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Indoor Test Conditions of Thermal Collector Channel Using Water as a Working Fluid to Enhance the Electrical and Thermal Efficiency of the PV / T System

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Abstract. The hybrid (PV/T) system or photovoltaic thermal collector generates the electrical and thermal energy simultaneously. The main objective of this study was to design, manufacture and evaluate the work of the PV/T system as a thermal collector to enhance heat transfer, by using (distilled water) as a working fluid used to cool (PV/T) system. The experimental setup of the system was constructed, using the optimal water guides for each configuration and was evaluated using the numerical results. thermal absorber collector of (PV/T) system is the box made of a heat-insulating material (foam), inside which contains a water guides that is operated by a CNC machine used to distributed of liquid inside of PV/T system, then installed later in the back surface of the photoelectric panel using epoxy wax, here, designed the thermal absorber collector channel to be within the geometrical shape of the PV panel to observe the rules placed to install the PV panels previously prepared. Results obtained from the numerical analysis indicated that the rectangular channel with round water guides, linear distribution [d = 10mm, h = 3mm, n = 66] has the best design used to heat transfer. The results showed that the thermal aggregation channel with round fluid flow guides, at linear distribution, had a 14.595% PV/T for maximum electrical efficiency and a 94.514% PV/T for maximum thermal efficiency for experimental results, where the total efficiency increase with increasing the flow rate, for all experience the was the volume flow rate is 5L/min minute and solar radiation was 1000 w/m^2.

Keywords: PV/T System, PV Module, (Electrical, Thermal) Efficiency, Thermal Collector Channel

1. INTRODUCTION

Solar technology is mainly broken into two systems; photovoltaic energy that converter the energy of the solar photons into (Electrical Energy), and thermal energy that transforms solar energy into (Thermal Energy). The thermal collector is one of the main components of the solar system. In the photovoltaic thermal system PV/T system, the thermal collector was heated by the incoming heat from the sun, where this heat is absorbed and transferred to the working fluid. In the photovoltaic thermal system, the system consists of photovoltaic panels (PV) that convert solar irradiance into electrical energy, which were connected by the thermal collector to obtain the photovoltaic thermal system (PV/T). The coupling between the photovoltaic and thermal collectors in the one integrated system is also known as a hybrid system to producing simultaneously both the (Electrical, Thermal) energy[1]. The hybrid system has many advantages compared to separately designed PV or thermal collector systems, including high total energy conversion efficiency, low cost, and less space needed.Many scholars have also performed theoretical and experimental experiments on the PV / T method, where [2]studied the flat plate of the photovoltaic thermal system and explored the effect of combining heating and photovoltaic power systems on the home climate. By [3], analyzed of PV/T system using the Hottel–Whillier model, and [4] explained numerical methods that predicted the performance of (PV/T) fluid and air in a flat plate collector. The research [5], a study presented the effect of the depth channel, the length of the covered absorber plate region, and the volume flow rate on the PV / T system performance.

Recently, a lot of scientific research and manufacturers have been interested in developing solar panel technologies that have focused on increasing the effectiveness of the PV/T collectors. PV/T system as a flat plate thermal collector can be classified into the (liquid) flow (PV/T) system, a mix of (liquid/ gas) flow PV/T system and (gas) flow PV/T system, depending on the type of working fluid used. While the height thermal conductivity for both working fluids and absorber thermal collector has always been the main objective in the development and improving heat transfer, performance, where the modifying and contraction of many engineering equipment by increasing the effectiveness of this equipment such as electronic devices and heat exchangers.

A series of comparisons have been made between different PV/T design patterns and different thermal system models [6]. In general, their experiments studied the sealed, exposed PV/T system and thermal collector with and without a heat pump. Their studies showed that the use of PV/T for low-temperature of (ground storage) combined with a (heat pump), and exposed (PV/T) demonstrates increased performance.

Research experimentally tested the efficiency of the solar PV / T system[7]. Numerical computations were used to carry out climate data and configuration parameters for the experimental integrated photovoltaic thermal system (IPV / T S). A daily thermal efficiency simulation study expected about 58%, Which was similar to the experimental value (61.3%) obtained [8]. They found that due to the addition of the thermal absorber energy provided by the water flow, the total thermal efficiency of the PV/T system increased from 24 to 58 percent.

A researcher designed and investigated a PV / T system consisting of the PV unit and a thermal collector absorber complex to collect energy at a geographical location in Cyprus. For this practical study, they only used two PV modules with an area of about 0.6 m^2. PV panels absorb significant amounts of solar radiation which generates unwanted heat. Thus the loss of electrical energy generation in the photovoltaic panels has been well compensated by significant gains in the thermal energy collected from PV panels by circulating water [9].

Bernardo et al. [11] assess the effectiveness of (PV/T) system Used to test the (PV / T) outputs in various terrain in a verification simulation model. This method included comparing the effectiveness of the PV/T system with the conventional PV unit that works side by side with it. The obtained results from the PV/T system are 6.4% for (Electrical Efficiency), 0.45% for (Optical Efficiency), and 1.9 W/m^2 °C for (U-value). These values were less than the values of Standard Test Condition (STC) of the PV panel and Flat Plate Thermal Collectors (FPTCs).

