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Experimental Study to Improve the Exergy Performance of Water Based Photovoltaic Thermal Collector (PV/T System) Using Water Guides

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Abstract. Photovoltaic panels can convert solar irradiance into (electrical and thermal) energy. The PV / T system was developed, created, and its performance tested in this experimental analysis. The experiment was performed with flow rate of water from 1 L / min to 5 L / min on the PV / T collector channel. The movement of water with the guides allows the PV / T collector to improve thermal heat transfer convection. The output of (electrical and thermal) energy increase with increase of radiation. The PV / T system performance varies with different of volume flow rate that was reported for (1-5) L/min in this experiment , where the total energy increase with increasing the flow rate. Energy and exergy tests is performed, and findings show the maximum electrical and thermal energy output for water-based PV / T system is 58.38 W and 465.8W at solar radiation 1000 W/m^2. Meanwhile the maximum electrical and thermal efficiency of PVT system are 14.595%, 94.49 % respectively at 5 LPM . While the maximum electrical percentage improvement in PV / T systems electrical output by the use of guides device is (36.78%), compared with traditional of PV module.

Keywords: (Electrical and Thermal) Energy analysis, Exergy analysis, PV module, PV/T system

1. INTRODUCTION

In light of greenhouse gas emissions and the depletion of fossil fuel resources, solar energy is one of the most promising sources of renewable energy. Most resources, however, come from the fossil-fuels that pollute the atmosphere by greenhouse gas emissions. The fossil-fuels are often considered non-renewable energy [1- 4]. As a result , researchers continued to explore clean and environmentally friendly energy as alternatives to environmentally polluting fossil fuels, solar panel manufacturing technologies reached a threshold of 20 percent of electrical efficiency, while increasing this energy would result in increased the PV module temperature. PV panels withstand temperatures at a certain amount, but if the panels are overheated above the acceptable limits, the PV module electrical efficiency will decrease [5]. Therefore, to achieve good conversion efficiency, the temperature of the PV unit should be kept as low as possible. Researchers [6, 7] used the air as a working fluid to cool the photovoltaic panels to increase the electrical quality. while researchers [8, 9] used water as a working fluid to cool it.

The previous researches [8] and [9] provided a related analysis of the principle of hybrid techniques for thermal PV assembly. They proposed and analysed nine separate prototypes, ranging from complex to plain, to analyse the potential return. They concluded that the channel thermal collector was designed with a thin metal plate comprising tubes to provide the maximum overall efficiency as transparent construction and put under PV module.

A flat-plate to be tested as a solar collector model, integrated with solar cells, was presented in the theoretical study [10]. They find for the PV/T system mixture of both providing around 60-80 percent performance by designing the PVT system's various algorithms to understand and forecast the (thermal efficiency) and (electrical energy) quantity.

The analysis of the PV/T system was developed using a solar photovoltaic polycrystalline module attached to the thermal collector plate [11]. To increase the coefficient of heat transfer and thermal conductivity, use the flat plate collector directly touching the photovoltaic module using the thermal grease. The layers from the insulating material were then placed under the PV / T panel and set with frame.

Using polycarbonate-made thermal collector built as the corrugated plate. Thus, water will flow into the ripple channel in the plate structure. The research was introduced for the hybrid PV / T system, which used water to absorb heat as worked the cooling working fluid with natural convection circulation, the thermal collector model like the flat box[12]. With approximately 40 percent of the daily contribution of thermal efficiency, the system shown a combined efficiency of 50 percent.

Therefore, in recent years, technology water cooling of the PV module have attracted more applications and increase in the absorbed of heat from the PV module and used in various industrial applications due to their high thermal conductivity and high heat transfer coefficient.

