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Experimental analysis on the effect of cooling surface area and flow rate for water cooled photovoltaic module

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Abstract. Application of water spray or water flow on the surface of photovoltaic (PV) modules is one of the techniques used to increase efficiency. Main parameter that affect the performance by this technique is water flow rate and cooling surface are. However, there is less study focus on those parameters. Thus, the objective of this paper is to investigate the effect of water-cooled surface area and water flow rate on the temperature and power output of the PV. Orifices were used to create half-cooled and fully-cooled surface area for water to flow as cooling techniques while the hand valve was used to control the flow rate of water at 120 L/h, 180 L/h and 240 L/h flowing onto the panel. A solar simulator was constructed and used to provide 600 W/m^2, 1,000 W/m^2, and 1,200 W/m^2 irradiance for the panel. The testing methodology consists of three different experiments for each irradiance level. It was found that more cooling surface area covered could significantly reduce temperature in any irradiance level, and fully-cooled module could keep the temperature at below 40 °C eventhough the irradiance was at 1,200 W/m^2. In addition, the optimum flow rate also depends on the cooling surface area. Thus, there is a unique relation between cooling surface area and optimum flow rate. Thus, further investigation is needed on this relation.

1. Introduction

Renewable energy is a source of energy which exists in this world, and solar energy is one of them. In the year 2017 alone, the capacity of electrical energy produced by PV panel is more than any other type of power generating with total of 402GW [1]. However, The PV panel efficiency in converting light into electricity has a decreasing rate from 0.25 % to 0.5 % per Degree Celsius, depending on the material of PV cell used [2]. Many methods were investigated to reduce the temperature of module, and one of it is by using water. It could be by spraying or flowing water on the surface of modules.

As the water covers the surface of the module, the temperature of module reduced the power output increased. However, this effect may depend on the possible heat transfer parameters which are the area of module covered with water or water cooling surface area, and the water flow rate. There are many studies on water cooled by spray method as reported in [3-6], and by water flow method as reported in [7-11]. However, all studies only focus on the possibility of water cooling, but less study in detail on the effect of surface and flow rate. Only studies in [5] and [6] considered flow rate as parameters, but only Basrawi et al. focused on the effect of cooling surface area on the performance of PV module [12], and only one flow rate was considered in the report. Thus, the objective of this study is to investigate the effect of cooling surface area and flow rate for water cooled PV module.

2. Methodology

Figure 1 shows the experimental setup. The setup had a sun simulator using six 150 W halogen lamps. Voltage, current, temperature and flow rate were measured from the experiment. PV module placed for the setup was at 10° inclination angle to help the water used for cooling could easily flowed on the surface of the module. The module used for this experiment is a brand of Venus Solar and table 1 shows the specifications. It has peak power output of 30 W, height of 66 cm and width of 39 cm.

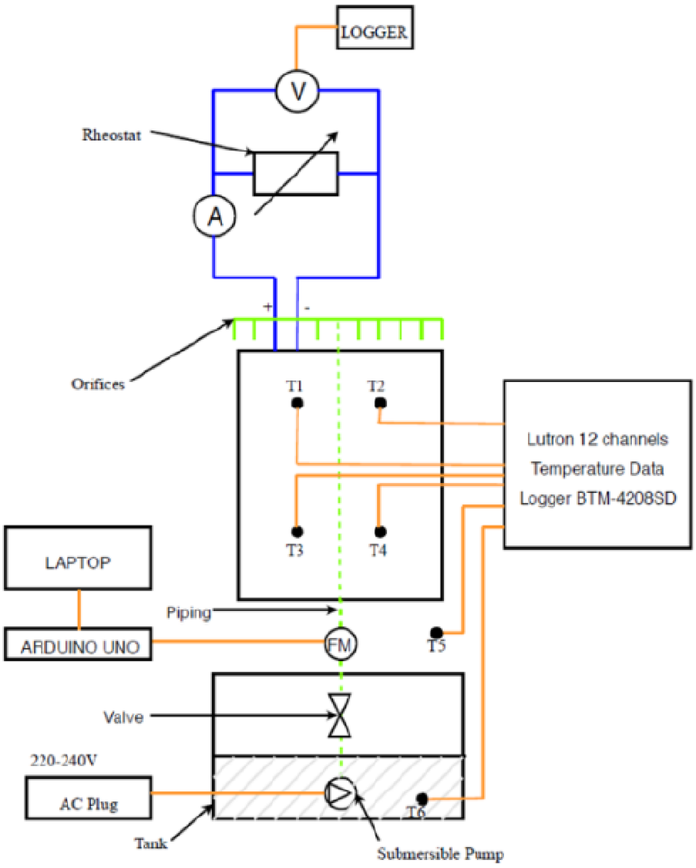

Figure 1. Schematic layout of the experimental setup.