Chow et al. [12]assed the annual performance of the building integrated PV/T system as a water-heating and improving the electrical energy of PV cells in the Hong Kong city. The performed predictions with the use of the (Numerical Simulation) and validated with the experimental results under forced and natural circulation modes. Modeling results indicate that the PV/T system performs more efficiently under natural convection circulation mode than the forced convection circulation mode because the (Pumping Power Consumption) can be saved. The obtained average yearly (Thermal Efficiency) was 37.5%, while the photovoltaic cells conversion efficiency was 9.39%. The recovery period for the project is estimated at 14 years.

In this paper, the development of the thermal collector of (PV/T S) is motivated by its capability to provide higher efficiency than traditional PV modules. This experimental study highlights the possibility and performance of (PV/T) system on producing two applications, whereas the electricity generation and also the water heating unit is compiled together and yield simultaneously.

The objective of this paper is to study the cooling performance of the thermal collector channel working by water as base fluid to remove the heat from the PV/T system and improving the efficiency of the PV module. This paper's description is as follows. In Section 2, the (PV/ T) device configuration is defined. An evaluation of the performance is provided in Section 3. In Section 4, the findings are presented and the conclusions are outlined in Section 5.

2. CONFIGURATION OF (PV/T) SYSTEM

The cooling of the base (PV/T) system which uses the water as working fluid consists of required and appropriate equipment to reduce PV panel temperature. The systems first and the main part is the PV module to be installed and cooled at system startup. The second and main part is the channel fluid flow collector, which is installed on the backside of the PV panel. The third part of the system contains water guides to the base of the (PV/T) system. The fourth part is the pump used to pump the water through the thermal collector channel, and the finish fifth part is the sun simulator consists of 12 lamps of halogen the capacity of each one is 500W installed in the steel structure and placed above the (PV/T) panels system 1mof distance, and the air is supplied on the PV / T system at a velocity of 1 (m / s) by an axial fan. The entire system was installed on a steel structure that can be moved at any height and any angle, the photograph of the experimental setup is shown in Figure 1. The schematic diagram of the complete experimental setup is shown in Figure 2. This unit's specifications are given in Table 1. The electrical properties of the PV panel given by the manufacturer are shown in Table 2. While Figure 3 and Figure 4 showed the Geometric shape of the thermal collector channel and PV module respectively.

1- PV/T system.
2- PV module.
3- Halogen lamps.
4- Voltage regulator.
5- Solar power meter.
6- Thermocouples wires.
7- Data logger.
8- PC.
9- Variable resistance load.
10- Clamp meter measurement.
11- Uno Arduino measurement device.
12- N.F. Heat Exchanger.
13- N.F Storage tank.
14- DC- solar pump Circulation.
15- N.F Flow meter.
16- DC Power supply.
17- Voltmeter.
18- Constant temperature bath tank.
19- AC- pump Circulation.
20- Water flow meter.
21- Junction wires to measuring electrical DC.
22- AC Power supply.
23- Steel structure.

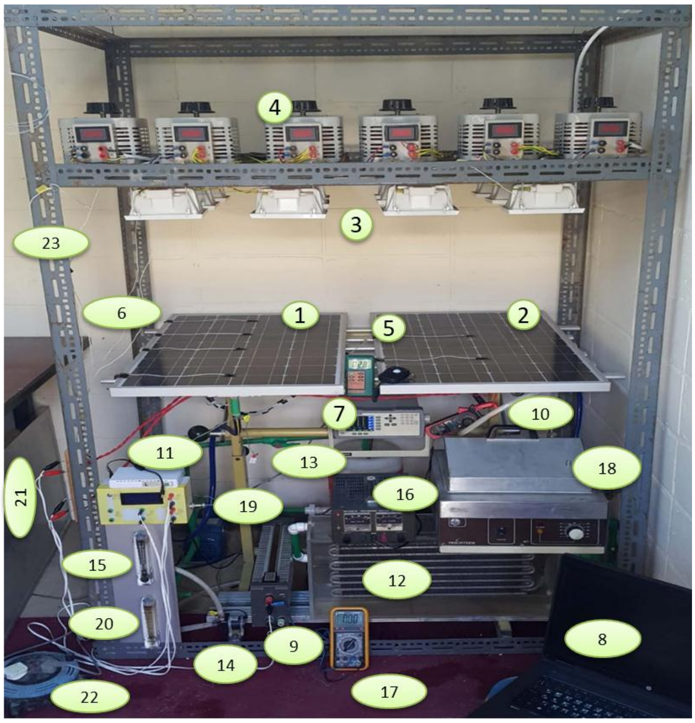

Figure 1. Photograph of the Experimental Rig Setup of the PV/T System with its all Parts

