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FEXPERIMENTAL INVESTIGATION OF PV/T SOLAR COLLECTOR EFFICIENCY WITH SPHERICAL-SHAPED PROTRUSIONS ON THE ABSORBER SURFACE

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Abstract

The Accumulated heat on the PV panels' upper surface could be dissipated by water circulation in the backside attached collector. This paper presents an experimental study to improve the performance of the PV/T system by modifying the collector design using a spherical bulge on the collector surface. The work was carried out at the University of Technology- Iraq. Two PV solar cells have been used in the experimental investigation. One is cooled by different water flow rates of 1.5, 2, 2.5, and 3.5 l/min; the other is a bare reference unit without any modification. The illustrated bludges are a matrix of spheres with a 25 mm radius arranged in 8 rows by 15 columns. The thermal efficiency of the PV/T increased by 8.08%, and electrical efficiency increased by 8.1% compared with the bare panel. Additionally, the impact of flow rate was discussed and evaluated in this study. Increased water flow rate decreased the PV surface temperature in the new model. With a flow rate of 3.5 l/m, the maximum surface temperature decrease was 15.4%.

Keywords: Collector performance, Open flow collector, Photovoltaic cells, PV/T system.

1. Introduction

Photovoltaic Cells (PV) are devices made of semiconductor materials and manufactured in different sizes and can be linked together in arrays in series or parallel circuits according to use [1]. The efficiency of the photovoltaic cell increases with the increase in solar radiation, while its generation efficiency decreases with the increase in photovoltaic cell temperature above the standard temperature [2, 3]. PV panels are designed to work in specific conditions depending on the geographic region they are used in [4]. For standard conditions, PV panels should work with the highest efficiency at these conditions: (1000 W/m2 solar radiation and 25° C). Thus, the PV efficiency decreases when the temperature increases over 25 °C. Therefore, researchers implement methods to reduce overheating. One of these methods is using a PV/T system [5, 6] by attaching a cooling system at the back of the PV module. Other methods, like water and airflow, are sprayed on the PV module's front or rear.

PV/T systems reduce the temperature of photovoltaic panels to ensure that they work at near-standard conditions, producing the highest amount of electricity. Heat collected in a photovoltaic unit throughout the day can be used for other purposes with this system [7, 8]. According to Al-Zurfi [9], PV/T systems operate well in warm climates, where solar cells act as heat absorbers. When a windshield is added, heat loss is reduced more, reflecting higher losses. To this day, researchers are still studying new designs [10-13]. A flat box-shaped water collector was installed at the back of polycrystalline PV modules. The results showed that the system performance improved. Power efficiency has improved in the new system [14, 15].

Researchers studied attached heat exchangers to the back of the PV panel in multiple configurations to improve heat withdrawal and dissipation [16, 17]. Another approach proposed connecting the backside heat exchanger to an underground buried heat exchanger to dissipate the PV/T heat to the ground and circulate warm water at night to prevent condensation on the PV surface [18-20]. Nanofluids with high conductivity can be a coolant [21-23]. Additionally, phase change materials were proposed to reduce temperature fluctuations of the solar cell and to facilitate the dissipation of accumulated heat when using air, water, or nanofluids [24-29].

Simulation analysis conducted by Othman et al. [30] has revealed that hybrid PV/T effectiveness depends on several design factors and operational conditions. In this way, seven groups of absorption collectors are designed. Heat collectors with flat plates or glass plates were determined to be the best. Tt was found that helical heat exchanger tubes have a maximum thermal efficiency of 50.12% and a maximum electric cell efficiency of 11.98%. This result has been supported by many empirical studies [31-33].

The objective of the current paper is to present the investigation results of a PV/T adopting an innovative collector design. The investigation was performed experimentally utilizing a designed and fabricated setup, including a bare PV panel and a PV/T panel. Temperatures, flow rates, solar irradiance, and all required process variables were measured on the two panels simultaneously and then used to estimate the performance parameters. The thermal and electrical efficiency of both panels permits proper comparison.

