mm with 12 slots of PCM container as shown in Figure 2. The fin type dimension is 370 x 310 x 47 mm. The width of the fin is 13 mm with 15 slots of PCM container as shown in Figure 3.

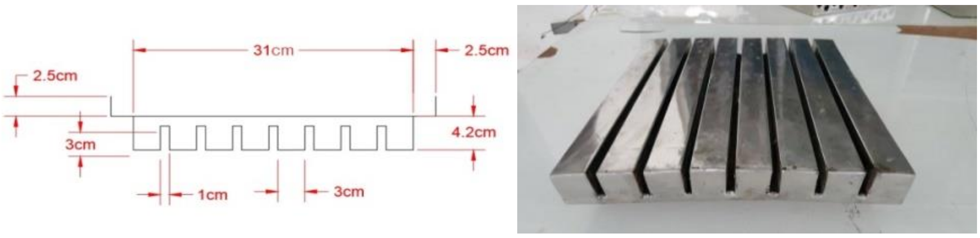

Figure 1. The groove type PCM container.

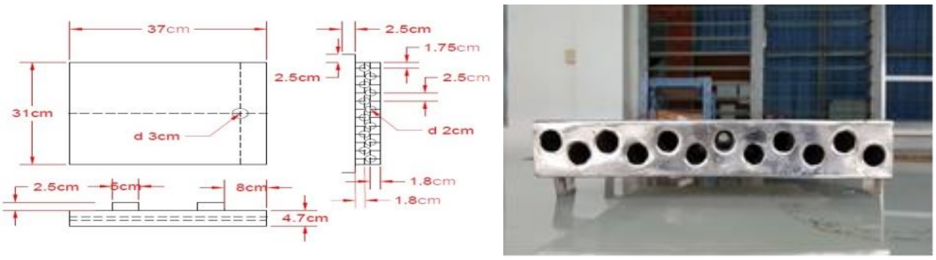

Figure 2. The tube type PCM container.

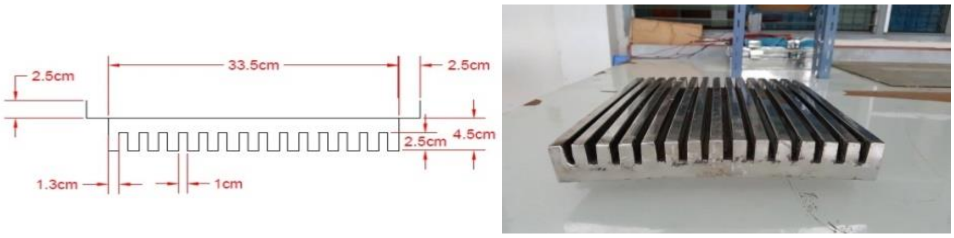

Figure 3. The fin type PCM container.

2.2. Palm wax as a PCM

Palm wax is a fat obtained from the palm oil production process. Its characteristic is in solid state phase at room temperature with white scaly flakes as shown in Figure 4. When it is heated at high temperature, it changes the phase into liquid state. Table 2 shows the characteristic of typical palm wax.

Table 2. The property of palm wax.

Physical state	Flakes
Melting point [℃]	48 - 59
Density [kg/m3]	850 - 900
Materials to avoid	Acids, Strong oxidizing
Acute toxicity (Oral)	LD50 (rat) : >2000 mg/g

Figure 4. Palm wax (solid state).

2.3. Experimental setup

The photovoltaic cell used in this research is polycrystalline type. Its characteristic is shown in Table 3. The experiment was to compare the test module with the reference module and conducted during 9:00 AM to 5:00 PM at an atmospheric condition. Both of the PV modules were installed facing south with an inclined angle of 15 degrees with respect to horizontal plane. Solar radiation is chosen during 11:00 AM to 1:00 PM due to its stability period as presented in Figure 5. The temperatures were measured at 3 spots on front of the PV surface panel using type K (WR 22) thermocouple. The electrical voltage was measured by a multimeter (UNI-T® ut 106). Solar radiation was measured by a pyranometer (CMP3, KIPP & ZONEN) as shown in Figure 6. All parameters were recorded every 3 minutes. The electrical power and the electrical efficiency are calculated using equations below.

$$P = V^2 / R \qquad (1)$$

$$Eff = P_{out} / P_{in} \qquad (2)$$

Where: P - is Power (Watts), V- is Voltage (Volts), R- is Resistance (ohms), Eff – is efficiency P_{out} - is Output Power (Watts) and P_{in} - is Intput Power (Watts)

Table 3. PV cell polycrystalline type.

