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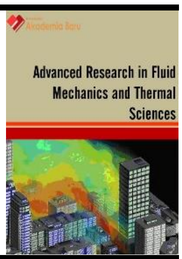

Improvement of Photovoltaic Module Efficiency using Spiral Absorber and Water

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ABSTRACT

This study presents an experimental investigation intended to improve the power output of a photovoltaic (PV) module using a spiral absorber and water as coolants. This cooling system, known as a photovoltaic thermal (PVT) water collector, can generate thermal (hot water) and electrical energy simultaneously. Results show that by adding coolants, the maximum power and open circuit voltages are improved; hence, the output power also increases. In addition, the power generated increases with the addition of solar radiation, and PV module efficiency becomes slightly higher than that of the PV module without cooling. The electrical characteristics of the PV module are represented by plotted current–voltage and power–voltage curves.

1. Introduction

The human population of the planet will only continue to increase. Economic development and the country's rapidly growing energy needs for maintaining human life are increasing sharply. However, the burning of fossil fuels is not the only problem facing humankind. Another serious issue is the lack of sources of fossil fuels, such as petroleum and natural gas. The diminution of fossil fuels is the most important global issue, especially with western countries prioritising the use of energy from fossil fuels. The demand for fossil fuels, especially petroleum, has been increasing worldwide, and the supply of petroleum is believed to have already reached its climax, as evidenced by the increasing price of crude oil. The vast demand for energy will eventually lead to the depletion of fossil fuel supply, and efficient solutions need to be created to deal with this inevitable problem. To handle this serious issue, western countries have been creating substantial progress in the issuance of national development policies to address high energy demand and low fuel source supply. Among the policies implemented, the most promising solution is to search for new energy sources [1–3].

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Thermal and electrical energy can be produced from solar energy. Heat energy can also be divided into two media: water and air. Both absorb heat from thermal energy for use in different fields. In terms of thermal energy, the warm water generated from solar energy can be used in hotels or inns, homes, hospitals and laundries. Hotels and residential houses usually require warm water for bathing and drinking. Hospitals also need an ample amount of hot water for washing medical devices. Solar energy received on the Earth's surface can be divided into two types: photons for generating electricity and thermal energy. Apart from the energy use of petroleum for vehicles, electrical energy is essential in our lives. Nearly all daily human activities require electricity. Heat energy can also be used for air heating during winter, production of hot water for bathing and washing, cooking and drying, among others [4-6].

The latest solar technology integrates solar thermal with photovoltaic (PV) technology and is called thermal photovoltaic technology (PV/T). This technology converts solar energy into thermal energy. Solar energy efficiency through PV/T is considerably higher than that of PV and solar collectors on the same surface area of the collector. PV cell efficiency decreases if the operating temperature of the system is high. Therefore, solar collectors attached to PV cells cool the cells and increase the overall efficiency of the PV/T system. Space-saving PV/T construction is suitable for domestic consumption, and long-term cost savings are the focus of current PV/T research in renewable energy technology. PV/T classification can be divided according to heat transfer medium, fluid flow mode, system installation and configuration. The air-based PV/T system is cheap and easy to develop, but the system has low efficiency when the ambient temperature rises above 20 °C. Therefore, water cooling is suitable for ensuring that the PV/T system works effectively. During its emergence, the PV/T system mostly used air as a coolant because of easy installation and low cost. Since then, various improvements in system design have been proposed to increase the efficiency of heat transfer and absorption of solar radiation of the system. These improvements include additional fins on the fluid route, thermal absorption design and multiple pathways on the coolant [7-16]. Kern and Russell [17] proposed the concept of PVT collectors using water or air as a heat removal fluid. Bahaidarah *et al.,* [18] performed an evaluation of a PV module via back surface water cooling and concluded that PV panel efficiency increased by 9% under water active cooling. Raghuraman [19] introduced several methods for predicting the efficiency achieved by an air and water PV/T collector flat plate. Chow *et al.,* [20] investigated energy and exergy analyses of a PV/T water-based collector system with and without glass cover.

