The Water Based Photovoltaic Thermal Fiberglass Collector: An Experimental Investigation

Wan Mustafa*,**, Ahmad Fudholi**,***‡, Kamaruzzaman Sopian**,

Muslizainun Mustapha**, Yoyon Ahmudiarto***

* Water and Energy Department, Malaysia France Institute, Universiti Kuala Lumpur, 43650 Selangor, Malaysia

** Solar Energy Research Institute (SERI), Universiti Kebangsaan Malaysia, 43650 Selangor, Malaysia

*** Research Centre for Electrical Power and Mechatronics, Indonesian Institute of Sciences (LIPI), Bandung, Indonesia

(wanmustafa@unikl.edu.my, a.fudholi@ukm.edu.my, ksopian@ukm.edu.my, muslizainun@gmail.com, yahmudiarto@yahoo.com)

‡ Ahmad Fudholi, Solar Energy Research Institute (SERI), Universiti Kebangsaan Malaysia. Tel: +603 8911 8572 , a.fudholi@ukm.edu.my

Received: 29.10.2021 Accepted:25.11.2021

Abstract- The increase in ambient and surface temperatures is one of the main factors that lead to the decrease in the output power and efficiency of photovoltaic panels. A thermal photovoltaic collector (PVT) system is a method introduced to overcome the problem of excess heat on photovoltaic panels. As a result, in addition to the cooling method, many other collector designs have been widely developed to improve the cooling rate and heat transfer between the photovoltaic module and the working fluid. The purpose of this study was to introduce and evaluate a fiberglass collector design in a laboratory environment with varying solar radiations, using water as the working fluid. The thermal and electrical performances of the PVT collector were determined under solar simulator radiation between 450 -850 W/m^2. Experiments were conducted at each solar simulator with flow rate adjustment between 1.4–3 l/min. Electrical properties such as voltage, current, output power, efficiency, and thermal efficiency will be evaluated throughout the experiment. Experiments revealed that the design of this fiberglass collector is capable of increasing the output power and achieving the highest thermal efficiency of 72.98%, a temperature reduction rate of 35.36%, with a flow rate of 3l/min at 850 W/m^2. This fiberglass collector produces a total efficiency equivalent of 82.68%, an electrical efficiency of 9.7%, and thermal efficiency of 72.98%. Aside from the demonstrated ability of the cooling method for improving the performance of PVT collectors, this collector is also simple to fabricate and inexpensive to manufacture.

Keywords Fiberglass collector, photovoltaic thermal (PVT) , thermal performance, photovoltaic module efficiency.

Nomenclature

Q Heat gain (W)
G Solar radiation (W/m^2)
U Heat loss coefficient (W/m^{2}K)
T Temperature (°C)
A Area (m^2)
W Tube spacing (m)
N Glass covers
D Diameter (m)
P Power (W)
V Voltage (V)
I Current (A)

Greek symbols

δ Thickness (m)
η Efficiency (%)
u Useful
ε Emittance
β Tilt angle (degree)

Subscripts

a Ambient
b Back
c Collector
g Glass
h Hydraulic
elec Electrical
Th Thermal
pv Photovoltaic

1. Introduction

Malaysia will experience increasing economic and social issues due to climate change and the rising cost of fossil fuels. Therefore, the government has launched effective programs to increase renewable energy sources, lowering dependence on oil and the emissions of greenhouse gases [1]. Furthermore, Malaysia is a tropical country with an average of 1643 kWh/m^2 /year and 10 hours of sunlight every day [2,3,4]. Photovoltaic systems provide another viable renewable energy source in such a climate. Therefore, photovoltaic systems have been selected as the energy source with the most significant potential to meet Malaysia's energy needs [5].

Solar panel efficiency is affected by photovoltaic panel material, solar radiation intensity, surface temperature, dust layer density, panel tilt angle, and wind velocity. As the surface temperature rises, the efficiency of the PV panel decreases [6,33]. The vast majority of incident solar radiation absorbed is converted into heat on the surface of the photovoltaic module, with only a tiny portion utilized to generate electricity [7, 34, 35]. As a result, the efficiency of photovoltaic modules drops by 0.4–0.5% for every degree of temperature rise [8]. In hot climates, the working temperature of PV panels ranges from 40ºC to 85ºC. While solar technology is extensively utilized worldwide, it has significant limitations, including a decrease in efficiency as the working temperature increases [9,36], insufficient energy conversion, and dust accumulation on the module's surface, all of which limit the technology's potential [10].

PV/T has been the subject of extensive experimental and theoretical research for more than three decades. In addition to enhancing the cell's efficiency by 10%, Krauter [11] claimed that a cooling water layer running across the cell's surface also significantly reduced its temperature. Rahul et al. [12] found that power generation and efficiency were increased when using water and air cooling systems combined with a solar thermal collector. Ali R. et al. [13] employed water and air to cool the PV system; the output power for an air-cooled solar panel and water cooling increased by 2.4% and 6.3%, respectively. In their work, Hussein et al. [14] found that active cooling of PV panels reduced PV temperature from 78 to 70ºC, increasing the PV module's electrical efficiency by 9.8%. Idoko et al. [15] used a water-cooled aluminum heat sink attached to the rear of PV modules to lower the temperature to 20°C. Their cooling system was able to boost the module's efficiency by at least 3%. Abdullah et al. [16], studied theoretically and experimentally the thermal performance of a water-hybrid PVT with a flow rate of 2 to 6 liters per minute and solar radiation of 500 to 1000 W/m^2. They noticed that by increasing the mass flow rate, overall efficiency improved. Kader et al. [17] presented a new air and water circulation dual PVT system design with air channel enhancements. Results determined that the trapezoid is the most effective. Kiran S. et al. [18] performed an experimental study of an absorbent plate with a cooling tube attached to the back of the panel. A comparison was made between a flat surface plate with a trapezoid-shaped absorber. The study results found that the efficiency of the trapezoid-shaped absorber is 64%, and the efficiency of the flat surface plate is 58%. Massimo et al. [19] presented a technical and cost-benefit analysis of the performance of a solar-generating facade. Two technologies, DSSC and a-Si thin-film solar windows, were compared, and three systems were directly tested (DSSC, blue and grey solar cell). In different hours and days, a technical study of the behaviour of PV walls in terms of generated power, efficiency, and fill factor were performed. It is highlighted that, when compared to DSSC cells, silicon cells produce more energy, have a more excellent fill factor and have a higher efficiency during the morning hours. DSSC cells, on the other hand, outperform silicon cells in the afternoon. Wisam et al. [20] employed the ray-tracing approach to do an optical simulation of the design of the V-trough concentrator used with photovoltaic modules. The results demonstrate that the discrepancy between simulation and experimental results is 1.99%, showing that the simulation and experimental work agree well.

