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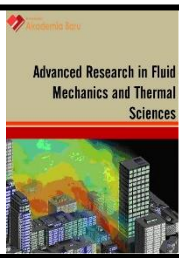

Electrical Characteristics of Photovoltaic Thermal Collector with Water–Titania Nanofluid Flow

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ABSTRACT

Photovoltaic thermal (PVT) studies show promising results from utilising waste heat under PV panels during intense solar radiation. Heat removal is essentially the base of a PVT collector. The heat absorption from the back of the PV panel is used for various purposes. Collected solar energy is mostly converted into heat and needs to be extracted to maintain PV efficiency. The PVT collector works similarly as a flat plate solar collector, except that the short wavelengths are converted into electricity and the remaining wavelengths into useful heat. The heat collected is also at a lower magnitude than those collected by solar thermal collectors. This research presents an experimental investigation that improves the efficiency of a PVT water collector with and without titania (TiO_2) nanofluid using a spiral absorber as a coolant. Results show that the highest maximum power increase is obtained when the 1.0 wt% TiO_2 nanofluid is used as a coolant. In addition, the generated power increases with the addition of solar radiation, and efficiency is slightly higher than that of the PVT water collector without TiO_2. The electrical characteristics of the PVT water collector are represented by plotted current–voltage and power–voltage curves.

1. Introduction

Growth in the field of renewable energy and the increasing energy efficiency have brought global stability. However, considerable carbon footprint is derived from the global use of energy and a decrease in the primary source of fossil fuels. Global awareness on the exploration of renewable energy has signalled that renewable energy would be an option in the future. Renewable energy to adapt to climate, continuous energy supply, new employment opportunities, nature and energy delivery to the interior. In 2013, renewable energy covered 19.1% of the world's total end energy use. Moreover, global renewable power capacity generated from electricity, wind and hydropower in 2014 was higher than in 2013 by 28%, 16% and 3.6%, respectively. The global demand for renewable energy sources is increasing by 1.6% annually, especially for developing countries. The

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government of Malaysia has provided targets for renewable energy of 2080 MW by 2020 and 4000 MW by 2030. At present, advancements in the field of renewable energy influence various fields, such as transport, cooling, heating and power generation in rural areas. However, yearly savings from the use of renewable energy are far from the target rate. This problem may be due to the ongoing fossil fuel subsidies, the low efficiency of renewable energy technologies and the prohibitive costs [1–8].

Solar energy is converted into electric energy using photovoltaic (PV) technology. PV cells are limited in efficiency conversion when the temperature is raised and are responsive only to a portion of the solar spectrum. The solar cell conversion efficiency ranges from 6% to 18%, which is a value measured at the nominal operating temperature, and the rest of solar radiation received are reflected and absorbed as heat energy. The low efficiency and high cost of PV cells brings about the idea of a hybrid PVT. The hybrid PVT is the integration of a solar thermal collector and a PV module. PVT enhances the electrical energy produced, removes waste heat from the PV module and minimises the usable space. Moreover, solar energy is converted into thermal energy as it is stored in air or water. PVT collectors can be classified into three categories: PVT air collectors, water PVT collectors and air/water PVT collectors. A PVT comprises a glass cover, a solar cell, encapsulated materials and a collector attached to the back. In terms of physical structure, the module could be classified as a flat plate of concentrated and building integrated types. The absorber receives the heat and simultaneously cools down the PV module. The collected heat is in the form of water or air. Heat energy can also be used for air heating during winter and production of hot water for bathing, washing, cooking and drying [9–18].

Recently, various studies have been conducted on PVT collectors with water and air as heat carriers. Experimental and theoretical studies on PVT collectors are also available in the literature [19–21]. Most studies have focused on the size, arrangement and type of fluid used for cooling in PVT, whereas studies using nanofluids as coolants are still at an early stage. In heat transfer applications, nanofluid has gained attention as new and efficient heat transfer fluid due to its superior thermophysical properties compared to conventional working fluid such as water, oil and ethylene glycol [22]. The emergence of advanced technology has produced nanoparticles, later dispersed in the fluid called as nanofluid enhanced heat transfer process substantially. The remarkable increase in thermal conductivity even when a low concentration of nanoparticles is added in fluid has been observed by many researchers [23]. One of the solutions is introducing foreign element of higher heat carrier capacity and thermal conductivity, known as nanoparticles which could improve the overall performance of heat transfer fluid [24]. Nanoparticles are materials produced via nanotechnology method. Nanoparticle physical properties, with size of less than 100 nm, include various types of materials with particular substances [25,26]. Xu and Kleinstreuer [27] showed that PV/T using nanofluids is more suitable for silicon solar cells compared with multijunction solar cells, and the overall energy conversion efficiency of the CPV/T system is higher than that of the conventional system. Yousefi *et al.,* [28] investigated the efficiency of a flat plate solar water heater collector by varying the mass flow rate and volume concentration of alumina nanofluid. Results indicated that by increasing the mass flow rate from 1 L/min to 3 L/min, the efficiency of the solar collector increased at a constant volume concentration. Sardarabadi *et al.,* [29] conducted an experiment on the effect of silica/water nanofluid on PV/T and found that the total exergy for 1 wt% and 3 wt% increased by 22.61% and 23.31%, respectively, compared with a PV system with no collector. The main objective of the present study is to investigate the efficiencies of PVT water collectors with and without TiO_2 nanofluid.