2. METHODS AND MATERIALS

Figure 1, demonstrates the configuration of the PV panel and PV / T device during the solar simulator experiment under indoor conditions. A typical mono-crystalline 60 W photovoltaic module represented an unglazed sheet of flat plate fixed to the top. The thermal collector channel made from thermal insulated material (Foam), which included a water guides to enhance of heat transfer, then placed underneath the PV module to water flow is inserted . The dimensions of PV/T system surface is 500 mm wide and 800 mm long. The K-type thermocouple was used to obtain the inlet and outlet fluid temperature from the data logger, also and the surface and base temperature of the PV panel. During the experiment the temperature change can be measured and reported in short time (5 minute) timer under steady state conditions. The average falling of radiation from the sun simulator on the PV module and PV/T system is measured by pyranometer (Solar-meter) device. The flow meter (2-18 L / min) is mounted at the fluid inlet opening to control on the volume flow rate.

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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.

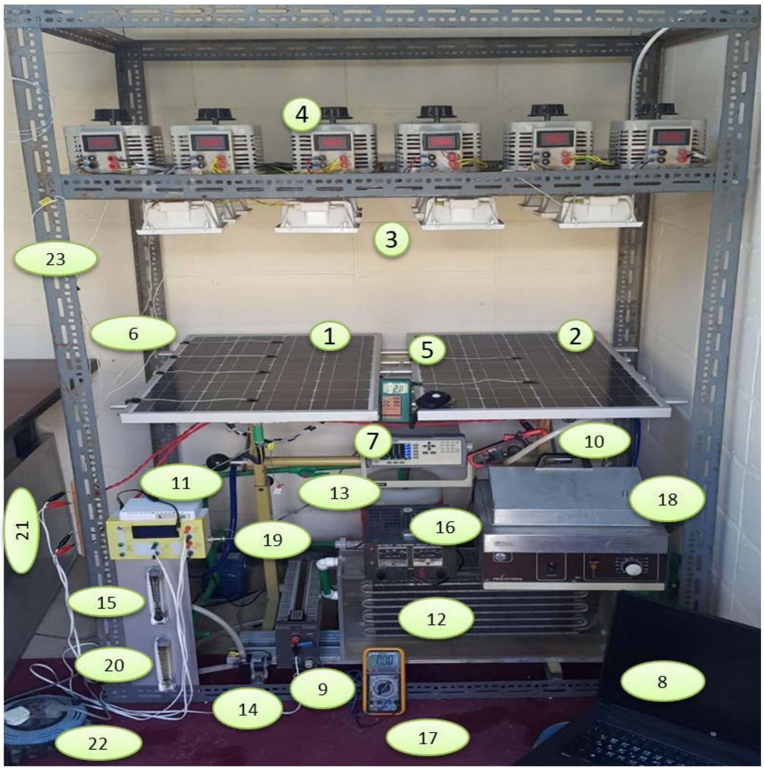

Figure 1. Set-up of Water Based PV/T Collector Under Solar Simulator

The experiment was performed using solar simulator under indoor test conditions of laboratory. The simulator consists of 12 halogen lamps with a power of 500W each, and the solar radiation intensity is controlled by a variable voltage controller. Before collecting data, the PV / T system was exposed to solar radiation of 1000 W / m2 for 30 minutes to ensure that the system's conditions reached a steady state. The change in voltage is recorded at different volume flow rates using electric loads. The water volume flow rate was set at a range of 1 to 5 L / min. The temperatures of the system was record by thermocouple connected in the Data Logger device for every 1 minute and later used to calculation the (electrical and thermal) efficiency for the system. The water was forced to flow around the PV / T system using the 8W power DC pump and heat exchanger used in the closed loop system to cool the fluid.