In Kottayam, India, Maatallah et al. [21] tested the performance of a PVT/water/PCM system compared to that of a standard PV panel. The PVT panel's efficiency was 17.33% higher than that of a standard PV panel, with thermal efficiency is 26.87% and electrical efficiency is 13.73%. Yazdanpanahi et al. [22] examined a theoretical analysis to investigate the exergy efficiency of photovoltaic thermal-water collector systems. The results of this idea's investigation are comparable to previous experiments that revealed similar outcomes. Wind speed, solar radiation, the surrounding temperature, and fluid temperature are all considered in the experiment. Fudholi et al. [23] presented three new designs of PVT collectors with water as the cooling medium. The authors investigated various collector types at different mass flow rates and radiation levels, including web-flow, direct flow, and spiral flow. According to the research, when mass flow rate and electrical efficiency improved, the panel temperature reduced. However, electrical efficiency and panel temperature increase as radiation levels increase. Therefore, thermal efficiency is best accomplished with direct-flow collectors. In contrast, spiral collectors best achieved electrical efficiency, with a thermal and electrical efficiency of 54.6% and 13.8% at an 800 wm^2 radiation level, and the spiral collector had the best overall performance. Hussain et al. [24] reported that by placing the aluminum honeycomb heat exchanger under the PVT-air collector, one could improve the thermal efficiency of the PVT collector. The experiment examined the phenomenon at various flow rates. The thermal efficiency was improved by 37% using honeycomb channels with a 0.11 kg/s mass flow rate.

This experiment developed a PVT system with a fiberglass collector and a 100W monocrystalline PV module. The experiments were conducted under a solar simulator at radiation levels of 850W/m^2, 650W/m^2, and 450W/m^2 with water selected as the working fluid. Total efficiency, electrical efficiency, and thermal efficiency will be investigated to determine the performance of the collector system.

2. Experimental Methodology

2.1 Collector design

A collector made of fiberglass sheets was used in this study, as shown in Figure 1. This study chose fiberglass for a variety of reasons, including its ease of fabrication and low cost. This collector is mounted directly behind the photovoltaic panel without an absorber plate to maximize the temperature difference between the photovoltaic panel and the cooling fluid. This method was developed to ensure that the working fluid comes into direct contact with the PV panel's rear surface, hence increasing thermal performance through the working fluid. The fabrication of this fiberglass collector was accomplished through the use of a pre-formed mold. Three layers of fiberglass cloth are alternatively placed, and each layer is covered with resin. This layer will be allowed to dry for one hour before the process is repeated for the next coat. The resin to hardener ratio is (100 gm: 1 ml). The collector has a thickness of 2 mm with these three layers, and the overall length of the fluid channel is 5.5 m with a depth of 5 mm, and the width is 40 mm. Since the depth of the collector is 5 mm, the working fluid with laminar flow (Re 1161–2270) is very suitable to ensure that the working fluid can absorb heat from the collector more efficiently.

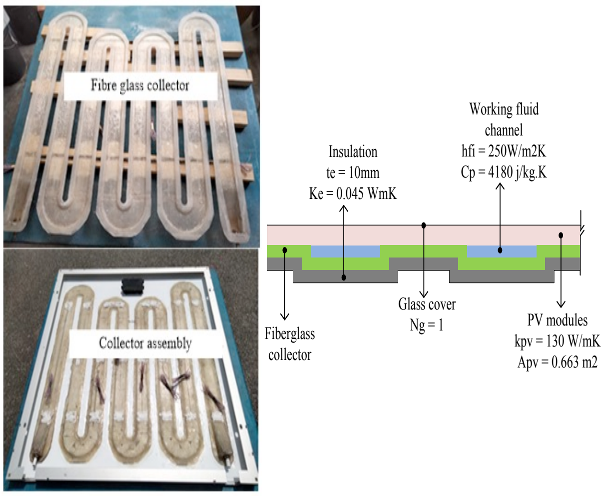

Fig.1 Fiberglass photovoltaic thermal collector

2.2 *Experimental setup*

Among the parameters controlled during the experiment was the intensity of solar radiation and the mass flow rate of water. The water-based photovoltaic thermal (PVT) fiberglass collector system depicted in Figure 3 was tested with different solar radiation levels at 450 to 850 W/m^2. Figure 2 shows a flow chart of a research study conducted in a laboratory. At the initial stage of the experiment, the uniformity of radiation intensity generated by the solar simulator must first be ensured so that the entire surface of the collector receives a uniform radiation intensity. Therefore, the simulator measured the radiation intensity value using a Zipp & Zonen Sp Lite 2 type pyranometer. Next, a map of solar radiation was made using a pyranometer. The pyranometer used is from the Sp Lite 2, Kipp & Zonen model. The sensitivity value of the pyranometer is 63.2 μ V/Wm^2. The pyrometer was placed on the surface of the solar collector at a distance of 1.0 meters below the solar simulator. The measured mapping area is (1.0 m x 1.0m), which corresponds to the surface area of the PVT collector studied. This mapping area is divided into 50 sections, and readings are taken after the light radiation is well established. Next, the pyranometer is moved from one section to another according to the predetermined mapping area. The simulator mapping was made with three different radiation intensity averages controlled by a voltage regulator. The average radiation intensity values produced by the solar simulators that have been built are 450 Wm^2, 650 Wm^2, and 850 Wm^2, with a percentage radiation uniformity of 5.71%, 6.52%, and 6.87 %, respectively. The input voltage of two direct current surface pumps rated at 70W each is regulated to control the flow rate between 1.4 to 3 l/min.