Table 1. Technical specification of the PV panel.

Item	Unit	Value
Model		Venus Solar KL-30W-36P
Pmax	[W]	30
Voc	[V]	21.6
Isc	[A]	1.8
Vmpp	[V]	17.28
Impp	[A]	1.73
No. of cells		36
Effective panel area	[m^2]	0.173

The module was connected to a rheostat 50W 4R7J that have a range of resistance between 1Ω and 1000Ω to act as a load. The voltage and current were measured by using Fluke 317 clamp meter and

Lutron CM-9930 Clamp meter. Lutron CM-9930 clamp meter was connected with Lutron DL-9602SD logger to record the voltage. The temperature was measured by using K-type thermocouples. They were placed at 4 different positions at the back side of the PV panel as shown in the figure 2. A two thermocouples were used to measure the ambient temperature and temperature of water in reservoir. All the thermocouples used in this experiment were connected to Lutron BTM-4208SD 12 channel temperature logger. A 10 W submersible pump was used to pump the water to the top of the PV panel to be run on the surface of PV panel. The pump has a head value of 1.33 m, it is more than enough to provide flow rate of water needed for the experiment. It was connected to a 240V AC power supply. The water flow rate was measured by using a flow meter and a valve was used to control the flow rate that was chosen to be 100 L/h and 250 L/h. These values were selected to be in the range of flow rate that being used by other research based on the literature. The flow rates were chosen also influenced by the ability of the submersible pump used for this experiment set up. The water was pumped from the reservoir to the top of the PV panel and flowed on top of the PV panel. It will recirculate back to the reservoir using the water harvesting pipeline. This was a recycle method of water usage.

The flow rate chosen was 120 L/h, 180L/h and 240 L/h as shown in table 2. The surface of cooling area was either uncooled, half-cooled, fully-cooled, and the condition of that is shown in figure 2 and 3. For each surface area three values of irradiance were investigated as shown in table 2.

Table 2. Parameters for the experiment.

Flow rate (L/h)	Cooling Surface Area	Irradiance (W/m^2)		
120	Half	600	1,000	1,200
	Full	600	1,000	1,200
180	Half	600	1,000	1,200
	Full	600	1,000	1,200
120	Half	600	1,000	1,200
	Full	600	1,000	1,200
Uncooled		600	1,000	1,200

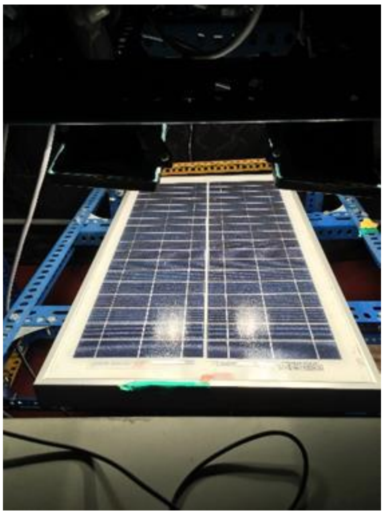

Figure 2. Uncooled PV panel.

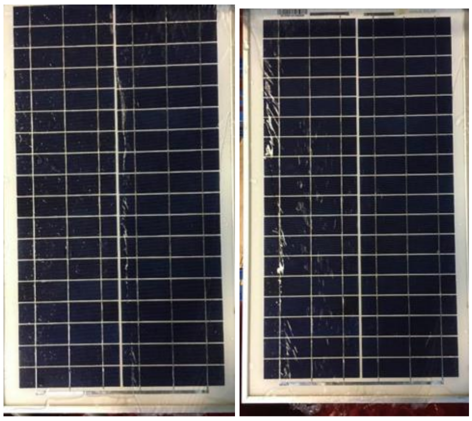

Figure 3. Half-cooled (left) and fully-cooled (right) PV module.

To calculate power output, the following formulas is used.

$$P = V \times I \quad (1)$$

where P is the power output [W], V is the instantaneous voltage [V], and I is the instantaneous current [A].