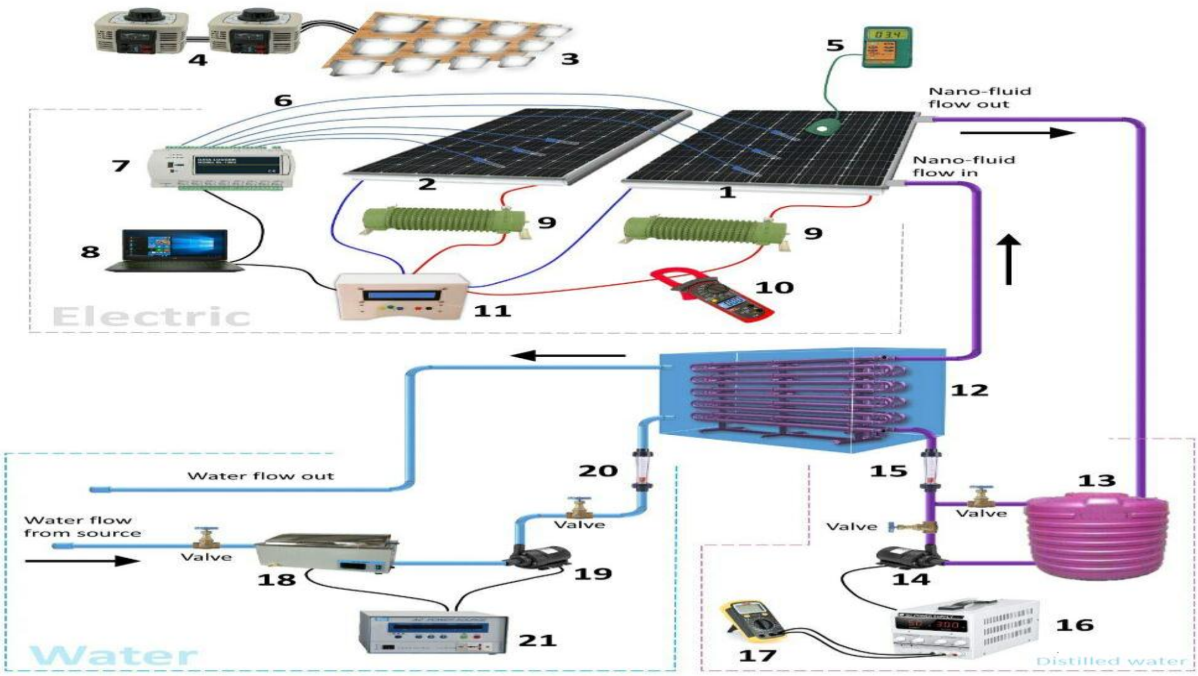

Figure 2. Schematic Diagram of the PV/T System with its all Parts

Table 1. Specifications of Solar Collector of the PV/T System

No.	Components	Dimensions
1	Effective area (m^2)	0.4
2	Insulation thickness (mm)	18
3	Number of guides	66
4	Collector material	SolidInsulation Foam
5	Width collector (m)	0.5
6	Length collector (m)	0.8
7	Height of water guide(mm)	3
8	The diameter of the water guide(mm)	10

Table 2. Typical Electrical Characteristics of Transparent PV Module

No.	Electrical performance under STC	Dimensions
1	Type	Mono-crystalline silicon
2	Cell dimension (mm)	62.5x125
3	Number of cells	36
4	Fill factor	0.78386
5	Open circuit voltage (V)	20.8
6	Short-circuit current (A)	3.68
7	Maximum power voltage (V)	17.9
8	Maximum power voltage (V)	3.35
9	Cell efficiency (QUOTE %)	15
10	Tempered glass thickness (mm)	3
11	Effective area (m^2)	0.4

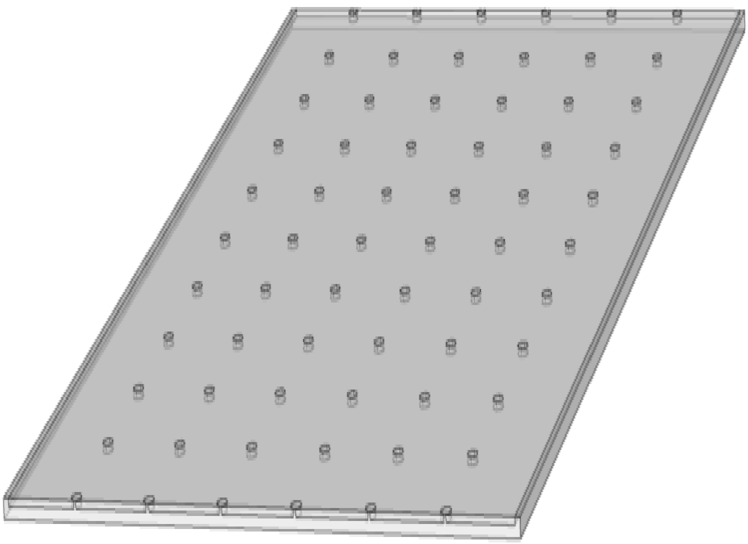

Figure 3.Geometric Shape Design of Thermal Collector Channel Including Water Guides