Current,voltage, and power measurements should be performed during data collection in the laboratory to study the electrical characteristics of the PVT collector. A solar analyzer module (Prova 200) was used to measure the parameters as described above. The resulting PV output is connected directly to the solar module analyzer and displayed on a computer screen. The values obtained are recorded in Microsoft Excel format and automatically graphed I-V, and P-V curves are plotted, including each reading measured. Temperature measurements were made using a K-type thermocouple connected directly to a data logger (Omron ZR-RX45). A K-type thermocouple is used for each of the 10 predefined points for surface photovoltaic panel temperature measurements. While the working fluid's output and input temperatures are also measured using a thermocouple of the same type. For the duration of the experiment, all-temperature readings will be recorded with a data logger at 1-minute intervals for 60 minutes. The PVT system had attained a steady state after 30 minutes, and measurement data was collected for analysis and performance evaluation. Table 1 summarizes the specifications for all measuring instruments, while Table 2 provides the specifications for the photovoltaic module.

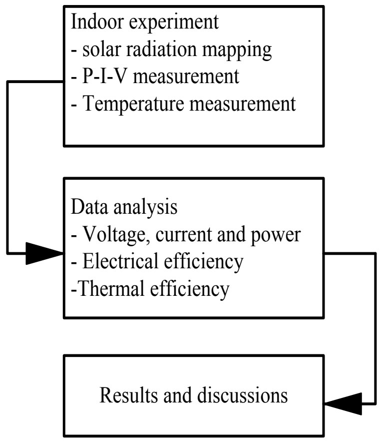

Fig. 2 Experimental flowchart

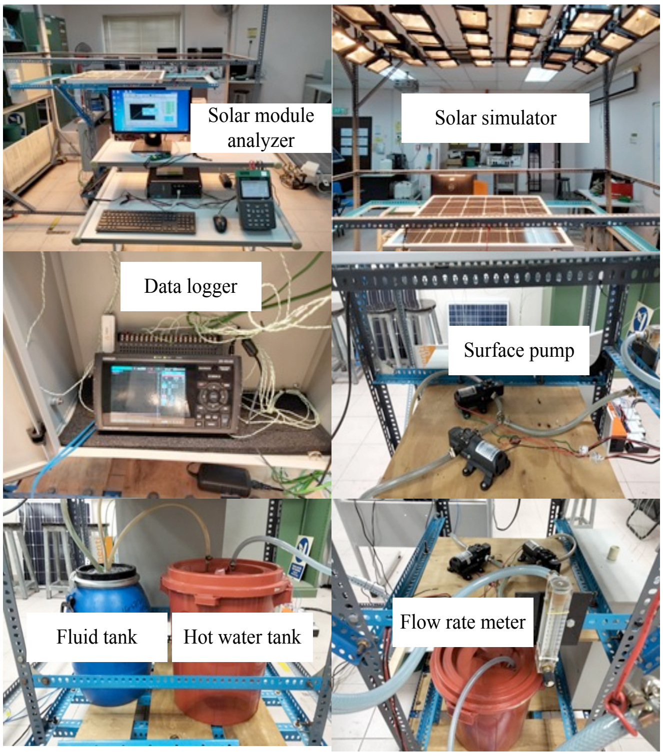

Fig. 3 Laboratory experimental setup

Table 1. Measurement device specification

Measurement device	Specification	Model
Thermocouple	K- Type, Max Temp sensed +260°C.	RS-PRO
Pyranometer	Maximum solar irradiance: 2000 W/m^2 Sensitivity : 63.2 µV/W/m^2	Kipp & Zonen SP Lite 2
Flow rate meter	1 L/min – 10 L/min ± 5 % Full scale Clear acrylic Temp.max : 65°C	Key Instruments FR2000
Data logger	K-type : Tmin -100°C, Tmax 1370°C	Omron ZR-RX45
Solar module analyzer	DC Voltage 10 – 60 V DC Current 1 – 6 A	Prova 200

Table 2. Photovoltaic module electrical characteristic

PV module specifications under STC	
Type	SPM100 Monocrystalline
Power	100 Wp
Open circuit voltage	22.53 V
Maximum voltage	18.75 V
Short circuit current	5.7 A
Maximum current	5.35 A
Panel efficiency	15.1 %
Number of cells	36
Panel dimension (cm)	820 x 808

2.3 *Uncertainties analysis*

The determination of uncertainty in the measurement of experimental results is essential. The uncertainty in an experiment is determined using Gauss's rule of propagation, as shown in Eqn (1)[25]. Where w_1, w_2, w_3,... w_n is independent variable uncertainty and R is a function of the independent variables x_1, x_2,... x_n.

$$W_R = \sqrt{\left[\left(\frac{\partial R}{\partial x_1}(w_1)\right)^2 + \left(\frac{\partial R}{\partial x_2}(w_2)\right)^2 + \ldots\ldots + \left(\frac{\partial R}{\partial x_3}(w_3)\right)^2\right]} \quad (1)$$

The parameters measured in the experiment were temperature (output, input, ambient, PVT collector, PV module), solar radiation, voltage, and current, as shown in Table 3. The maximum uncertainty for PVT's electrical and thermal efficiencies was ± 0.09% and ± 1.12%.