Maximum power	20 W
Maximum power voltage	17.6 V
Maximum power current	1.14 A
Open circuit voltage	21.4 V
Short circuit current	1.57 A
Dimension (L x W x D)	485 x 350 x 20 mm
Weight	2.0 kg

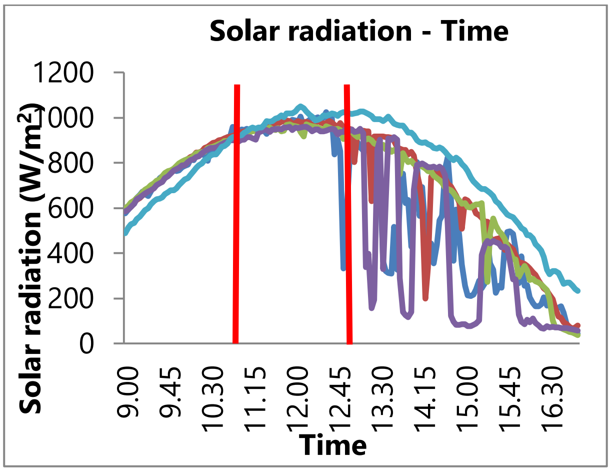

Figure 5. Solar radiation.

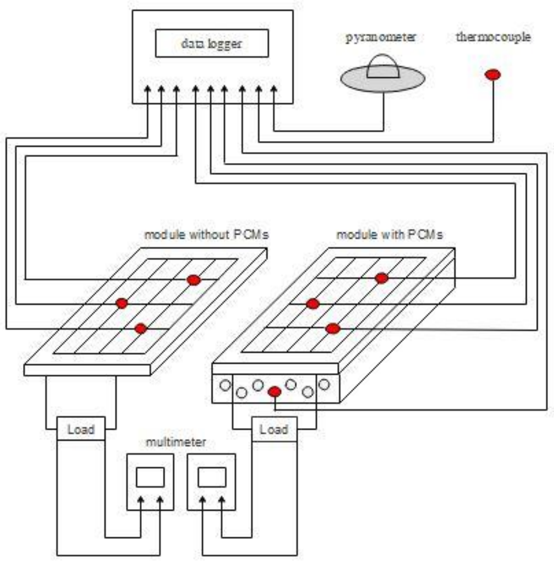

Figure 6. Experimental setup.

3. Results and Discussions

3.1. Groove type

Figure 7 shows the temperature profile of the groove type test module (blue line). It is found that the tested module has lowered the temperature than the reference module (yellow line). Also, Figure 8 shows the electrical power of the tested module (red line) and the reference module (blue line). It can be seen that there are slightly improvement on power that can be obtained. Table 4 revealed the temperature that is decreased by 4.764 ℃ and the electrical power increased by 0.466 Watts, resulting to an increased of electrical efficiency by 4.042 per cent.

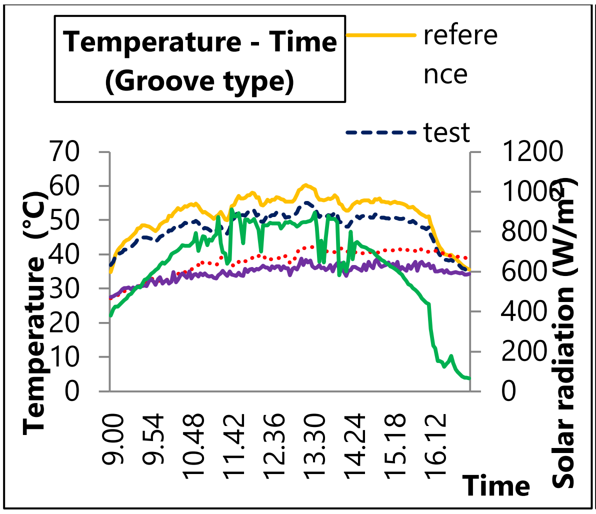

Figure 7. Temperature profile of groove type.

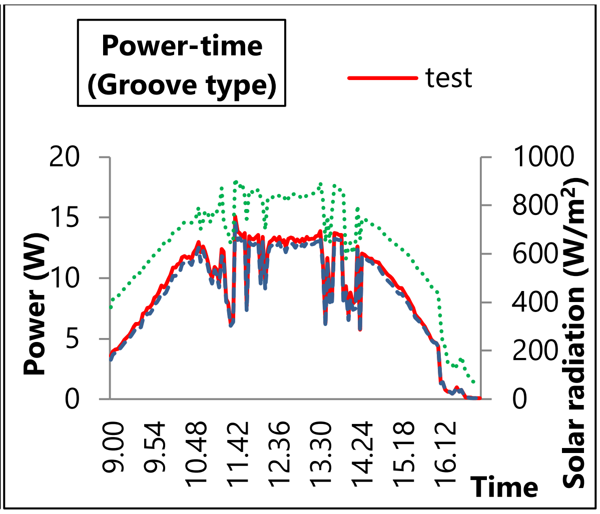

Figure 8. Electrical power output of groove type.