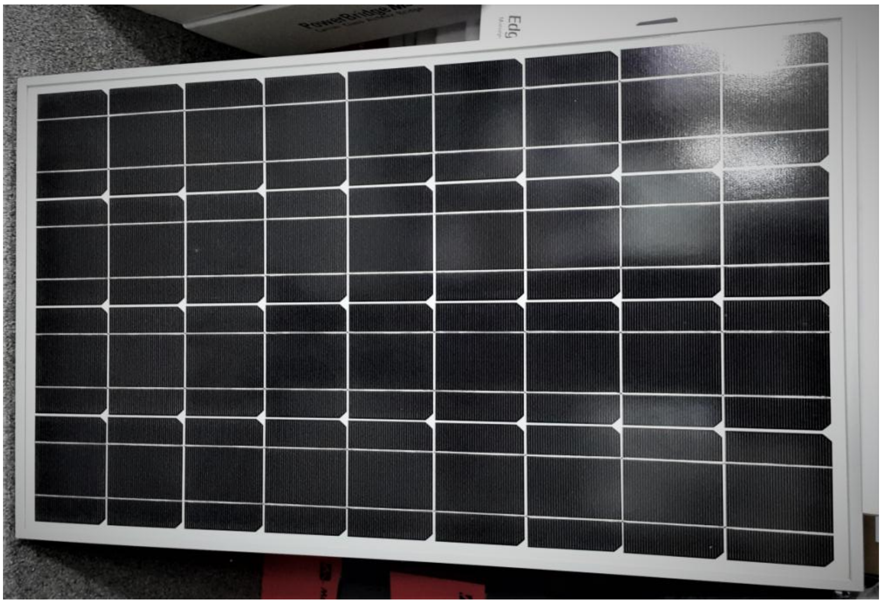

Figure 4. Photographed of Transparent PV Module

The water flow channel is the main and important parts of the (PV/T) system and which fixed on the back base of the PV panel. The dimensions of the water flow channel have been carefully chosen according to the dimensions of the photovoltaic panel, where use the best temperature distribution for PV panel using the thermal camera is used to obtain the best heat exchange process with water as shown in Figure 5, where the inside of channel a water guides and thermocouples to measure the temperature as shown in Figure 6. Channel length (800mm), width (500mm), thickness (15mm), height (18mm) from the base of the PV unit to the base of the channel. The channel material made from foam was very light with good heat insulation. The entire channel surface is coated with a thermal insulation material (Epoxy wax) to be more fixed and to avoid leaks affecting the surroundings. At the terminals of the channel, holes are designed to inlet and outlet the water flow, with use water pump.

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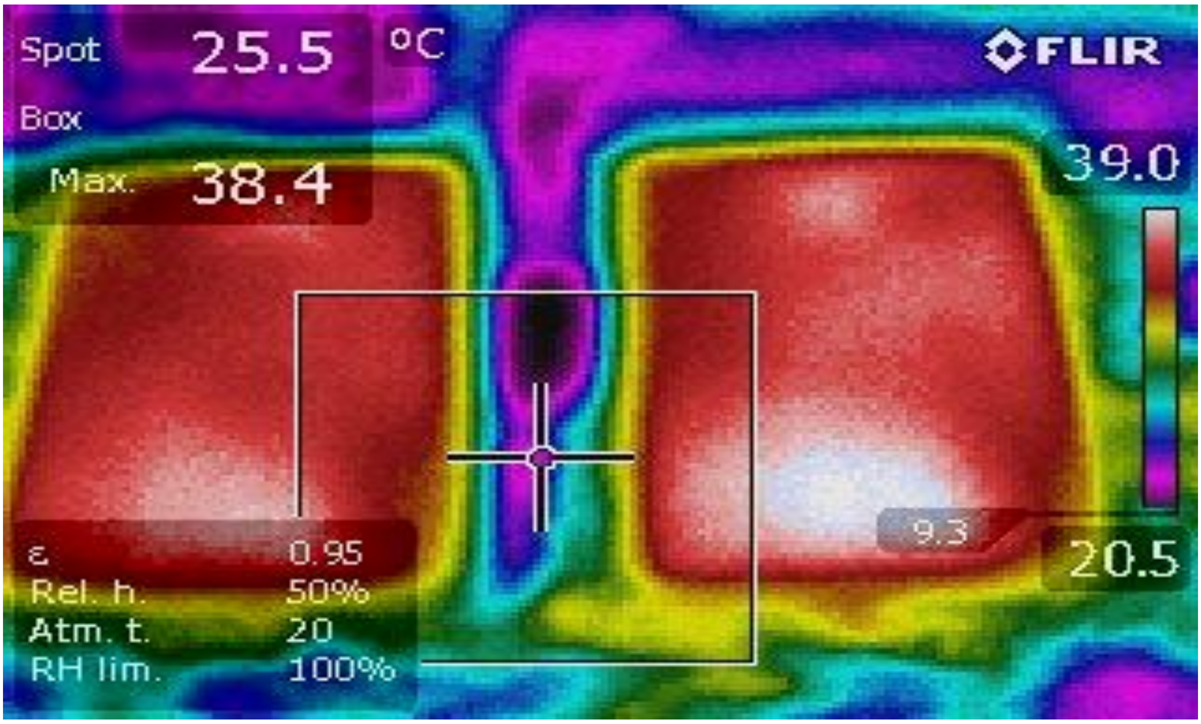

Figure 5. Real Thermal Image of Mono-Crystalline PV Module

Figure 6. Fluid Collector Channel with PV Module

On other hand the, the PV/T system setup also includes the data logger connecting with 14 K- type of thermocouples sensors using to reading the temperature at any position, then they are connected directly with the PC system to collect data from the practical results. In all areas of the collector device, a silicone gel and aluminium adhesive are used to plug a leak at any region.The procedure is carried out in the laboratory with variable parameters that are manipulated.The solar simulators have a solar irradiance intensity ranges from 500 W / m^2 to 1000 W / m^2. The flow rate of fluid mass often ranges from 1 L/ min to 5 L / min. During the tests, the following receptive parameters were measured:

3. EVALUATIONOFCORRESPONDINGDATA

The electrical efficiency of Cells (η_c) indicates the maximum power of the PV module, according to the amount of absorbed solar irradiance by the solar cells, where it can be expressed in the equation below as the following [13].

$$\eta_c = \frac{P_{\max}}{G \times A_c} \quad (1)$$

Where $\boldsymbol{\eta}_c$ is the (electrical efficiency), $P_{max}$is the (maximum electrical power), G (W/m^2) is the (solar radiation), A_c(m^2) is the (area of collector).