Many experiment studies focused on the size, arrangement and type of fluid used for cooling in PVT collectors. The main objective of the current work is to investigate the efficiency of PV module with and without cooling (spiral absorber and water).

2. Materials and Methods

Experiments were performed in the Solar Lab at Level 3 of the Physics Building, Universiti Kebangsaan Malaysia. The radiation was sourced from a simulation lamp, and the experiment was set up with different radiation intensities (500, 700 and 900 W/m^2). Figure 1 shows the setup of the PV/T collector during an indoor experiment under the solar simulator. In this experiment, a standard PV panel with 80 W rated power was used. The surface area of this PV panel was 1.2 m × 0.5 m, and its width was 0.0045 mm. The ambient temperature and other temperatures (inlet, outlet and PV) were measured using a K-type thermocouple and were obtained from several places around the PV/T water collector. The radiation from the simulation lamp was measured by a pyranometer. Data from the thermocouple and pyranometer were recorded in a computer linked by the data acquisition system ADAM, which was selected for its capability to record data of input voltage, current and temperature simultaneously. The change in temperature during the experiment could be tracked and recorded in a short step time (1 min). The total incident radiation on the system was measured by a pyranometer. A flow meter (1–4 G/M) was mounted at the opening of the fluid inlet to control the mass flow rate.

Spiral collecting spider tanks were selected in this study, according to Ibrahim *et al.,* [21], Aisyah *et al.,* [22] and Fudholi *et al.,* [23]. The improvement of the looser form of this study was in the diameter of the absorber, which was raised to increase the touch surface area between the PV module and the absorber. The material used to build this absorber was a rust-proof patient. The conductivity of the terminus was 16.3–20.0 W/mK. This material was selected because it is cheaper than copper and has high calorific resistance. Figure 2 shows the spiral stainless absorber. The width of the absorber is 1.9 cm × 1.9 cm, and the thickness is 1 mm.

The experiment was conducted in an indoor testing facility using a solar simulator. The simulator consisted of 40 halogen lamps, and the intensity of solar radiation was controlled by a variable voltage controller. The PV/T water collector was exposed to solar radiation of 900 W/m^2 for 40 min before data collection to ensure an equilibrium state of radiation. The change in voltage was recorded using an electric load under different mass flow rates. The mass flow rate of water ranged from 0.01 kg/s to 0.0255 kg/s. The temperature of the system was recorded from the thermocouple stored in ADAM every minute and was subsequently used to calculate the electrical and thermal efficiency of the collector. The water was circulated around the system using a pump and heat exchanger, which are used for cooling fluids in closed-loop systems.

Electrical data collection for current, voltage, short circuit current (I_{sc}) and open circuit voltage (V_{oc}) used the electronic load of an 8500 model from BK Precision. Data obtained were used to plot the I–V curve graph. Maximum power (P_m) can be determined from the graph.