2. Materials and Methods

The setup of the PVT system during the indoor experiment under a solar simulator is shown in Figure 1. A standard polycrystalline 80 W photovoltaic module represented as a flat plate unglazed sheet is attached on top. The collector, which consists of a single unilateral channel for fluid flow, is inserted underneath the PV module. The surface of the PV/T collector measures 0.5 m wide and 1.2 m long. A K-type thermocouple is used with a data logger for collecting the inlet and outlet fluid and the PV panel surface temperature. The change in temperature during the experiment can be tracked and recorded in a short step time (1 min). The total incident radiation on the system is measured by a pyranometer. A flow meter (1–4 G/M) is 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.,* [30,31], Fudholi *et al.,* [32] and Aisyah *et al.,* [33]. The improvement of the looser form of this study was in the diameter of the absorber being raised to increase the touch surface area between the PV module and the absorber. The material used to make this absorber was a rust-proof patient. The conductivity of the terminus was 16.3 W/mK to 20.0 W/mK. This material was selected because it is cheaper than copper and has high calorific resistance. Figure 2 shows the stainless spiral absorber. The width of the absorber is 1.9 cm × 1.9 cm with a thickness of 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 PVT system 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 and volume concentrations of nanofluid. The mass flow rate of water was 0.0255 kg/s. The temperature of the system was collected from the thermocouple stored in the data acquisition system ADAM every minute and subsequently used for calculating the electrical and thermal efficiencies of the collector. The water was circulated around the system using a pump and heat exchanger used for cooling the fluid in the closed-loop system. The cooling fluids used in this experiment were water and TiO_2/water with 0.5 wt% and 1.0 wt% concentrations, respectively. Nanofluids were prepared with a sonicator, and a stabilizer was added. The sonication process for dispersing nanoparticles in distilled water lasted approximately 1 h. The zeta potential was used to examine the stability of the prepared nanofluid. The properties of fluid used are stated in Table 1.

Fig. 1. PVT water collector under a solar simulator

Fig. 2. Spiral absorber attached to the back of the PV

Table 1
Fluid properties

Fluid	Particle Size (nm)	Heat Capacity (J/kgK	Density (kg/m3)	Thermal Conductivity (W/mK)
TiO_2/water	25	690	3900	8.9

Electrical data collection for current, voltage, short circuit current (Isc) and open circuit voltage (Voc) used an electronic load of an 8500 model from BK Precision. Data obtained were used to plot the I–V curve graph, from which the maximum power (Pm) can be determined.

The fill factor (FF) of a PVT water collector is a measurement of the real I–V characteristic curve. It is defined as the maximum power ratio (P_m) produced by the cell against the open circuit voltage product (V_{oc}) and the closed circuit current (I_{sc}). The FF can be written as

$$FF = \frac{P_m}{V_{oc} \times I_{sc}} \quad (1)$$

The electrical efficiency of the PVT water collector is measured by the maximum power ratio (P_m) to the intended radiation.

$$\eta_{pv} = \frac{P_m}{SA_c} \quad (2)$$

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

$$P_m = V_m \times I_m \quad (3)$$

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

3. Results and Discussion

PVT water collectors with and without TiO_2 nanofluid were tested in a laboratory. The effect of mass flow rate change on the PVT water collector without TiO_2 nanofluid is shown in Table 2. At a mass flow rate of 0.012 kg/s and with the solar radiation 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 solar radiation. The increase in I_{sc} and the decrease in V_{oc} were recorded when the water 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 2
Effect of radiation intensity and mass flow rate on the V_{oc} and I_{sc} of the PVT water collector

S	ṁ = 0.012 kg/s			ṁ = 0.0255 kg/s		
(W/m^2)	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