For expression of electrical efficiency (η_{el}) and according to of the temperature is given for PV panel, will be the equation of electrical efficiency as below [14]:

$$\eta_{el} = \eta_r \left(1 - \beta\left(T_c - T_r\right)\right) \quad (2)$$

Where $\eta_{el}$is the (electricaefficiency) of PV module (η_{el}0.15), β is the [temperature coefficient (β=0.0045^{o}C)], T_C(^{o}C) is the (cell temperature) and T_r(^{o}C) is the (reference temperature).

To have the largest volume of water vortices that travel directly to the base of photovoltaic cells to collect heat from it, the use of water guides that lead the water to the base of the photovoltaic cells:

$$Q_u = m^{\bullet} Cp(T_o - Ti) \quad (3)$$

Where $\dot{m}$= mass flow rate (Kg/s), Cp= specific of heat for working fluid (J/kg K), and Ti = fluid inlet temperature (K) and To = fluid outlet temperature (K).

Hottel-Whillier equations describe the difference between the absorber solar radiation and the thermal losses [14]:

$$Q_u = A_c F_R \left[S(\tau\alpha) - U_L\left(T_i - T_a\right)\right] \quad (4)$$

Where Ac = area of collector (m^2),FR = flow rate factor, S=absorbed of solar energy (W/m^2), U_L = overallheat loss coefficient of collector (W/m^2 K), Ti =inlet temperature of fluid (K), Ta = ambienttemperature (K),

$$S = (\tau\alpha) G_T \quad (5)$$

The flow rate coefficient (FR) can be calculated as below, where F' is the corrected fin efficiency, can be neglected, and taken equal (one) as no fin.

$$FR = \frac{m^{\bullet}C_p}{A_C U_L}\left[1 - \exp\left(-\frac{A_C U_L F'}{m^{\bullet}C_p}\right)\right] \quad (6)$$

For total Overall heat loss coefficient (UL) obtained from [15], and can be written as below:

$$U_L = (\alpha \cdot \tau \cdot I_{(t)} + \eta_c \cdot I_{(t)}) / (T_c + T_a) \quad (7)$$

The thermal efficiency of the (PV/T) system is described as follows, obtained from [16]:

$$\eta_{th} = \frac{Q_u}{G \times A_c} \quad (8)$$

4. RESULTS AND DISCUSSION

The performance and effectiveness of the PV/T system have been determined by the electrical and thermal characteristics. Applied all experiments on the final design of the PV/T system have been segregated into (electrical, thermal) efficiency. The testing has been performed in Al-Najaf Technical Institute-Iraq (Indoor Test Condition) for the PV/T system under a constant of (Solar Radiation) and (Ambient Temperature) respectively with different volumetrically flow rates to predict in the temperatures of [PV module, (PV/T) system and water Inlet and Outlet] at the testing, for PV module, PV/T system can be calculated the (electrical, thermal) efficiency.

A mass flow rate that passes through the collector by designed channels directly by the CNC machine, therefore, affects the cooling of the PV unit and increases the convection heat transfer coefficient. This effect due to an increase in the volume flow rate to the absorber collector and can be seen in Figure 7 and Figure 8 and summarized in Table 3. The test has been conducted with indoor conditions, whereby the temperature of input T_{in} and ambient $T_a$were constants for every test. The volumetric flow rates comprised of 1 to 5 L/min, have been used in this testing which was later applied with solar radiations for indoor test conditions, were selected (500,600,700,800,900 and 1000 W/m^2). The results showed that increasing the volumetric flow rate simultaneously decreased the temperature of base and surface (T_b, T_s) respectively for the PV/T system, besides, decreased the temperature of the outlet water (T_{out}) at any solar irradiance levels. For the same mass flow rate.