2. Experimental Implementation

2.1. Experimental setup

This study aims to investigate an experimental PV panel cooling system designed for power generation. By utilizing a closed-circle water flow in an open-flow flat collector system, it was possible to subtract heat energy from the system. Typical PV panels are equipped with thermal collectors (absorbers). Based on the PV system, all experiments were performed to determine PV/T system characteristics. A portion of the collected energy was extracted as electricity instead of heat, as shown in Fig. 1. PV panels and PV/T systems are both inclined with 30^o from horizontal. A temperature measurement unit took PV/T system temperature measurements before entering the collector. A flow rate device was used to measure the flow rate of water. One-way valves were used to control the flow rate of water precisely.

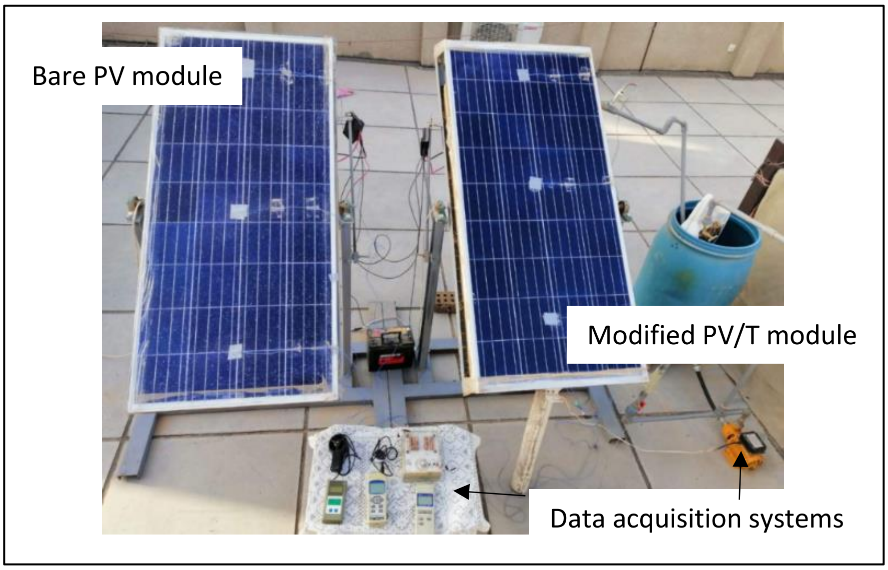

Fig. 1. Schematic view of the experimental setup.

The open-flow flat collector removes heat from the back surface of the photovoltaic panel to the water flowing into it. An important parameter in the collector is the tangential and vertical geometry of the interior, the increase in the contact area between the heat transfer material and hot surfaces, and the difference in temperature between water entering the collector and ambient air.

This new design uses uniform aluminum fins connected to the collector cover from the bottom to provide powerful heat transfer and water movement. Since there are no fins on the collector cover, the velocity components of water flow are more valuable. The present work uses sphere-shaped fins in the new design. Featuring 120 sphere fins and a diameter of 25 mm, this model allows for powerful heat transfer. There were 8 spheres within one row of fins on the collector cover's bottom surface, while there were 12 rows total, as shown in Fig. 2.

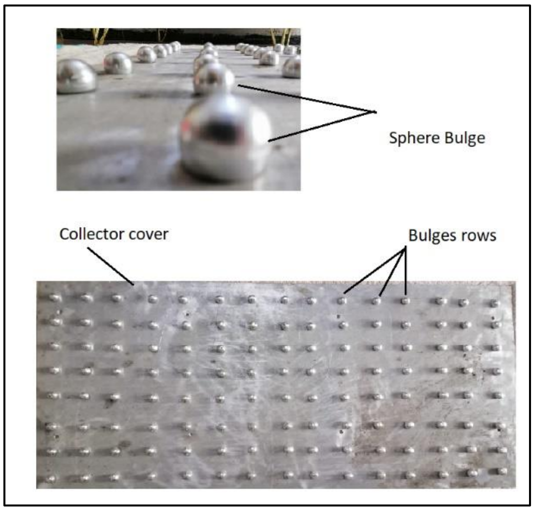

Fig. 2. Structural pictures of the modified absorber of the collector.