Table 3 Uncertainty for the devices used in the experiment

Instrument	Parameter	Accuracy	Uncertainty
Prova 200 analyzer	Voltage	± 1.0%	± 0.102 V
Prova 200 analyzer	Current	± 1.0%	± 0.041 A
Pyranometer	Solar radiation	± 0.18 W/m^2	± 3.5 %
Thermocouples	Temperature	± 1.1%	± 1.09 °C

2.4 *Thermal analysis*

PVT thermal efficiency, η_{th} is defined as [23] :

$$\eta_{th} = \frac{Q_u}{G_t} \quad (2)$$

Equation (3) [27], can be used to compute useful heat gain, (Q_u) :

$$Q_u = A_c F_R \left[G_t (\tau\alpha)_{pv} - (T_i - T_a) U_L \right] \quad (3)$$

Where $(\tau\alpha)_{pv}$ photovoltaic cell transmittance-absorptancce, (G_t) solar radiation, (U_L) total collector heat loss coefficient, cooling medium inlet temperature (T_i) and ambient temperature (T_a) are all used to calculate the useful heat gain, which is given by this equation as a function of collector area (A_c). The collector's thermal efficiency of PVT water- based can be represented as [26] by rearranging Eq. (2) and (3).

$$\eta_{th} = F_R \left[(\tau\alpha)_{pv} - U_L \left(\frac{T_i - T_a}{G_t} \right) \right] \quad (4)$$

There are three components of the collector's overall loss coefficient (U_L) [26], and they can be expressed as follows :

$$U_L = U_e + U_b + U_t \quad (5)$$

Top loss coefficient (Ut), can be calculated using Klein's equation (Eq.6) which Soteris. A [27], suggest.

$$U_t = \left[\frac{N_g}{\left(\frac{C}{T_{pm}}\right)\left(\frac{T_{pm} - T_a}{N_g + f}\right)^{0.33} + \frac{1}{h_w}} \right]^{-1} + \frac{\sigma (T_a + T_{pm})(T_a^2 + T_{pm}^2)}{\left(\frac{1}{(1-\varepsilon_p)0.05 N_g + \varepsilon_p}\right) + \frac{2N_g + f - 1}{\varepsilon_g} + N_g} \quad (6)$$

Where

$$f = \left(0.091 N_g + 1\right)\left(0.0005 h_w^2 - 0.04 h_w + 1\right)$$

$$C = 365.9\left(0.091 N_g + 1\right)\left(0.0001298\beta^2 - 0.00883\beta + 1\right)$$

Where, (σ) Stefan-Bolzman constant, (N_g) the number of glass covers, (ε_p) the plate emittance, (ε_g) the glass emittance, (β) the collector tilt, and (h_w) the wind forced convection heat transfer coefficient. Equation (7) [28] can be used to calculate the wind forced convection heat transfer coefficient (h_w).

$$h_w = 2.8 + 3v \quad (7)$$

The energy lost from the collector's bottom (U_b) and edge (U_e) are conveyed through the insulation before being transmitted to the surrounding environment via convection and infrared radiation [27]. The conduction resistance of the collector rubber insulating mat controls the heat loss from the collector through the backside.

$$U_b = \left(\frac{t_b}{k_b} + \frac{1}{h_{c,b-a}} \right)^{-1} \quad (8)$$

$$U_e = \left(\frac{t_e}{k_e} + \frac{1}{h_{c,e-a}} \right)^{-1} \quad (9)$$

Given in this study, back and edge materials are composed of the same material and dimension then $(t_e = t_b)$ insulation thickness and $(k_e = k_b)$ insulation thermal conductivity. The back surface $(h_{c,b-a})$ and edge loss coefficient $(h_{c,-e-a})$ can be taken as (0.3 – 0.6 W/m^{2}K) and (1.5-2 W/m^{2}K) [27]. An equation (10) [23], can also be used to compute the heat removal efficiency factor (F_R), which takes into consideration the collector's mass flow rate $(\dot{m})$ and the collector cooling fluid's specific heat (C_p).

$$F_R = \frac{\dot{m} C_p}{A_C U_L} \left[1 - \exp\left(\frac{-F' A_C U_L}{C_P \dot{m}} \right) \right] \quad (10)$$

The collector efficiency factor (F') is calculated as follows [23][27]:

$$F' = \frac{\left(\frac{1}{U_L}\right)}{W \left\{ \frac{1}{U_L \left[D_h + F(W - D_h) \right]} + \frac{1}{h_{fi} D_h \pi} \right\}} \quad (11)$$

Where (D_h) is the hydraulic diameter of the collector tube, (h_{fi}) indicates the heat transfer coefficient of the working fluid, (W) represents the spacing between collector tubes and (F) defines the fin efficiency factor [27], which is written as :

$$F = \frac{\tanh\left(\frac{W - D_h}{2} M \right)}{\left(\frac{W - D_h}{2} M \right)} \quad (12)$$

The thermal conductivity (k_{pv}) and thickness (δ_{pv}) of PV cell are accounted for by the coefficient (M), which is described by Eq.(13) [26].

$$M = \sqrt{\frac{U_L}{K_{pv} \delta_{pv}}} \quad (13)$$

The design specifications for a fiberglass PVT water-based system are shown in Table 4.