After testing the PVT water collector without TiO_2 nanofluid, the optimum fluid flow rate was determined at 0.0255 kg/s. The PVT collector was studied with various TiO_2 nanofluids at different concentrations (0.5 wt% and 1.0 wt%). Figures 3 to 5 show the I–V and P–V curves at the mass flow rate of 0.0255 kg/s and solar radiation of 500 W/m^2 to 900 W/m^2 and are summarized in Table 3. For the PVT water collector without TiO_2 nanofluid, I_{sc} increased from 0.878 A to 2.080 A when the solar radiation changed from 500 W/m^2 to 900 W/m^2, whereas for the PVT water collector with 0.5 wt% and 1.0 wt%, I_{sc} increased from 0.951 A to 2.146 A and 0.967 A to 2.211 A, respectively. Meanwhile, the V_{oc} for the PVT water collector without TiO_2 nanofluid decreased from 17.43 V to 16.84 V, whereas for the PVT water collector with 0.5 wt% TiO_2 nanofluid, V_{oc} decreased from 17.31 V to 16.92 V. V_{oc} for the PVT water collector with 1.0 wt% TiO_2 nanofluid changed from 17.26 V to 16.73 V. Maximum power increase was recorded when solar radiation changed from 500 W/m^2 to 900 W/m^2, as shown in Table 3. The maximum power generated from the PVT water collector without TiO_2 was 10.336 W to 23.58 W, whereas for the PVT water collector with 0.5 wt% and 1.0 wt% TiO_2, the maximum power increase was from 10.894 W to 24.012 W and 11.316 W to 24.453 W, respectively.

Table 3
Effect of radiation intensity on the V_{oc} and I_{sc} of the PVT water collector with and without TiO_2

S (W/m^2)	TiO_2	I_{sc} (A)	V_{oc} (V)	P_m (W)	FF	η_{el} (%)
	Without	0.878	17.43	10.336	0.679	3.32
500	0.5 wt%	0.951	17.31	10.894	0.670	3.50
	1.0 wt%	0.967	17.26	11.316	0.686	3.64
	Without	1.424	17.25	16.728	0.689	3.68
700	0.5 wt%	1.476	17.10	17.200	0.685	3.77
	1.0 wt%	1.516	16.97	18.020	0.705	3.96
	Without	2.080	16.84	23.580	0.673	4.01
900	0.5 wt%	2.146	16.92	24.012	0.673	4.08
	1.0 wt%	2.211	16.73	24.453	0.669	4.16

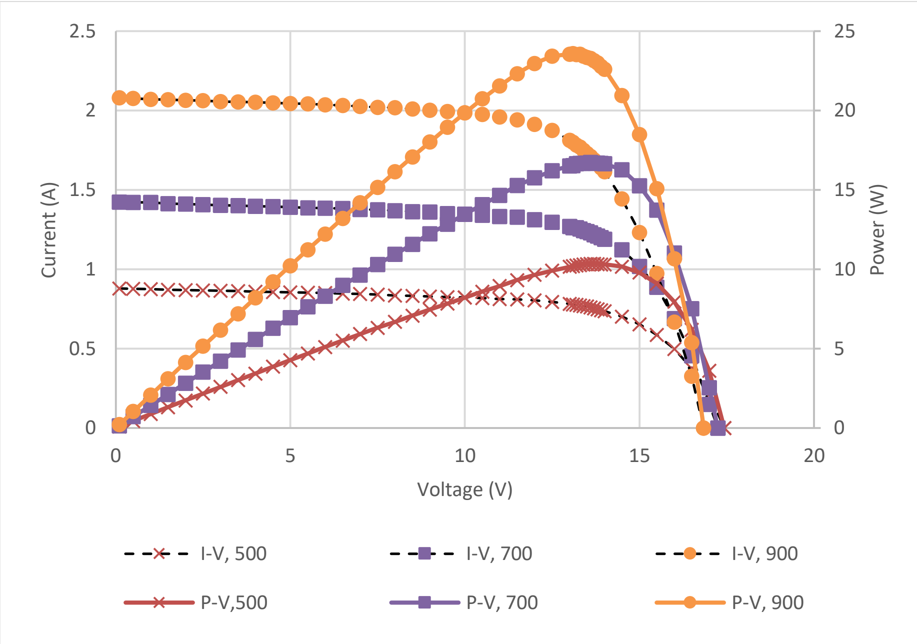

Fig. 3. Current (I) and power (P) over voltage (V) for the PVT water collector without TiO_2 at a solar radiation of 500 W/m^2 to 900 W/m^2