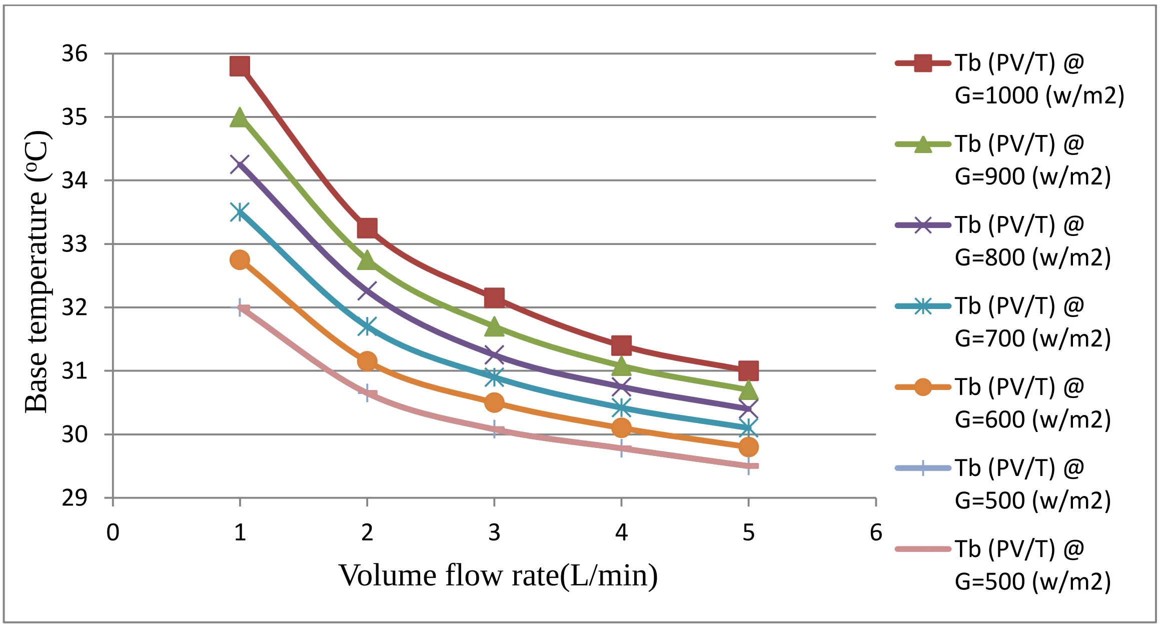

Figure 7.Changes of Base Temperature (T_b) of Water PV/T System Over Volume Flow Rates Under Various Solar Irradiance

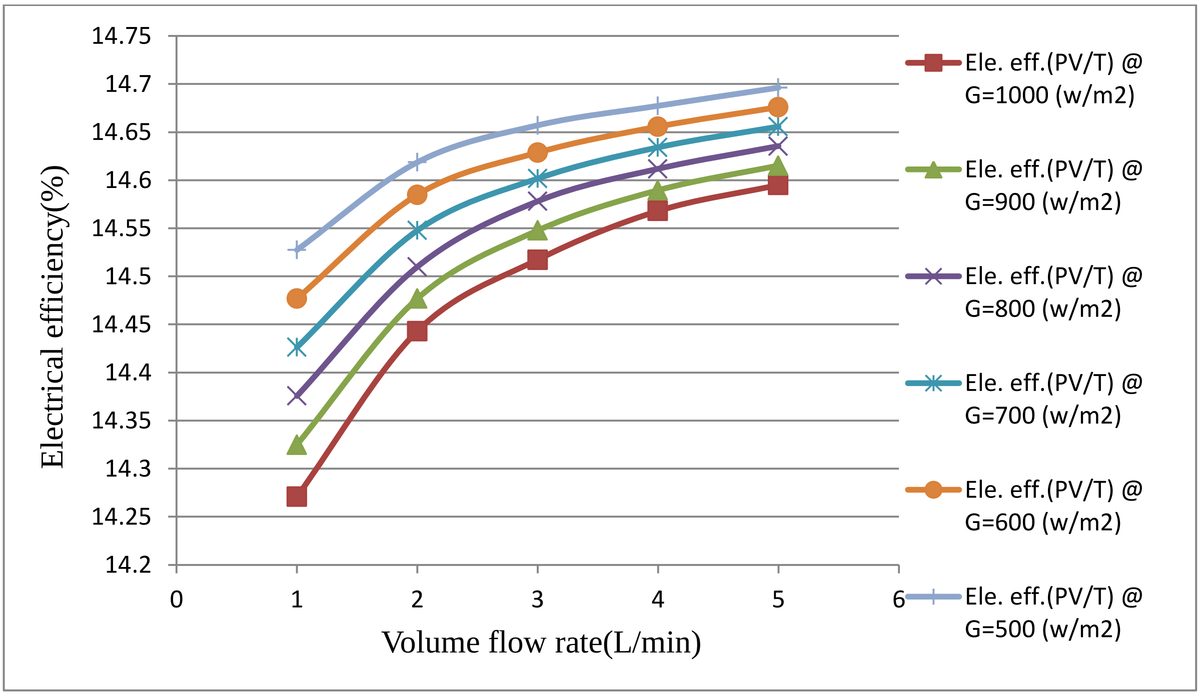

Figure 8.Changes of Electrical Efficiency (η_{el})of PV/T System Over Volume Flow Rates Under Various Solar Irradiance

This case can be seen clearly at a lower mass flow rate level. As shown in Figure 7 of the PV/T system at volume flow rate 1 to 5 L/min at solar radiation of 500 W/m^2 indicated temperature decreased from 32^{o}C to 29.5^{o}C simultaneously increased the electrical PV/T efficiency from 14.53% to 14.7% as shown in Figure 8. When the solar radiation increased up to 1000 W/m^2, the temperature decreased from 35.8 ^{o}C to

31°C as shown in Figure 7 and the electrical (PV/T) efficiency increased from 14.27% to 14.6% as shown in Figure 8.

Table 3. Results of (T_b) and (η_{el}) for PV/T Water System Under Various Mass Flow Rates and Solar Irradiance

ṁ (L/min)	500 (w/m²)		600 (w/m²)		700 (w/m²)	
	T_b (°C)	η_{el} (%)	T_b (°C)	η_{el} (%)	T_b (°C)	η_{el} (%)
1	32	14.53	32.75	14.48	33.5	14.43
2	30.65	14.62	31.15	14.58	31.7	4.55
3	30.08	14.66	30.5	14.63	30.9	14.6
4	29.78	14. 8	30.1	14.66	30.42	14.63
5	29.5	14.7	29.8	14.68	30.1	14.66
ṁ (L/min)	**800 (w/m²)**		**900 (w/m²)**		**1000 (w/m²)**	
	T_b (°C)	η_{el} (%)	T_b (°C)	η_{el} (%)	T_b (°C)	η_{el} (%)
1	34.25	14.38	35	14.33	35.8	14.27
2	3 .26	1 .51	32.75	14.48	33.25	14.44
3	31.25	14.56	31.7	14.55	32.15	14.52
4	30.75	14.61	31.08	14.59	31.4	14.56
5	30.4	14.64	30.7	14.62	31	14.6