3. Results and discussion

3.1. Analysis data for the effect of cooling surface area on the efficiency of the PV panel

3.1.1. Temperature (T). Figure 4 shows the result of average temperature of the module throughout the experiment for 30 minutes at 120 L/h. The colours differentiate the amount of irradiance used for different sets of experiments. The dashed lines, dotted lines and normal lines show the temperature of uncooled PV module, half-cooled, and fully-cooled.

It was found that a clear trend in which all uncooled PV module recorded the highest temperature for each irradiance. The highest temperature was at the irradiance of 1,200 W/m² and the lowest was at the irradiance of 600 W/m². Following the uncooled PV panel was all the half-cooled PV module. This set recorded temperature values in between the uncooled and fully-cooled module. The fully-cooled recorded the lowest temperature with all three different irradiance below 40 °C which is very good for the performance of the PV module.

The reason for the uncooled PV panel with irradiance of 1,200 W/m² had the highest temperature value is because it gained the highest amount of irradiance compare with the other two irradiances, 1,000W/m² and 600 W/m². The set for half cooled PV panel recorded a lower temperatures values compare to the set of uncooled PV panel. This is because the presence of the water on the surface of the PV panel that carried away the heat from the PV panel. However, the set of fully cooled PV panel recorded lower temperature values.

It can be concluded that more cooling surface area covered could significantly reduce temperature in any irradiance level. In addition, fully-cooled module could keep the temperature of module at below 40 °C eventhough the irradiance was at 1,200 W/m².

There were two more flow rates that have been experimented which is 180 L/h and 240 L/h. However, both flow rates show the same pattern with the results shown in figure 4. Thus, only the final data at 30 minutes are shown in table 4. Table 4 shows the values of the final temperature for all sets of experiment. There were 3 sets of experiment consist of uncooled, half-cooled and fully-cooled module. Each set have 3 subsets based on irradiance which were 600 W/m², 1,000 W/m² and 1,200 W/m². The water-cooled PV panel with flow rate of 120 L/h has been the bench mark to make comparison for the other two flow rates, 180 L/h and 240 L/h. The percentage of the difference of temperature were also shown.

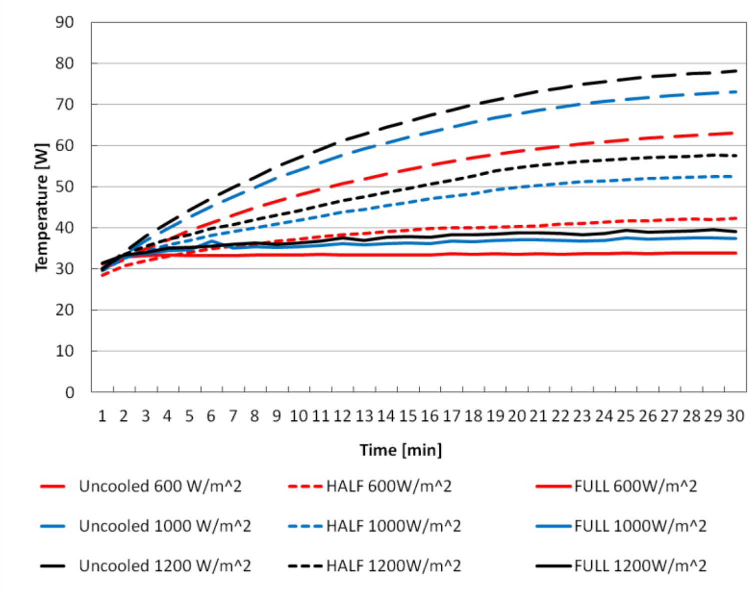

Figure 4. Results of temperature changes.

Table 3. Results of temperature for different flow rate.