2.2. Measurement and instrumentations

Temperature measurement tests were carried out experimentally. The experiment procedures were performed on sunny days, while cloudy or partially cloudy days were avoided during testing. All temperature tests on the PV/T module were performed to become acquainted with and confident with the measuring procedure. Experiment measurements were carried out at the solar research facility, where two PV panels, including the collector, were installed. Temperature measurement can be divided into several groups, as illustrated in Fig. 3.

- Group A used three thermocouples for measuring the PV panel surface.
- Group B used two thermocouples for measuring inlet and outlet water temperature.
- Group C used three thermocouples for measuring the **collector's** surface.

All thermocouples used were Type-K with a selector switch and digital thermometer.

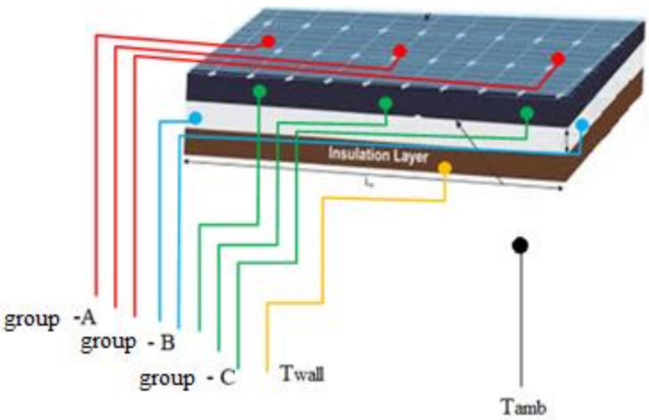

Fig. 3. Temperature measurement locations and the groups of thermocouples.

2.3. Experimental procedure

The experimental work was conducted outdoors on sunny days. To become acquainted with and confident with the measuring procedure, basic tests of water temperature, surface temperatures, wind speed, water flow rate, and solar intensity were performed at various positions of the PV/T system. Also, the period time ranges were chosen from 7:00 AM to 7:00 PM to provide a range for studying the effect of PV panel heating due to solar radiation on its performance. The experiments for open flow flat collector were conducted by a temperature measurement system and water circling system for recording PV panel surface temperature, water inlet, and outlet temperatures, as well as collector surface temperature from a collector with varied water flow rates at several days. Also, a solar meter was used for solar intensity measuring through daily time, as mentioned in Table 1. Also, Table 2 shows the PV panel's specifications.

Table 1. Data collected for PV/T system for the new flat collector.

No.	Water flow	T-PV	T_{co}	G (W/m^2)	T_{amb}	Tw_{in}, Tw_o
1	1.5 l/min	3 points	3 points	24-1112	1	2 points
2	2.0 l/min	3 points	3 points	24-1112	1	2 points
3	2.5 l/min	3 points	3 points	24-1112	1	2 points
4	3.5 l/min	3 points	3 points	24-1112	1	2 points

Table 2. PV panel's specifications.

Model of PV panel	MSM150S
Type of cells (mm)	Mono (156×104)
No. of cells and connections	4×9=36
Dimensions (mm) (L×W×H)	1470×670×30
Weight (kg)	11.0
Glass	3.2 mm Tempered glass
Encapsulation	EVA
Rated maximum power	150 W
Cell efficiency	17.7%
Open circuit voltage (Voc)	22.4 V
Maximum power voltage (Vmp)	17.5 V
Short circuit current (Isc)	9.05 A
Maximum power current (Imp)	8.63 A

3. Results and Discussions

Figure 4 shows the thermal energy gain as the temperature changes between the water inlet and outlet temperature (T_{out}-T_{in}). It shows that ΔT is affected by parameters such as solar irradiance, G, and water flow rate, m_w. An increase in radiation leads to an increase in ΔT. Therefore, an increase in flow rates during a given input decreases ΔT by this value. Lower T with a higher flow rate leads to increased efficiency, and the highest temperature difference is at the highest radiation at 12:30 PM.