PV/T system performance may be depicted by combining efficiency expression. Is comprised of the (η_{th} and η_{el}), these efficiencies usually include the useful (thermal and electrical) gain of the PV/T system. The total efficiencies, which is known as combined PV/T efficiency (η $_{combined}$) have been used to assess the (Overall performance) of the system. Based on experiments carried out on the final thermal collector, it has been proved that all the efficiencies increased when the mass flow rate increased. Therefore, will be the combined PV/T efficiency increased concurrently when the volumetric flow rate increased. Figure 9, Figure 10, and Figure 11 illustrate the variation in the traditional PV module efficiency and (PV/T) efficiency (η_{el}, η_{th}) at the volumetric flow of 5 (L/min). The results have been shown that the traditional PV module efficiency without cooling varied between (10.7 to 12.9)%, while the electrical PV/T efficiency varied between (14.37 to 14.595)%, the thermal PV/T efficiency (89.886 to 94.514)%.

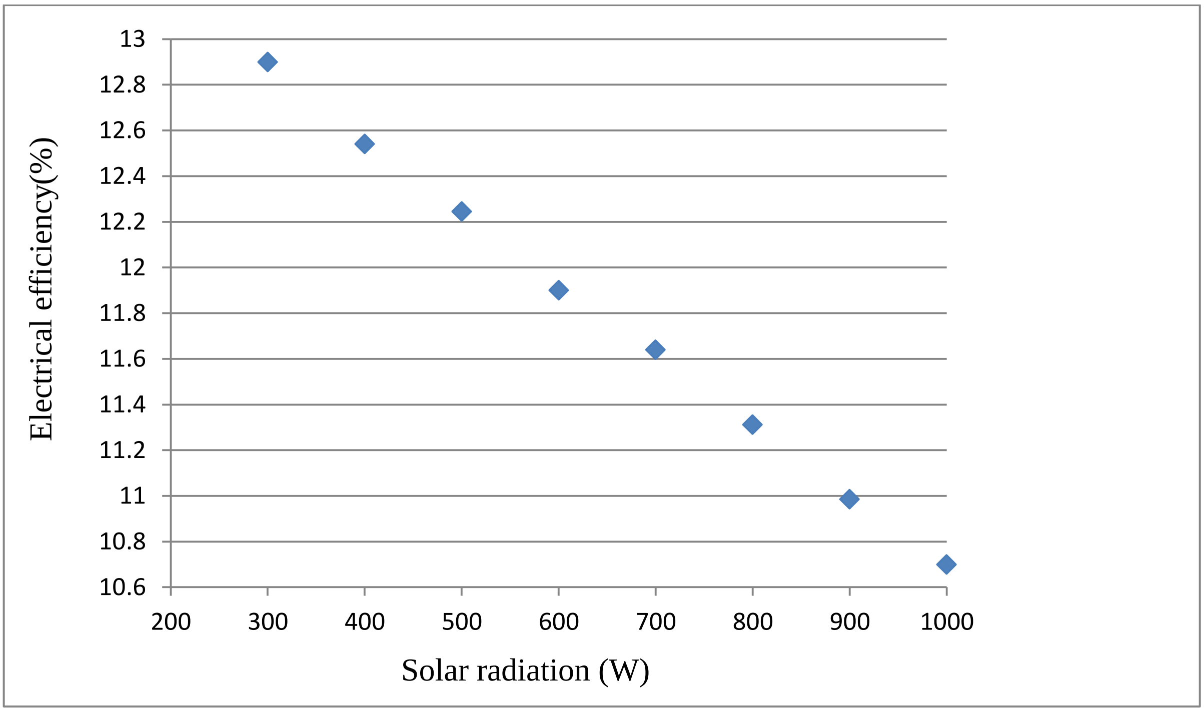

Figure 9. Electrical Efficiency (η_{el}) of the PV Module Without Cooling Over Several Solar Irradiance at Volumetric Flowrate of 5 (L/min)