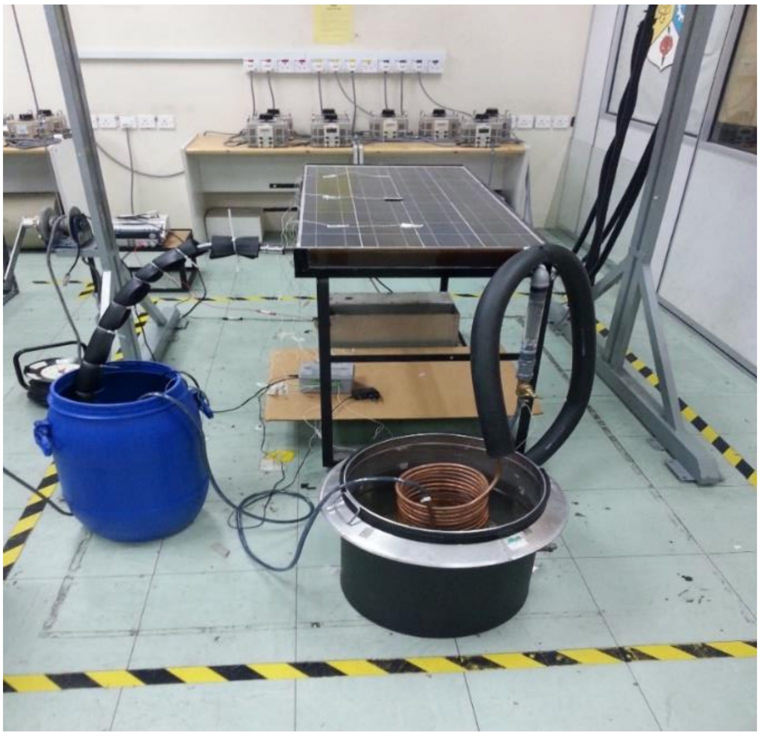

Fig. 1. PV/T water collector under a solar simulator

Fig. 2. Spiral absorber

The electrical efficiency of the PV module was measured by the maximum power ratio (P_m) to the intended radiation.

$$\eta_{pv} = \frac{P_m}{GA_c} \tag{1}$$

where A_c is the surface area of the collector, G is the intensity of radiation, and P_m is derived from the equation.

$$P_m = V_m \times I_m \tag{2}$$

The features of a PV module can be removed from the PV module output, which can be explained by the resulting I–V curve nature. The curve changed as a function of the PV temperature (T_{pv}) and of the radiation intensity (S) received by the module.

The fill factor (FF) of a PV module is a measure of the real I–V characteristic curve. It is defined as the Pm produced by the cell against the open circuit voltage product (V_{oc}) and the closed-circuit current (I_{sc}). FF can be written as

$$FF = \frac{P_m}{V_{oc} \times I_{sc}} \tag{3}$$

3. Results and Discussion

The PV module without a collector needs to be studied first for obtaining reference data for the actual capabilities of the PV module used. The PV module was thus studied for exploring the PV/T water collector. The output power and PV temperature data were recorded to assess the efficiency of the PV module. Figure 3 shows the I–V curve and the power changes generated from the PV module without cooling. Results of these tests are summarized in Table 1. I_{sc} changed from 0.868 A to 2.114 A, and V_{oc} decreased from 16.44 V to 15.66 V when the intensity of radiation changed from

500 W/m^2 to 900 W/m^2 directly. The power increased from 9.562 W to 21.692 W when the intensity changed within the same range. The FF of the PV module ranged from 0.670 to 0.655.

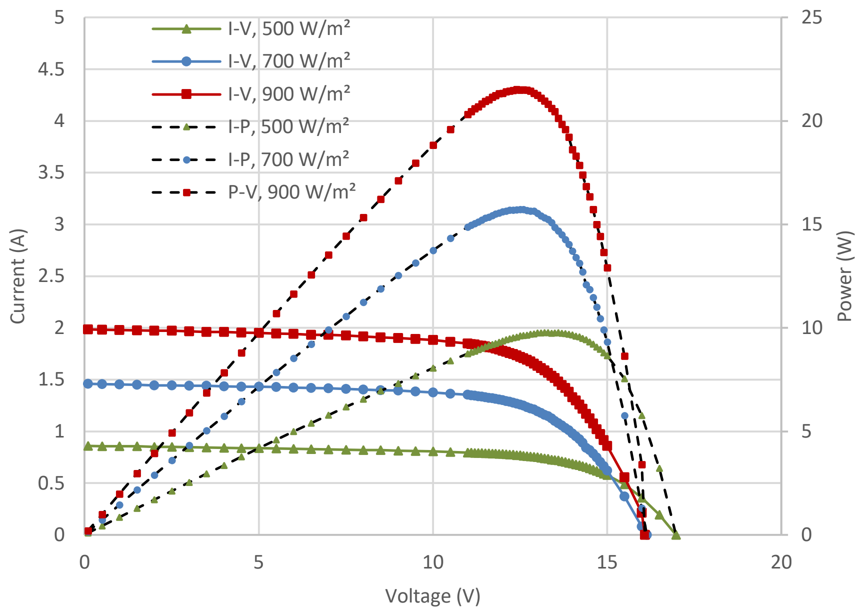

Fig. 3. Current (I) and power (P) over voltage (V) for the PV module without cooling under different radiation intensities