Table 4. Results of a groove type.

No. of test	Temp (ref) ℃	Temp (test) ℃	ΔTemp ℃	Power (test) W	Power (ref) W	ΔPower W	eff (test)	eff (ref)	Δeff	%Δeff
1	58.673	53.875	4.798	10.854	10.440	0.415	0.084	0.081	0.003	4.279
2	47.755	43.602	4.154	14.417	13.892	0.525	0.114	0.110	0.004	3.803
3	57.221	51.982	5.239	11.739	11.277	0.462	0.093	0.089	0.004	4.311
4	54.263	49.225	5.038	12.554	12.084	0.470	0.104	0.100	0.004	3.854
5	54.507	49.998	4.508	11.918	11.485	0.434	0.109	0.105	0.004	3.807
6	56.482	51.628	4.854	12.206	11.7148	0.4914	0.110	0.106	0.004	4.196
	Average		**4.765**			**0.466**				**4.042**

3.2. Tube type

Figure 9 shows the temperature profile of the tube type test module (blue line). It is found that the tested module has lowered the temperature than the reference module (yellow line). Also, Figure 10 shows the electrical power of the tested module (red line) and the reference module (blue line). It can be seen that little amount of power were achieved. Table 5 revealed the temperature that is decreased by 5.265 ℃ and the electrical power increased by 0.505 Watts, resulting to an increase in electrical efficiency by 4.307 per cent.

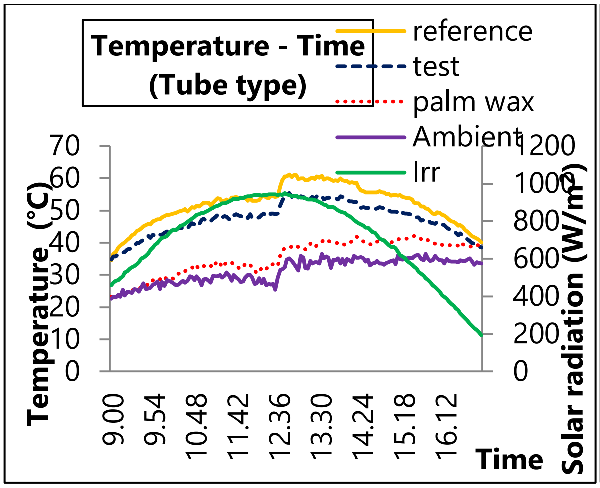

Figure 9. Temperature profile of a tube type.

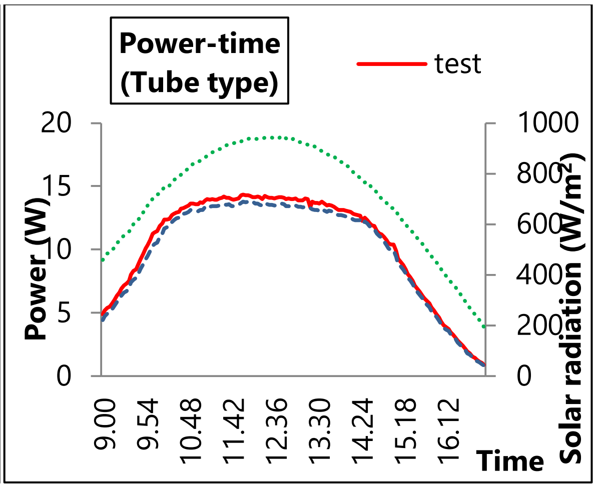

Figure 10. Electrical power output of a tube type.

Table 5. Results of a tube type.

No. of test	Temp (ref)	Temp (test)	ΔTemp	Power (test)	Power (ref)	ΔPower	eff (test)	eff (ref)	Δeff	%Δeff
	℃	℃	℃	W	W	W				
1	52.885	48.301	4.585	10.661	10.232	0.430	0.090	0.086	0.004	4.782
2	57.004	51.536	5.468	11.141	10.776	0.366	0.084	0.081	0.003	4.175
3	50.400	45.038	5.362	13.025	12.475	0.549	0.103	0.099	0.004	4.459
4	53.358	48.646	4.712	14.496	13.931	0.565	0.114	0.109	0.004	4.057
5	54.502	49.399	5.103	13.760	13.199	0.562	0.115	0.111	0.005	4.254
6	54.781	49.327	5.454	14.065	13.509	0.556	0.114	0.109	0.004	4.117
	Average		**5.265**			**0.505**				**4.307**

3.3. Fin type

Figure 11 shows the temperature profile of the fin type test module (blue line). It is found that the tested module has lowered the temperature than the reference module (yellow line). Also, Figure 12 shows the electrical power of the tested module (red line) and the reference module (blue line). As with some earlier cases, it can be seen that output power has improved slightly. Table 6 revealed the temperature that is decreased by 6.167 ℃ and the electrical power increased by 0.596 Watts, resulting to an increase in electrical efficiency by 4.858 per cent.