The difference in temperature decreases with the increase in the water flow rates, where the decrease rates were 14 %, 26.2%, and 44% when changing the flow rates by 2.0 l/min, 2.5 l/min, and 3.5 l/min, respectively, at 12:30 PM. Accordingly, the heat loss increases due to cooling the water and reaching a higher temperature. The loss decreases when the flow rate increases. The results are consistent with those reported by Mojumder et al. [33], where, at a flow rate of 3.5 l/ min, the temperature rise is equal to 1.3. On the other hand, at a flow rate of 1.5 l/min, the temperature rise is equal to 3.7.

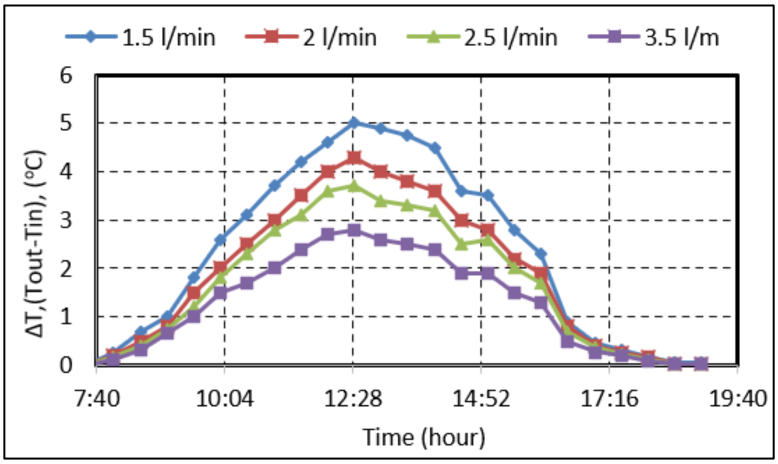

Fig. 4. Variation of ΔT (Tout -Tin) with time during the day at the flow rate from (1.5 to 3.5 l/min).

Figure 5 shows the thermal efficiency of PV/T, defined by solar energy input, and can be converted into thermal gain. Upon investigation, we found noticeable changes in the PV/T thermal efficiency with radiation, G, at different flow rates. The radiation is directly proportional to the $\acute{\eta}_{th}$. When the flow rate increases, the thermal efficiency increases; thus, the highest thermal efficiency is achieved at the highest radiation. At the following flow rates, 2.0 l/min, 2.5 l/min, and 3.5 l/min, the thermal efficiency proportions were increased by 7.8%, 16.6%, and 27.3%, respectively, compared to the flow rate of 1.5 l/min at 1:00 PM. These results are consistent with those of Mojumder et al. [33].

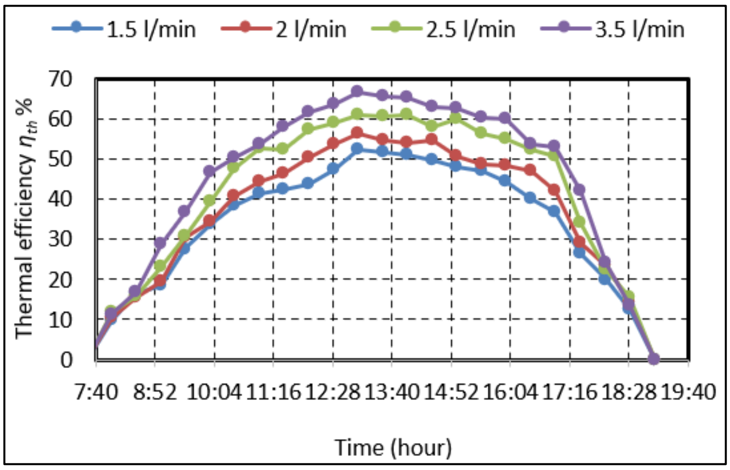

Fig. 5. Variation of thermal efficiency with time during the day at different flow rates.