Table 4 : PVT collector specifications

Parameter	Symbol	Value	Unit
The quantity of glass covers	N_g	1	-
Plate emittance	ε_p	0.95	-
Glass emittance	ε_g	0.88	-
PV area	A_{pv}	0.663	m^2
PV thickness + Glass cover	δ_{pv}	3.5	mm
PV thermal conductivity	k_{pv}	130	W/mK
Fluid heat transfer coefficient	h_{fi}	250	W/m^2K
Channel spacing	W	70	mm
Wind speed	v	2	m/s
Water specific heat	C_p	4180	J/kg°C
Insulation thickness	$t_e = t_b$	10	mm
Insulation thermal conductivity	$k_e = k_b$	0.045	W/mK

2.5 Electrical efficiency

Studies were conducted to determine the impact of module cooling on module performance. Electrical efficiency is defined as a module's actual electrical output divided by the amount of solar energy incident on its surface, as given in equation (14) [29].

$$\eta_{elec} = \frac{V_{mp} I_{mp}}{A_{pv} G_t} = \frac{P_{mp}}{A_{pv} G_t} \tag{14}$$

Where *(P_{mp})* PVT maximum electrical power, *(I_{mp})* maximum current and *(V_{mp})* maximum voltage. These values were measured using a solar module analyzer at intervals of every 1 minute.

3. Experiment results and discussions

3.1 Voltage, current and power characteristics at different solar irradiance

Figure 4 shows the I-V characteristics of a PVT water collector at a flow rate of 3 l/min and various solar radiation levels. Additionally, experimental results indicate that the power generated is maximum at a 3 l/min flow rate, which remains valid for all solar radiation levels (450 - 850 W/m²). The PVT water results will be compared to those obtained from standard photovoltaic panels to determine how cooling influences electrical characteristics. The experiment results found that when the solar radiation changed to 450 W/m², the short circuit current (I_{sc}) increased by 15.6%, from 1.482 A to 1.714 A. While at 650 W/m², short-circuit current increases from 2.194 A to 2.636 A. At 850 W/m² of solar radiation, an increasing trend of short-circuit current can be observed. In this instance, the highest percentage increase observed was 20.5 % (2.583 A - 3.113 A). However, open circuit voltage is inversely proportional to short circuit current at all levels of solar radiation. According to Solanki [30], the rate of change of Voc with solar cell temperature is always negative, while the rate of change of Isc with solar cell temperature is favourable. As shown in Table 5, the open-circuit voltage value marginally reduced from conventional PV panels to a flow rate of 3 l/min.

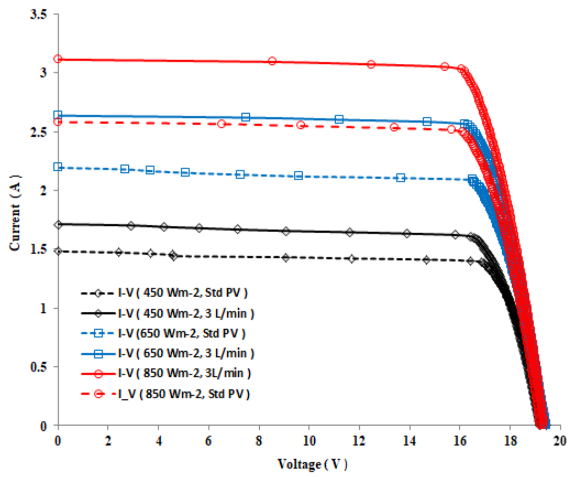

Fig.4 I-V curves at different solar radiation and 3 L/min flow rate

Figure 5 shows the P-V relation between solar radiation (450-850 W/m²) and a 3 l/min flow rate. At 850 W/m² solar radiation, the maximum output power was 47.46 W, compared to 40.26 W for a conventional PV panel, followed by 41.65 W at 650 W/m² radiation and further at 450 W/m², the output power was 26.48 W. However, at 650 W/m², the highest percentage increase in output power was observed at 20.74%. In contrast, the percentage increase in output power is 17.86% at 850 W/m² and 12.89 % at 450 W/m² solar radiation. The increase of this value is influenced by the photocurrent, which is directly proportional to the received radiation intensity. As seen in Table 5, the rising trend is proportional to the increase in electrical efficiency; with increasing the working fluid flow rates, electrical efficiency increased due to a drop in the surface temperature of the photovoltaic panel. This increase in efficiency indicates that photon energy at high intensities has more energy than the gap energy of the solar cell strip, allowing more photocurrents to generate.

At a solar radiation level of 650 W/m², the experiment revealed that the highest electrical efficiency achieved was 9.7%, increasing a percentage of 21.25%. However, electrical efficiency decreased slightly to 8.9% when solar radiation was 450 W/m² but increased to 8.4% when solar radiation was 850 W/m². This decline in efficiency is because the surface temperature of the photovoltaic panel rises proportionately to the increase in solar radiation.

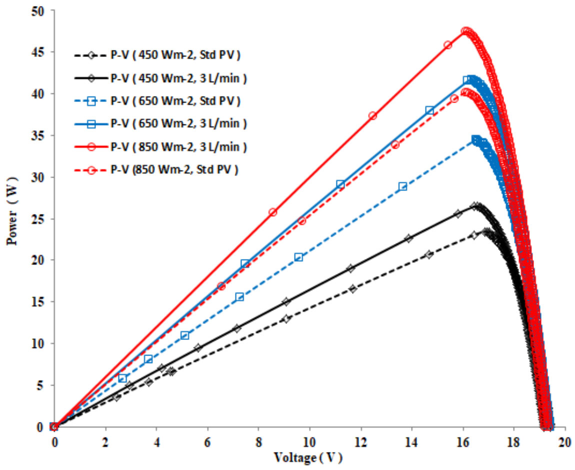

Fig.5 P-V curves at different solar radiation and 3 L/min flow rate

Table 5 . Voltage, current, power characteristic and electrical efficiency at different solar irradiances and flow rates.