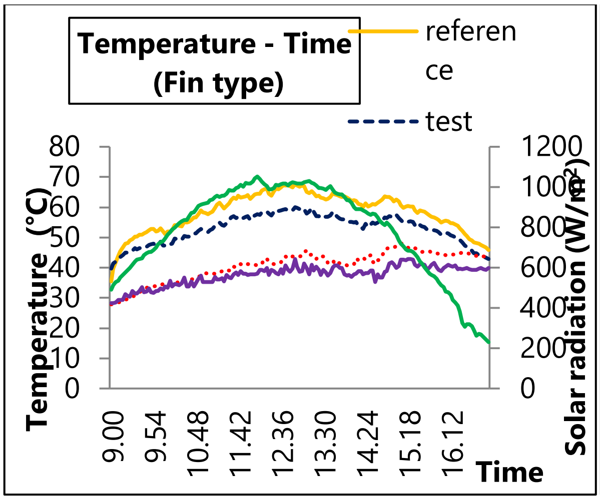

Figure 11. Temperature profile of a fin type.

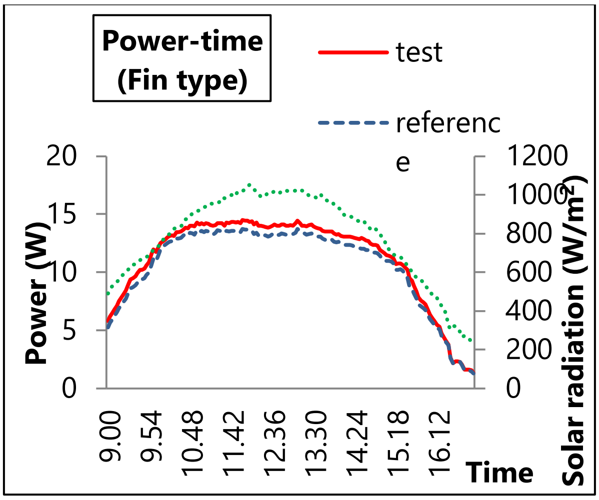

Figure 12. Electrical power output of a fin type.

Table 6. Results of a fin type.

No. of test	Temp (ref) ℃	Temp (test) ℃	ΔTemp ℃	Power (test) W	Power (ref) W	ΔPower W	eff (test)	eff (ref)	Δeff	%Δeff
1	61.062	54.685	6.377	13.208	12.656	0.552	0.102	0.098	0.004	4.423
2	59.108	53.474	5.634	10.676	10.254	0.423	0.083	0.079	0.004	5.194
3	57.265	51.213	6.052	13.608	13.037	0.570	0.104	0.100	0.004	4.375
4	54.682	49.263	6.033	12.775	12.188	0.587	0.107	0.102	0.005	4.942
5	63.638	56.837	6.801	14.144	13.409	0.736	0.105	0.100	0.005	5.491
6	52.221	46.115	6.107	15.780	15.072	0.708	0.139	0.133	0.006	4.723
Average			**6.167**			**0.596**				**4.858**

This research uses palm wax as PCM for heat absorption. The PCM container is designed to increase the heat exchange capability. Utilizing both methods can enhance the heat transfer to the environment. In all cases, the temperature of the test module has been found to be lowered than the reference module. When the temperature of the PV module is lowered, electrical efficiency is increased. The results showed that the designed fin type has achieved the best performance on PCM container. This is because of larger surface area (5,402 cm^2). Currently, Thailand produces electricity from PV cell at 2,651 MW per year. Considering that if this cooling method is applied to it, electrical efficiency can be increased by 4.858 per cent. So that, there will be more electricity production by 128.79 MW per year.

4. Conclusion

The PCM container is designed and constructed to enhance heat exchange capability. When the temperature of a PV cell is lowered, it affects the electrical generating efficiency. The results showed that, during stable solar radiation period, the reference module heats up to a higher temperature than the tested module. The designed fin type has been found to be the best performance on PCM container. It was found that the temperature reduction can be reached by 6.167 ℃ and the electrical efficiency is increased by 4.858 per cent. This is due to the incremental of surface area which is 29.89 per cent more when compare with the groove type. Also, when compared with the tube type, fin type has more surface area than the tube type of 24.28 per cent. Hence, PCM container designed is the key parameter that attributes most on cooling enhancement. The PCM using palm wax has found to achieve the break even because it is inexpensive and can be easily found elsewhere in Thailand.

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