Figure 6 represents the relationship between electrical efficiency and η_{el} with time during the day at different flow rates. For a certain flow rate, the η_{el} was decreased with G increase; the reason is due to the increase of T_{cell}. The photovoltaic cell cooling increased when the flow rate was increased through the thermal collector and constant radiation (G). This, in turn, leads to a relatively low temperature, resulting in large increases in η_{el}. Thus, the highest electrical efficiency is at a constant radiation flow rate. As shown from the results in Fig. 6, the electrical efficiency of the uncooled cell was 13.5% at 1:00 PM. The percentages of increased electrical efficiency are 4.3%, 5.1%, 5.9%, and 7.4%, using flow rates of 1.5, 2, 2.5, and 3.5 l/min, respectively, at 1:00 PM. These results are consistent with those of Abdul-Ganiyu et al. [15]. Electrical efficiency increased from 10.1% to 10.83% with an increase in the flow rate from 0.025 to 0.067 kg/s.

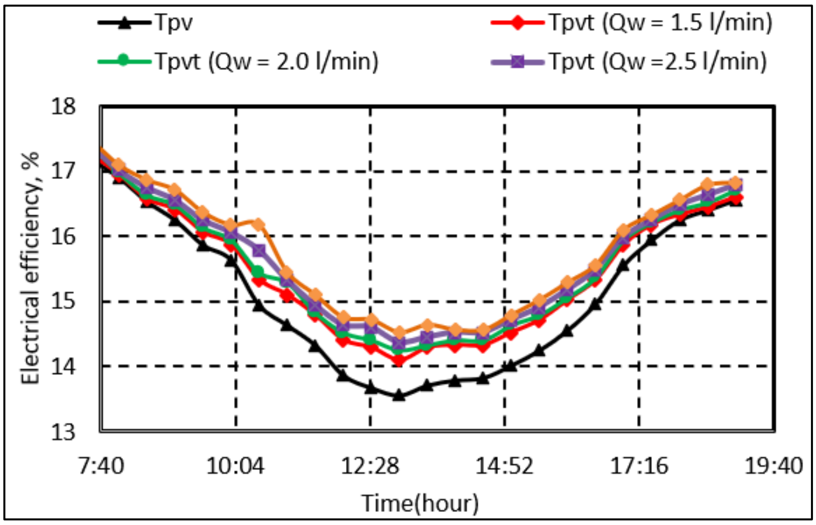

Fig. 6. Variation of electrical efficiency with time during the day at various cooling water flow rates.

4. Conclusions

A new design of an open-flow flat collector was used in this study to improve the cooling process for PV panels. Using experimental methods, we investigated and analysed an open-flow flat collector. There was a statistically significant difference between the temperature of the uncooled PV panel at 1:00 PM and the cooled PV panel at the same time. In contrast, the performance of the PV panel increased to 25.3% at the same time. According to the evaluation results, PV/T system performance improved, and open-flow collector fins helped enhance system performance.

Nomenclatures

A	Area, m^2
G	Solar radiation intensity, W/m^2
I	Current, Amp

PV	Photovoltaic module
PV/T	Photovoltaic/thermal
T_{amb}	Ambient temperature, °C
T_{co}	Collector temperature, °C
T_{PV}	PV panel temperature, °C
Tw_{in}	Entering water temperature, °C
Tw_o	Outlet water temperature, °C
Greek Symbols	
η_{el}	Electrical efficiency, %
η_{th}	Thermal efficiency, %

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