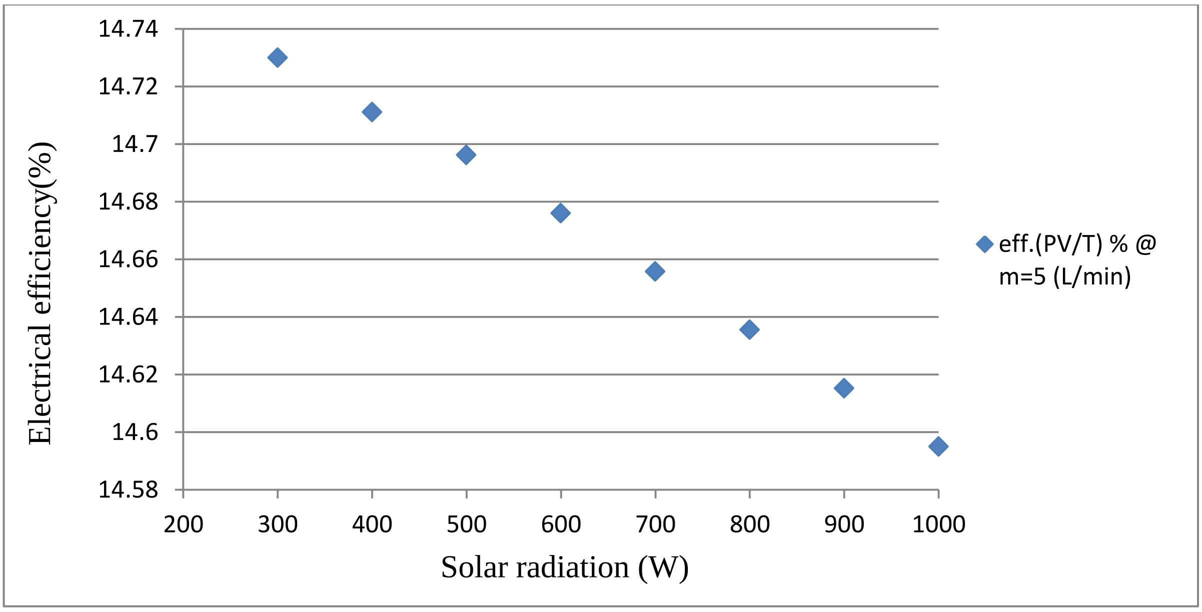

Figure 10. Electrical Efficiency (η_{el}) of the (PV/T) Water System Variation with Different Solar Irradiances at Volumetric Flowrate of 5 (L/min)

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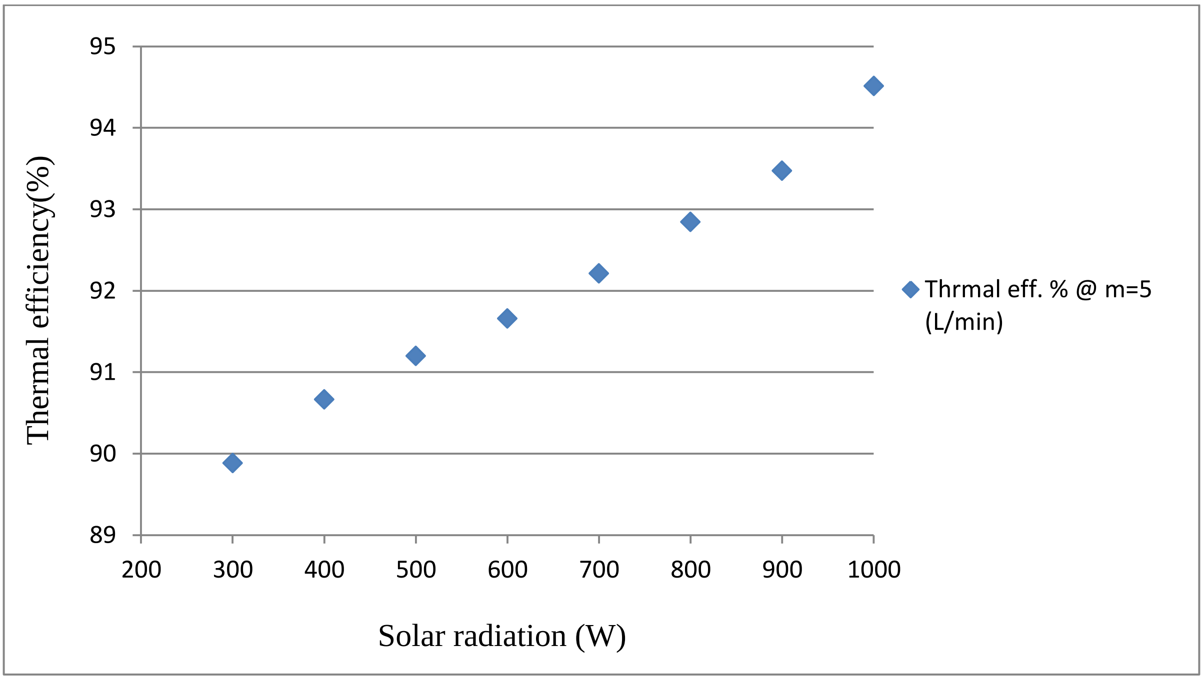

Figure 11.Thermal Efficiency (η_{th}) of PV/T Water System Variation with Different Solar Irradiances at Volumetric Flowrate of 5 (L/min)

5. CONCLUSIONS

This research is a test of the water PV / T design method as the heat exchanger medium. The indoor test conditions for the experiment are prepared for the thermal collector channel connected to the PV unit. At a controlled surrounding condition, the experiment is conducted under a solar radiation setting from 500 W/m^2 to 1000 W/m^2. The fluid volume flow rate also is varied from 1 L/min to 5 L/min.

The analysis of this study is focused on the (electrical, thermal) efficiency. The calculations and relations are originally employed from the Hottele-Whilliere-Bliss equation. Where the maximum increase in electrical efficiency in PV / T system is (36.78%). While the highest electrical and thermal efficiency calculated from the study was 14.595%, 94.514% respectively.

The evaluation of the (thermal, electrical) efficiency for PV/T system. The increment of solar intensity contributes to increasing the PV cells temperature and outlet water temperature from the PV/T system, And therefore enhancement (thermal, electrical) energy of the whole system. Volume flow rate plays an important for the cooling effect on PV solar cells by reducing both the PV module base temperature and outlet water temperature from the thermal collector channel.

It was found that the Channel collector with round liquid guides linear distribution [H=3mm, d=10mm] contribute to rising thermal and electrical efficiency compared to the other shapes of thermal collectors due to the more flow over the round liquid guides surface contacting underneath the PV module.

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