	Std PV	1.4 l/min	2 l/min	2.4 l/min	3 l/min
Voc,(V) 450 W/m^2	19.42	19.34	19.32	19.20	19.17
Voc, (V) 650 W/m^2	19.42	19.37	19.36	19.21	19.20
Voc, (V) 850 W/m^2	19.71	19.62	19.36	19.23	19.17
Isc, (A) 450 W/m^2	1.48	1.615	1.66	1.68	1.71
Isc, (A) 650 W/m^2	2.19	2.33	2.55	2.58	2.63
Isc, (A) 850 W/m^2	2.58	2.85	3.03	3.04	3.11
Pmp, (W) 450 W/m^2	23.45	25.09	25.86	25.90	26.48
Pmp, (W) 650 W/m^2	34.49	36.01	39.88	40.17	41.65
Pmp, (W) 850 W/m^2	40.26	44.53	45.71	45.94	47.45
Eff, (%) 450 W/m^2	7.9	8.4	8.7	8.7	8.9
Eff, (%) 650 W/m^2	8.0	8.4	9.3	9.3	9.7
Eff, (%) 850 W/m^2	7.1	7.9	8.1	8.2	8.4

3.2 The cooling effect of photovoltaic module surface temperature

Figure 6 demonstrates the influence of cooling on a photovoltaic panel's surface temperature at various solar radiation and flow rates. At 850 W/m^2 solar radiation, the experiments discovered a temperature decrease by 35.26% (73.31°C to 54.2°C). While at 3 l/min flow rates, the panel temperature of a standard PV is 67.67°C at 650 W/m^2, it decreases by 34.43% to 50.34°C. Following this decreasing pattern, at 450 W/m^2, the temperature reduced from 60.71°C to 46.07°C. Additionally, the findings of this experiment demonstrated that the cooling effect and a high flow rate are capable of lowering the surface temperature of a photovoltaic panel. The configuration of the PVT collector installed without the absorber plate also has a significant effect on the module surface temperature drop. The working fluid is in contact with the back surface of the panel, thereby increasing the rate of heat absorption.

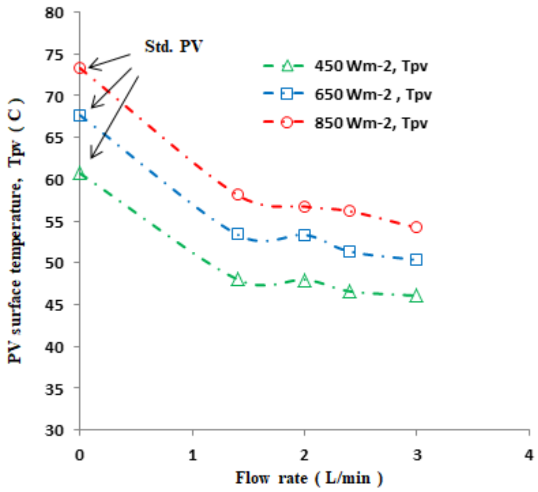

Fig.6 PV surface temperatures at various solar radiations and flow rates

3.3 The cooling effect on the output temperature of PVT collector

Increases in the PVT collector's output temperature are proportional to increases in its working fluid flow rate from 1.4 to 3 l/min. In contrast, the PVT collector output temperature is inversely related to the photovoltaic panel's surface temperature. This can be explained by the fact that the photovoltaic panel's surface temperature is reduced due to the effective heat transfer, resulting in a higher output temperature.

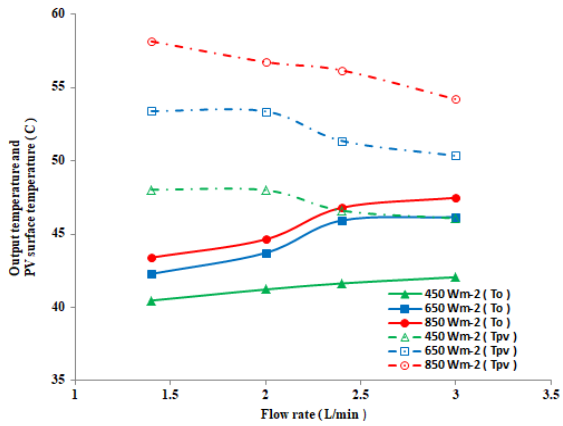

Fig.7 Variation of the output temperature with various solar radiations and flow rates

When the water flow rate increases from 1.4 to 3 l/min, Figure 7 illustrates the maximum output temperature obtained at 850 W/m^2 solar radiation increasing from 43.4 to 47.48°C. At 650 W/m^2, the output temperature varies between 42.29°C and 46.16°C, while at 450 W/m^2, a similar rising trend from 40.47°C to 42.06°C is observed.

3.4 PVT collector thermal efficiency

As previously stated, the efficient heat transfer from the PV panel's surface to the working fluid determines the rate at which the temperature of the PVT collector output increases. An increase in surface temperature drop rates results in greater thermal efficiency of the PVT collector. Figure 8 illustrates the thermal efficiency at various radiation levels and flow rates. It can be shown that when the panel temperature decreases, the thermal efficiency increases. At 850 W/m^2 radiation, the rate of decrease in surface temperature is the highest (35.26%). This occurs as the effect of cooling at the maximum flow rate (3 l/min). The effect of the high surface temperature drop of PVT causes the rate of thermal efficiency to increase. Therefore, the highest thermal efficiency recorded was 72.98%. In addition to the flow rate, the level of solar radiation also contributes to the thermal efficiency of PVT collectors. When the solar radiation level is adjusted to 650 W/m^2, the decrease in surface temperature is 34.43%. This rate of decline led to a fall in thermal efficiency of 67.89%. The same effect is seen to occur at 450 W/m2 of solar radiation. The highest thermal efficiency recorded was 66.15%, the lowest thermal efficiency compared to the efficiencies achieved at 850 W/m^2 and 650 W/m^2.