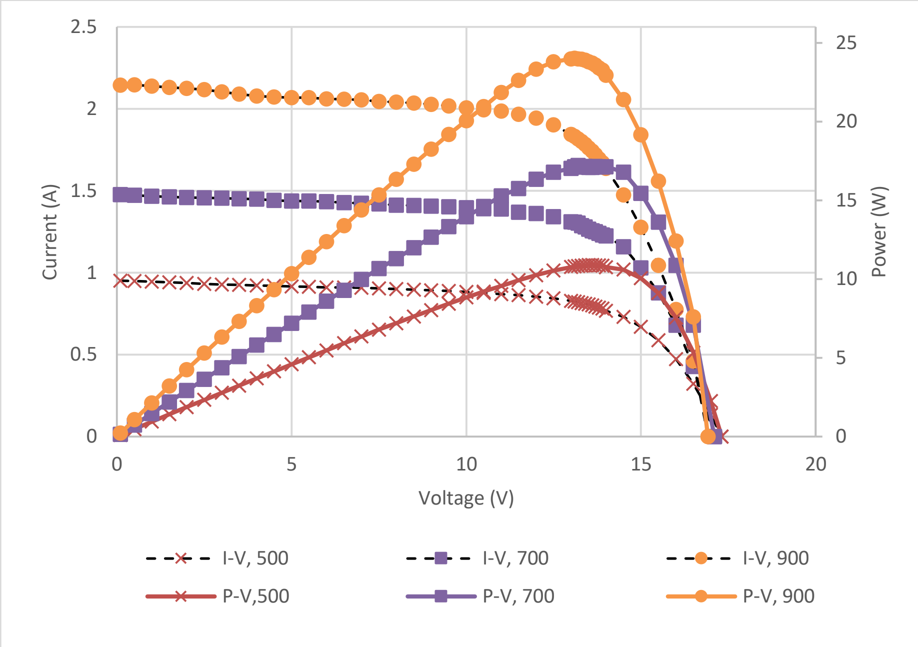

Fig. 4. Current (I) and power (P) over voltage (V) for the PVT water collector with 0.5 wt% TiO_2 at a solar radiation of 500 W/m^2 to 900 W/m^2

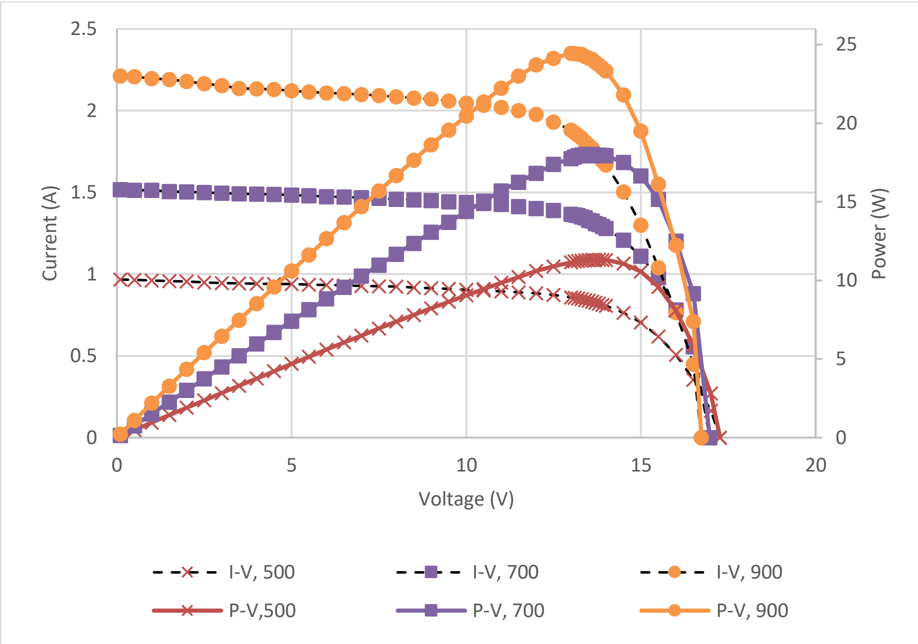

Fig. 5. Current (I) and power (P) over voltage (V) for the PVT water collector with 1.0 wt% TiO_2 at a solar radiation of 500 W/m^2 to 900 W/m^2

4. Conclusions

Results lead to the following conclusions.

i. The generated power increases with the addition of solar radiation, and efficiency is slightly higher than that of the PVT water collector without TiO_2 nanofluid.
ii. The highest maximum power increase is obtained when 1.0 wt% TiO_2 nanofluid is used as a coolant in the PVT collector.

iii. The increase in efficiency of TiO_2 fluid at 0.5% and 1.0% concentrations at the same conditions was recorded at 10.57% and 12.74%.

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