The measurement of (Energy and Exergy) was used to determine the (Overall Efficiency) of the PV / T system. The PV / T system energetic and exergetic analysis tests quantity and quality, respectively. Thermal efficacy and electrical efficiency is main part of the PV energy research system. The ratio of electrical and thermal energy gain for the PV / T system to the incident solar radiation know by efficiencies. It is possible to express the (Total Efficiency) of PV / T as below.

$$\eta_{Total} = \eta_{el} + \eta_{th} \quad (1)$$

From the below equation can be calculated the thermal efficiency:

$$\eta_{th} = \frac{Q_u}{G \times A_c} \quad (2)$$

Also from the below equation can be calculated the useful thermal energy:

$$Q_u = \dot{m}_f \, Cp(T_{f,out} - T_{f,in}) \quad (3)$$

Where $\boldsymbol{\eta}_{el}$ is the (electrical efficiency), $\boldsymbol{\eta}_{th}$ is the (thermal efficiency), G (W/m^2) is the (solar radiation), m_f (L/min) is the (mass flow rate) of fluid, C_p (J/kg K) is the (specific heat capacity) of fluid and $T_{f,in}$, $T_{f,out}$ (^{o}C) are the (inlet and outlet temperatures) of fluid. therefore, considered the (electrical efficiency) of the PV module, is a function of the temperature of the PV module defined by [13, 14]:

$$\eta_{el} = \eta_r \left(1 - \beta\left(T_C - T_r\right)\right) \quad (4)$$

Where η_r is the (reference efficiency) of PV module (η_r = 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). The rate of electrical energy generated from PV/T system is given as

$$\dot{E}_{ele,net} = \eta_r \times A_{PV} \times I \quad (5)$$

Considering the electrical energy is a high-grade from of energy gain, the net electrical energy should be converted to the thermal energy using conversion efficiency of thermal power plant C_{Power} as follows:

$$\sum Q_{u,overall} = \sum Q_u + \frac{\sum \dot{E}_{el}}{C_{Power}} \quad (6)$$

Where E_{el} (W) is the (electrical power), C_{Power} can be taken as (0.38) for good quality of coal.

Thermal energy does not generate work, unless a temperature differential occurs between a heat source and a heat sink,, while electrical energy does turn fully into work. To include the Carnot efficiency for a qualitative and systematic hybrid performance assessment is in the exergy review. The total performance of the PV / T system's energy can be expressed in the form given.

$$\sum \dot{E}x_o = \sum \dot{E}x_{th} + \sum \dot{E}x_{PV} \quad (7)$$

Where

$$\dot{E}x_{th} = Q_u\left(1 - \frac{T_a + 273}{T_o + 273}\right) \quad (8)$$

and

$$\dot{E}x_{PV} = \eta_C A_C N_C \dot{E}x_{in} \quad (9)$$

Where

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$$\dot{E}x_{in} = A_C N_C G\left[1 - \frac{4}{3}\left(\frac{T_a}{T_s}\right) + \frac{1}{3}\left(\frac{T_a}{T_s}\right)^4\right] \quad (10)$$

Where A_c (m^2) is the (area of collector), N_c is the (number of cells), Ex_o , Ex_{in} Ex_{th} Ex_{PV} (W) is the (outlet, inlet, thermal and electrical exergy), I (W/m^2) is the (solar radiation), T_a (^oC) is the (ambient temperature) and T_s (^oC) is the [sun temperature (T_s=5777K)], and from equation above, we can calculated the exergy efficiency.

3. RESULTS AND DISCUSSION

From this study it can be known how the change in solar irradiance and volumetric flow rate affects the performance of the PV / T system. The practical results for temperature variation (ambient, inlet, outlet, and PV) under varying volumetric flow rates are seen in Figure 2 and Figure 3. Decrease in the base temperature of the PV module as the volumetric flow rate increases. At 700 W / m^2 the minimum temperature of PV/T system was recorded at (1-5) L / min by compared to that the PV module is 30.1 ° C, while the temperature drop at 1000 W / m^2 is 31 ° C.