Furthermore, Figure 8 shows that the highest percentage increase occurs at a flow rate equivalent to 3 L/min, with the highest percentage increase of 9.5 % observed at 850 W/m^2, followed by 9.08% at 450 W/m^2, and a percentage increase of 7.88 % at 650 W/m^2. The thermal efficiency increases in line with the increase in the mass flow rate of the water. At low mass flow rates, the movement of water molecules is relatively slow, and this condition will slow down the heat transfer process from the collector. On the other hand, the heat transfer process occurs rapidly at a high mass flow rate, which involves the movement of high water molecules in reducing the PV temperature so that the collector's performance is at an optimum level. Thus, the increase in thermal efficiency is in line with the decrease in temperature as the mass flow rate increases. In this study, there is little difference if the results of this study are compared with the theoretical values. Among the factors are:

- The level of solar radiation
  In the experiments, the adjusted solar radiation level could not be adjusted to the exact value.
- Temperature
  The surface temperature is slightly higher because this temperature is generated by the solar simulator, which is more focused on the PVT surface.

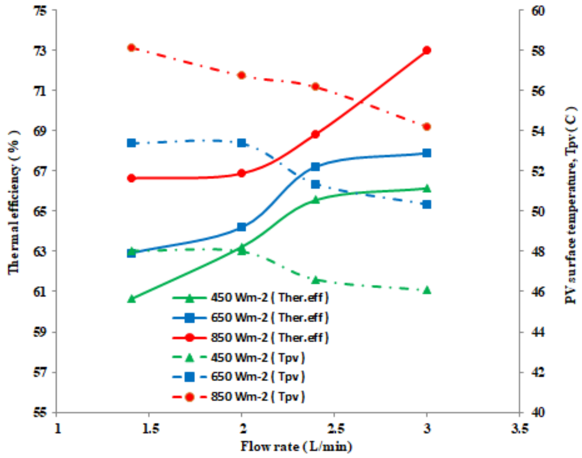

Fig.8 Thermal efficiency at different solar radiations and flow rates

Table 6 lists several past studies of PVT collectors that were chosen for comparison with this study. The PVT collectors investigated in this study are made of fiberglass and are utilized as collectors. Furthermore, the PV panel's collector assembly method is placed without an absorbent plate. . Therefore, this developed collector has never been studied or reported by any previous researcher. As such, it is one of the new models in the solar energy system. Nevertheless, the performance of the study results in terms of overall efficiency, electrical efficiency, and thermal efficiency of PVT collectors can be compared with previous studies. The study yielded electrical efficiencies in the range of 7.9 % to 9.7%. Furthermore, the thermal performance analysis shows that the average efficiency obtained is between 66.14 - 72.98%.

Table 6 : Comparison of the results of the experiment with previous studies

PVT system	η_{elec} (%)	η_{th} (%)	η_{total} (%)
Current study	9.7	72.98	82.68
PVT water system [31]	10.9	51.25	62.15
PVT water (spiral flow) [32]	9.1	26	35.1
PVT water – PCM [20]	5.3	60	65.3
PVT water – cooling chamber [19]	16.6	80	96.6
PVT water (spiral flow)[23]	13.8	54.6	68.4

4. Conclusion

Under various solar radiation and flow rates, the performance of water-based PVT collectors with PV panels and fibreglass collectors was examined. According to the study's findings, the output power of PV panels increased at high radiation levels and flow rates. The increased working fluid flow rate can also significantly reduce the temperature of the photovoltaic module, resulting in higher thermal efficiency. The maximum thermal efficiency of 72.98 % was achieved, while the highest electrical efficiency of 9.7% was obtained. Furthermore, the collector design of this fibreglass can minimise photovoltaic module surface temperature by 35.26%. As a result, this collector and cooling system is the perfect solution for increasing the output power of photovoltaic panels while lowering the temperature. These results have been obtained by increasing the cooling factor and heat transfer rate as the working fluid flow rate changes.

References

[1] R. M. Abdul, K. T. Lee, 2005. "Energy for sustainable development in Malaysia: energy policy and alternative energy". Energy Policy 34, pp.2388–2397.

[2] Solar Radiation, 2008. Mean Daily Solar Radiation

Available at https:// www.met.gov.my

(accessed date : 28 October 2021)

[3] AH Haris, MBIPV Project: Catalyzing Local PV Market. Kuala Lumpur, Malaysia: Finance & Investment Forum on PV Technology; 2008.

[4] N. Amin, CW Lung, K. Sopian "A practical field study of various solar cells on their performance in Malaysia". Renewable Energy 2009;34(8):pp.1939–1946.

[5] SC Chua, TH Oh, "Solar Energy Outlook in Malaysia", Renewable and Sustainable Energy Reviews, 16, 1, pp.564–574.

[6] J. Zhao, T. Ma, Z. Li, A. Song, "Year-round performance analysis of a photovoltaic panel coupled with phase change material", Appl. Energy 245 (2019),pp. 51–64.

[7] A. Shukla, K. Kant, A. Sharma, P.H. Biwole, "Cooling methodologies of photovoltaic module for enhancing electrical efficiency: a review", Sol. Energy Mater. Sol. Cells 160 (2017),pp. 275–286.

[8] S. Preet, ''Water and phase change material based photovoltaic thermal management systems: A review," Renewable and Sustainable Energy Reviews, vol. 82. Elsevier Ltd,2018, pp. 791–807

[9] E. Skoplaki, J.A. Palyvos, "On the temperature dependence of photovoltaic module electrical performance: a review of efficiency/power correlations", Sol. Energy 83 (2009),pp. 614–624.

[10] P. Sudhakar, R. Santosh, B. Asthalakshmi, G. Kumaresan, R. Velraj, "Performance augmentation of solar photovoltaic panel through PCM integrated naturalwater circulation cooling technique", Renew. Energy 172 (2021), pp. 1433–1448.

[11] S. Krauter, "Increased electrical yield via water flow over the front of photovoltaic panels", Sol. Energy Mater. Sol. Cell. 82 (2004),pp. 131–137.