Setting Condition		**120 L/h (°C)**	**180 L/h**		**240 L/h**	
			T_3(°C)	**ΔT_3(%)**	**T_4(°C)**	**ΔT_4(%)**
600 W/m^2	Uncooled	63.3	63.3	0	63.3	0
	Half-cooled	42.3	36.2	14.4	36.8	13.1
	Fully-cooled	33.8	33.1	2.1	33.1	2.2
1,000 W/m^2	Uncooled	73.3	73.3	0	73.3	0
	Half-cooled	52.5	40.1	23.4	39.8	24.1
	Fully-cooled	37.4	34.7	7.2	34.1	8.7
1,200 W/m^2	Uncooled	78.3	78.3	0	78.3	0
	Half-cooled	57.5	42.2	26.6	41.3	28.2
	Fully-cooled	39.2	34.1	12.9	34.7	11.4

It was found that for half-cooled module, the difference percentage of ΔT_3 of half-cooled for all the 3 different irradiances have values between 14.41 % and 26.73 %. This shows that the temperature of the module when water flowed onto it at 180 L/h has significant differences compare to the 120 L/h flow rate. However, there are only small temperature differences on the percentage difference between the 180 L/h and 240 L/h flow rate. This shows that the optimum flow rate of water-cooled technique for the module lies in between these flow rates, 180 L/h and 240 L/h. However, for fully-cooled module there is no significant difference between every flow rate, and therefore the optimum flow rate lies at the flow rate less than 120 L/h. Thus, the optimum flow rate depends on the cooling surface area.

3.1.2. Power (*P*). Figure 5 shows the result of power generated by the PV panel throughout the experiment for 30 minutes at 120 L/h. The pattern of power generation for the PV panel is related to the pattern of the temperature shown in figure 4. Since all fully-cooled module could maintain temperature below 40 °C, the power generation of module also was kept at its initial power output. Then, half-cooled module at the middle range of power output, and finally the uncooled module at the lower range of power output.

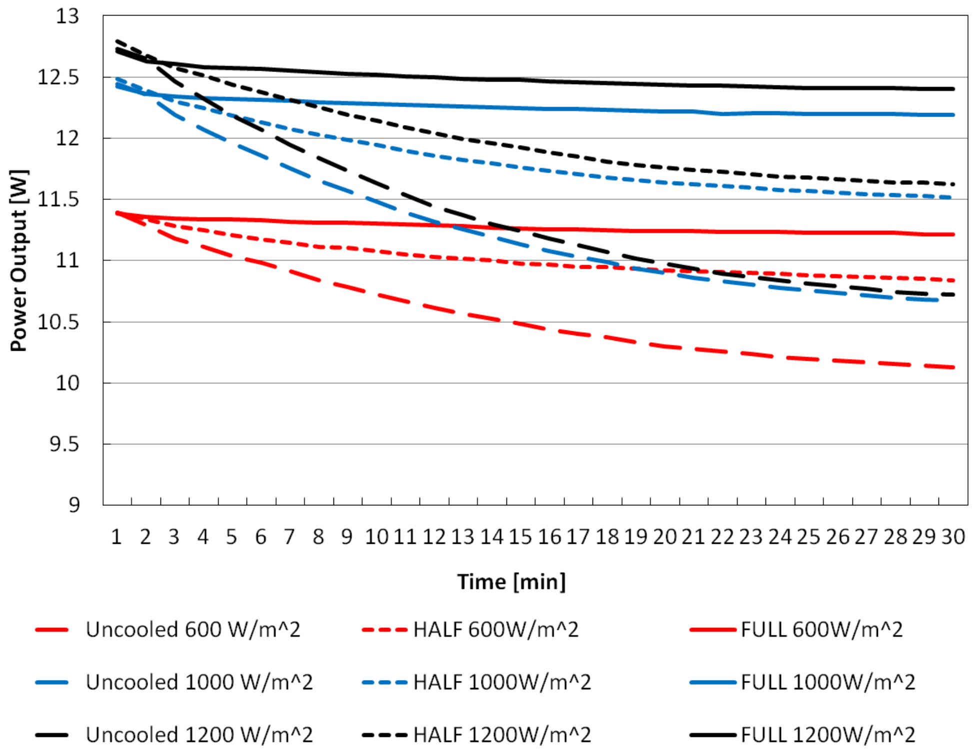

Figure 5. Results of power output changes.

Table 4 shows the values of the final power generated for flow rate at 120 L/h, 180 L/h and 240 L/h. Similar trend was found with table 3 for temperature. However, referring to the set of experiment with 1,000 W/m² irradiance, the percentage of the increment of the power generation for the module did not improve as much as the percentage of the reduced temperature. This was probably due to the power generation for the module did not depends on the temperature of the module only.

Table 4. Results of power output for different flow rate.