Table 1
Electrical characteristics of the PV module without cooling under the intensity of the simulator radiation

S (W/m^2)	I_{sc} (A)	V_{oc} (V)	P_{maks} (W)	FF	η_{el} (%)
500	0.868	16.44	9.562	0.670	3.08
700	1.472	15.77	15.348	0.661	3.38
900	2.114	15.66	21.692	0.655	3.69

The efficiency obtained from this test was relatively low, ranging from 3.08% to 3.69%. Consequently, the modules used in this PV/T water collector were identified to a have lower electrical performance (12.5%) than the specs obtained from the suppliers. PV module testing under standard conditions of 1000 W/m^2 and 25 °C obtained an I_{sc} of 5.15 A, V_{oc} of 21.6 and η_{pv} of 12.5%. The difference in I_{sc} value was more pronounced than the V_{oc} value compared with the tests conducted due to the long-term PV module quality factor. The performance of the PV module was important for comparison with that of the PV/T water collector. The PV/T collector was operated under the same test conditions to ensure that the electrical capabilities of the PV module were in line with the theory of PV/T water collector construction.

This PV/T water collector was tested in the laboratory at the same temperature and humidity as that of the test of the PV module. The effect of thermal collectors on water on the I_{sc} and V_{oc} of PV modules was studied firstly. The PV/T water collector was placed under the intensity of the simulator radiation at 500, 700 and 900 W/m^2 rays and mass flow rates of 0.012 kg/s to 0.0255 kg/s. The inlet water flow temperature was set at 26 °C by cooling the fluid in the cooling tank before entering the collector. I_{sc} and V_{oc} were recorded for each change in radiation intensity and mass flow rate. All recorded I–V values were then plotted in Figure 4 to 6. Results of the study on intensity and fluid flow rates for the PV/T water collector are summarized in Table 2.

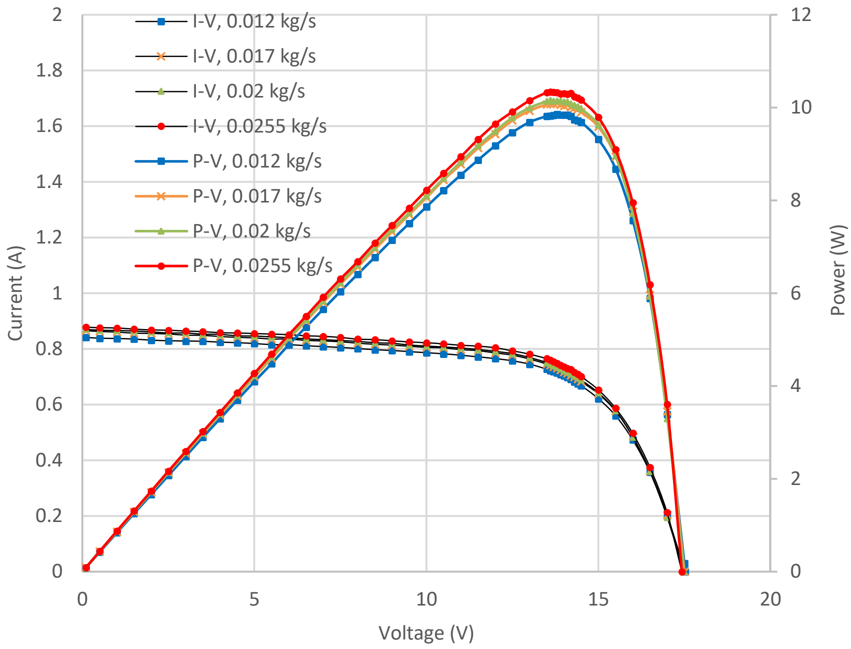

Fig. 4. Current (I) and power (P) over voltage (V) for the PV module with cooling at 500 W/m^2 intensity