[12] S. R. Rahul and R. Hariharan, "Performance Study of Solar Photovoltaic Thermal Collector Integrated with Cooling System", Int. J. of Emerging Engineering Research and Technology, Vol. 2,2014, pp.132-145

[13] R. Ali and C. Serdar, "Effect of Cooling on Solar Panel Performance " Int. Proceedings of Chemical, Biological and Environmental Eng. 2017, Vol.100, pp.118-123.

[14] H.A. Hussien, A.H. Numan, A.R. Abdulmunem, "Improving of the photovoltaic/ thermal system performance using water cooling technique", IOP Conf. Ser. Mater.Sci.Eng.78 (2015).

[15] L. Idoko, O. Anaya-Lara, A. McDonald, "Enhancing PV modules efficiency and power output using multi-concept cooling technique", Energy Rep. 4 (2018),pp. 357–369.

[16] A.L. Abdullah, S. Misha, N. Tamaldin, M.A.M. Rosli, F.A. Sachit, "Theoretical study and indoor experimental validation of performance of the new photovoltaic thermal solar collector (PVT) based water system", Case Stud. Cherm. Eng. 18 (2020).

[17] M.F. Kader, M. Awal Khan, M.H. Huq, "Thermal Characteristics of Hybrid Photovoltaic Solar Thermal System during Summer", in: 1st Int. Conf. Adv. Sci. Eng.Robot.Technol. 2019, ICASERT 2019, 2019.

[18] S. Kiran, and U. Devadiga., "Performance Analysis of Hybrid Photovoltaic/ Thermal Systems", Int. J. of Emerging Technology and Advanced Eng., Vol. 4(3), pp. 80-86, 2014.

[19] Massimo Caruso, Rosario Miceli, Pietro Romano, Giuseppe Schettino, Fabio Viola, "Technical and economical performances of photovoltaic generation facades", International Journal of Smart Grid, Vol.2, No.2, 2018, pp. 87-98.

[20] Wisam A.M. Al-Shohani, Raya Al-Dadah, Saad Mahmoud, Abdulmaged Algareu, "Performance of a V-trough photovoltaic system", 5th International Conference on Renewable Energy Research and Applications, (ICRERA 2016), pp. 946-951.

[21] Maatallah, T., Zachariah, R., Al-amri, F.G., 2019. "Exergi-economic analysis of a serpentine flow type water based photovoltaic thermal system with phase change material (PVT-PCM / water)". Sol. Energy 193, pp. 195–204.

[22] J. Yazdanpanahi, F. Sarhaddi, M.M. Adeli, 2015. "Experimental investigation of exergy efficiency of a solar photovoltaic thermal (PVT) water collector based on exergy losses". Sol. Energy. 118, pp. 197–208.

[23] Fudholi A, Sopian K, Yazdi MH, Hafidz M, Ibrahim A, Kazem HA. "Performance analysis of photovoltaic thermal (PVT) water collectors". Energy Convers Manag 2014;78, pp.641–51.

[24] F. Hussain, MYH Othman, B. Yatim, H. Ruslan, K. Sopian, Z. Ibarahim, "A study of PV/T collector with honeycomb heat exchanger". AIConProc 2013;1571: pp.10–6.

[25] J. P. Holman, and W. J. Gajda, Experimental Methods for Engineers, 5th edition, McGraw-Hill, 1989, pp.62-72.

[26] G. Vokas, N. Christandonis, F. Skittides, "Hybrid photovoltaic–thermal system for domestic heating and cooling-a theoretical approach". SolEnergy 2006;80(5):pp. 607–615.

[27] Soteris A. Kalogirou. (2013). Solar Energy Engineering Process and System. Academic Press.

[28] J. H. Watmuff, W. W. S. Charter, D. Proctor, "Solar and wind induced external coefficients for solar collector". Comples 1977; pp. 2-56

[29] A. Singh, O. P. Shukla and N. Saxena, "Energy and Exergy Analysis of Crystalline Silicon Solar Photovoltaic Module for clear sky Day at Bhopal", Int. Research J. of Eng. and Technology, Vol. 3(8), 2016

[30] S. C. Solanki, 2009. Solar Photovoltaics: Fundamentals Technologies And Applications. India : Prentice-Hall of India Pvt. Limited.

[31] K.A. Omer, A.M. Zala, "Experimental investigation of PV/thermal collector with theoretical analysis", Renew. Energy Focus 27 (2018).pp. 67–77,

[32] Hussein A. Kazem , Ali H. A. Al-Waeli, Miqdam T. Chaichan , Karrar H. Al-Waeli , Anwer Basim Al-Aasam, K. Sopian, "Evaluation and comparison of different flow configurations PVT systems in Oman: A numerical and experimental investigation". Solar Energy Volume 208, 15 September 2020, pp. 58-88.

[33] Zehra Ural Bayrak, Muhsin Tunay Gencoglu, "Simulation and Experimental Study of A Hybrid System for Different Loads", 3rd International Conference on Renewable Energy Research and Applications, (ICRERA 2014), pp. 451-456.

[34] Yusuke Yoshida, Yuzuru Ueda, "Verification of Consumer's Benefits for Different Area Ratio ofPV Array and Solar Thermal Water Heater Considering Regional Characteristics", 4th International Conference on Renewable Energy Research and Applications, (ICRERA 2015), pp.472-477

[35] Sameer Simms, Jean-Francois Dorville, "Thermal Performance of a Hybrid PhotovoltaicThermal Collector with a Modified Absorber", 4th International Conference on Renewable Energy Research and Applications,(ICRERA 2015), pp. 600-605.

[36] Velaphi Msomi, Ouasin Nemraoui, "Improvement of the performance of solar water heater based on nanotechnology", 6th International Conference on Renewable Energy Research and Applications (ICRERA 2017), pp. 524-528