Setting Condition		120 L/h (W)	180 L/h T_3(W)	ΔT_3(%)	240 L/h T_4(W)	ΔT_4(%)
600 W/m^2	Uncooled	10.13	10.13	0	10.13	0
	Half-cooled	10.84	10.84	2.95	11.19	3.23
	Fully-cooled	11.21	11.22	0.09	11.29	0.71
1,000 W/m^2	Uncooled	10.67	10.67	0	10.67	0
	Half-cooled	11.51	11.61	0.09	11.64	1.17
	Fully-cooled	12.19	12.20	0.08	12.31	0.98
1,200 W/m^2	Uncooled	10.72	10.72	0	10.72	0
	Half-cooled	11.62	12.12	4.3	12.14	4.48
	Fully-cooled	12.40	12.45	0.04	12.59	1.53

3.2. The effect of water flow rate and cooling surface area on water cooled PV module

Figure 6 shows the relation between cooling surface area and temperature at different flow rates. The colours refer to different irradiance in which red line is for 600 W/m², blue line is for 1,000 W/m², and grey line is for 1,200 W/m². The dotted lines, dashed lines and normal lines show water flow rate 120 L/h, 180 L/h, and 240 L/h.

It was found that when cooling surface area increases from 0% to 100%, temperature of the module decreases in any irradiance, and difference of temperature between different flow rates is insignificant. However, there is a large difference of temperature at 50% of surface area between flow rate of

120 L/h and 180-240 L/h. This suggests that there is a unique relation between cooling surface area and optimum flow rate. Thus, further investigation is needed on this relation.

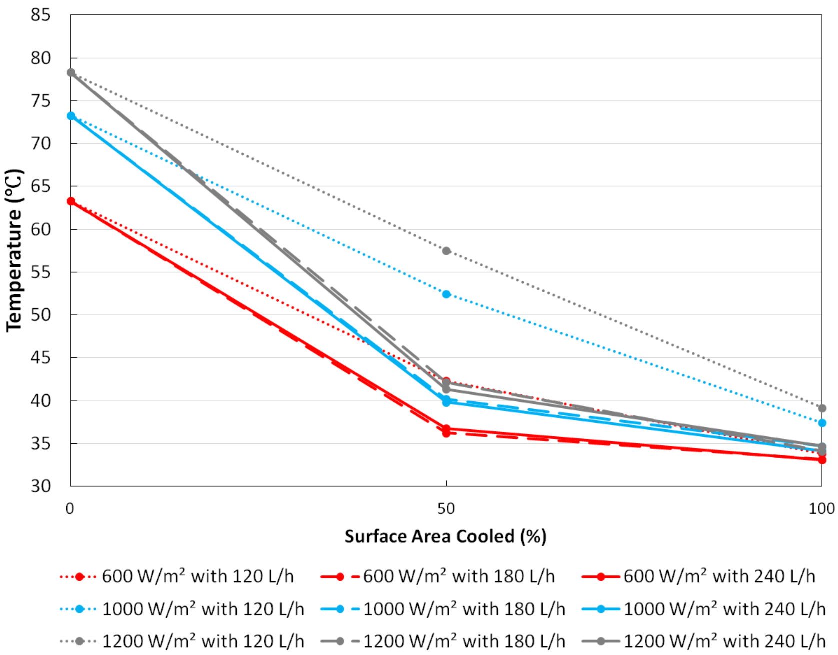

Figure 6. Relation between water-cooled surface area and temperature for different irradiance.

4. Conclusion

Effect of water flow rate and cooling surface area were investigated by a 30 W PV module. It was found that:

i) More cooling surface area covered could significantly reduce temperature in any irradiance level. In addition, fully-cooled module could keep the temperature of module at below 40 °C eventhough the irradiance was at 1,200 W/m^2.
ii) The optimum flow rate of water-cooled technique for the module lies in between 180 L/h and 240 L/h. However, for fully-cooled module there is no significant difference between every flow rate, and therefore the optimum flow rate lies at the flow rate less than 120 L/h. Thus, the optimum flow rate depends on the cooling surface area.
iii) All fully-cooled module could maintain temperature below 40 °C the power generation of module also was kept at its initial power output.
iv) There is a large difference of temperature at 50% of surface area between flow rate of 120 L/h and 180-240 L/h. This suggests that there is a unique relation between cooling surface area and optimum flow rate. Thus, further investigation is needed on this relation.

Acknowledgment

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