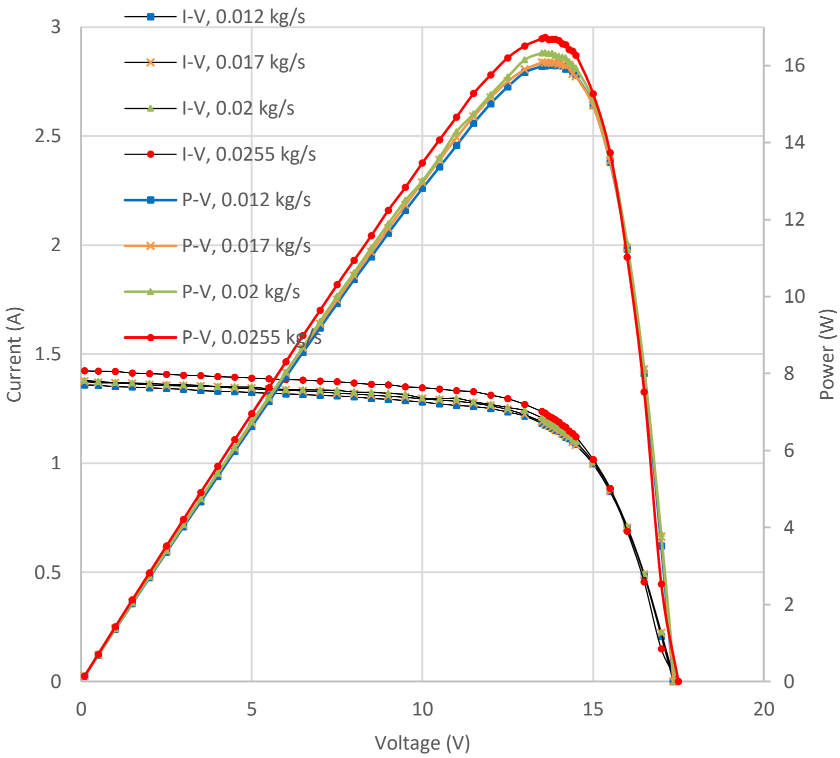

Fig. 5. Current (I) and power (P) over voltage (V) for the PV module with cooling at 700 W/m^2 intensity

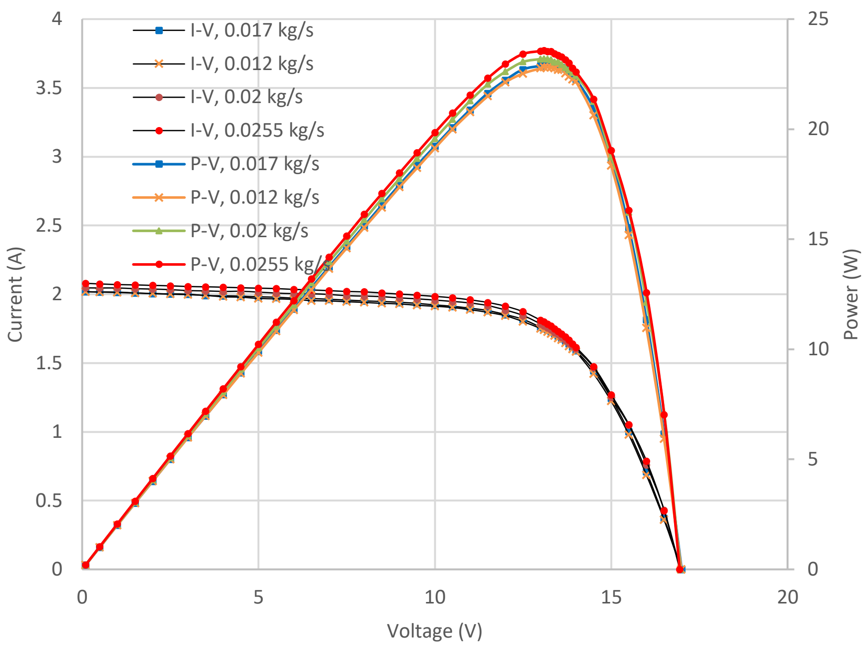

Fig. 6. Current (I) and power (P) over voltage (V) for the PV module with cooling at 900 W/m^2 intensity