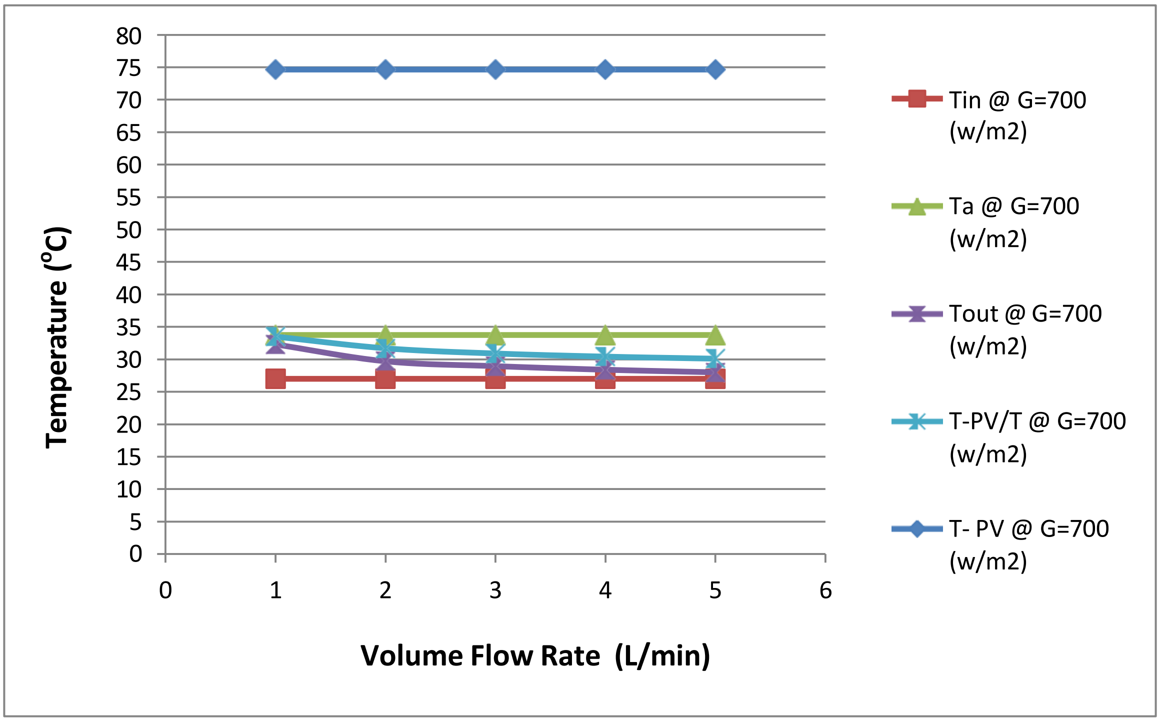

Figure 2. (Ambient, Inlet, Outlet, and PV) Temperatures for Water Based PV/T System Compared with PV Module Temperature for Solar Irradiance of 700 W/m^2