Table 2
Effect of radiation intensity and mass flow rate on the V_{oc} and I_{sc} of the PV/T water collector

S (W/m^2)	$\dot{m}$ (kg/s)	I_{sc} (A)	V_{oc} (V)	P_{maks} (W)	FF	η_{el} (%)
	0.012	0.841	17.52	9.853	0.669	3.17
500	0.017	0.866	17.45	10.089	0.668	3.25
	0.02	0.870	17.38	10.159	0.672	3.27
	0.0255	0.878	17.33	10.336	0.679	3.33
	0.012	1.360	17.35	16.029	0.679	3.53
700	0.017	1.376	17.26	16.079	0.677	3.54
	0.02	1.380	17.14	16.333	0.691	3.59
	0.0255	1.424	17.05	16.728	0.689	3.68
	0.012	2.018	17.00	22.823	0.665	3.88
900	0.017	2.020	16.99	22.996	0.670	3.91
	0.02	2.046	16.90	23.200	0.671	3.95
	0.0255	2.080	16.84	23.580	0.673	4.01

The effect of radiation intensity on V_{oc} and I_{sc} can be observed when radiation intensity increased from 500 W/m^2 to 900 W/m^2; I_{sc} increased from 0.878 A to 2.08 A with the mass of water content set at 0.0255 kg/s. V_{oc} decreased with the increase in radiation intensity; at 500 W/m^2 intensity, V_{oc} was 17.33 V, whereas at 900 W/m^2, V_{oc} was 16.84 V. P_m increased with the increase in radiation intensity from 10.34 W to 23.58 W. Electrical efficiency also increased when radiation intensity increased. The PV module efficiency ranged from 3.33% to 4.01%, whereas the efficiency of the PV module without cooling ranged from 3.08% to 3.69%. The FF experienced a slump from 0.679 to 0.673 when radiation intensity increased. Meanwhile, the FF value was reduced due to the increase in series resistance value R_s when radiation intensity increased.

The effect of mass flow rate change on the PV/T water collector is shown in Table 3. At a mass flow rate of 0.012 kg/s, radiation intensity changed from 500 W/m^2 to 900 W/m^2, I_{sc} increased from 0.841 A to 2.018 A and V_{oc} decreased from 17.52 V to 17.00 V. The resulting power also increased from 9.853 W to 22.823 W under the same range of radiation intensity. The increase in I_{sc} and the decrease in V_{oc} were recorded when the mass flow rate was changed to 0.0255 kg/s, whereas the maximum power was recorded at 5.04%, 4.36% and 3.32% at 500, 700 and 900 W/m^2, respectively, under the same mass flow rate ranging from 0.012 kg/s to 0.0255 kg/s.

Table 3
Effect of radiation intensity and mass flow rate on the V_{oc} and I_{sc} of the PV/T water collector

S (W/m^2)	$\dot{m}$ = 0.012 kg/s			$\dot{m}$ = 0.0255 kg/s		
	I_{sc} (A)	V_{oc} (V)	P_m (W)	I_{sc} (A)	V_{oc} (V)	P_m(W)
500	0.841	17.52	9.853	0.878	17.33	10.336
700	1.360	17.35	16.029	1.424	17.05	16.728
900	2.018	17.00	22.823	2.080	16.84	23.580

4. Conclusions

Results lead the following conclusions.

i. The generated power increases with radiation intensity, and PV module efficiency is slightly higher than that of the PV module without the spiral absorber.
ii. The solar radiation and mass flow rate affect open circuit voltage, closed circuit current and maximum power.
iii. The range of electrical efficiency obtained from the PV module without spiral absorber and water is 3.08% - 3.69%. At the intensity of 900 W/m^2 and mass flow rate of 0.0255 kg/s, an increase in electrical efficiency compared to PV module using spiral absorber and water fluid is 8.67%.

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