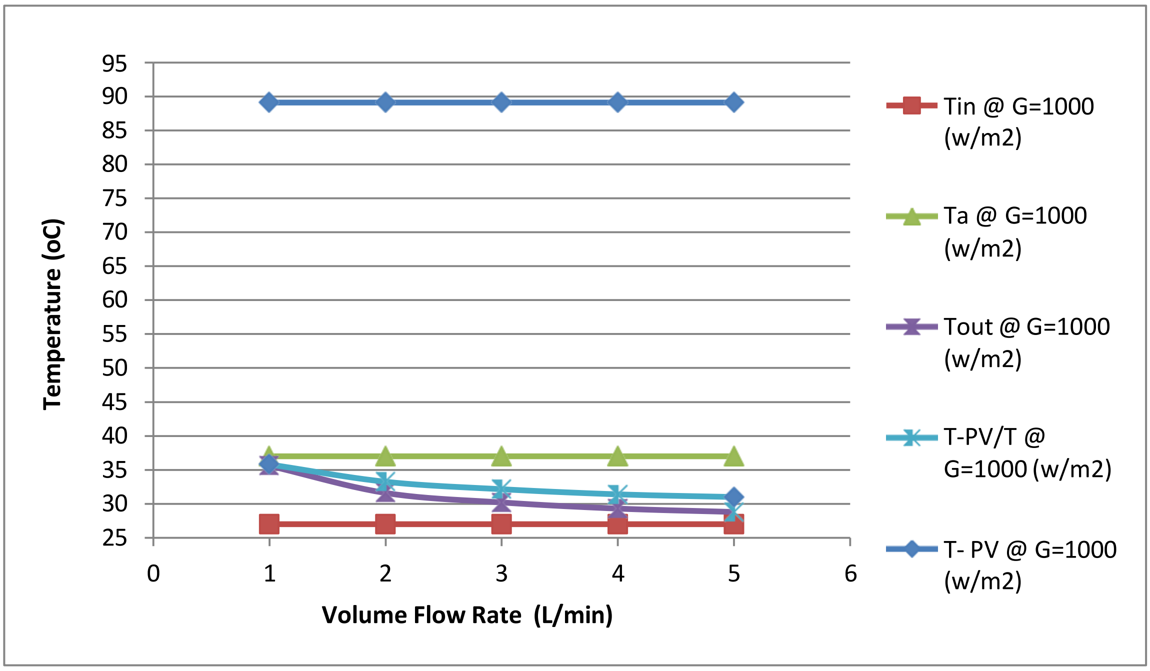

Figure 3. (Ambient, Inlet, Outlet, and PV) Temperatures for Water Based PV/T System Compared with PV Module Temperature for Solar Irradiance of 1000 W/m^2

Table 1 shows thermal, electrical efficiencies (η_{th}, η_{el}) calculated at solar radiation 1000 W/m^2 under volume flow rate range (1-5) L / min. The thermal efficiency produced from about 91.121% to 94.49%, while it produced 14.271% to 14.595% for electrical efficiency at 1000 W/m^2. The average thermal and electrical efficiency increase about 3.565% and 2.22% respectively at 1000 W/m^2 solar radiation and flow rate range (1-5) L / min. Results indicates that higher volume flow rate of cooling fluid increase the heat transfer rate from the surface of PV module to the passing fluid. The maximum electrical efficiency increase of PV/T system compared with traditional PV module from about 10.67 to 14.595% and the maximum percentage of enhance electrical efficiency is 36.78%, for 1000 W/m^2 and flow rate of 5 (L/min).

Table 1. Result the Energy Analysis of the Water Based PV/T System at Solar Irradiance of 1000 W/m^2

Flow rate (L/min)	η_{th} (%)	η_{el} (%)
1	91.121	14.271
2	93.24	14.443125
3	93.94	14.517375
4	94.294	14.568
5	94.49	14.595

The performance of (thermal and electrical) energy is determined using the equations (3) and (5), at 1000 W / m^2 of solar radiation and the flow rate range (1-5) L / min. The thermal and electrical output from about 444.9W to 465.8W and 57 W to 58.38 W as shown in Table 3. In this experimental study, applied work to the PV panel without a cooling as reference system. From Table 2, the (electrical power) of PV module is 42.68W at 1000 (W/m^2) of solar radiation. Increase in electrical power compared to the traditional PV module is 36.78% at 1000 W/m2 solar radiation and flow rate of 5 (L/min).

Tables 2. Result the Energy Analysis of the PV Module and PV/T System with Water Based Flow at Solar Irradiance 1000 W/m^2

Flow rate (L/min)	PV/T system		PV module	
	Thermal Power (W)	Electrical Power (W)	Thermal Power (W)	Electrical Power (W)
1	444.9146	57.084	-	42.68
2	457.527	57.7725	-	42.68
3	462	58.0695	-	42.68
4	464.373	58.272	-	42.68
5	465.7928	58.38	-	42.68

Table 3. Result the Exergy Analysis of Water Based PV/T System at Solar Irradiance of 1000 W/m^2

Flow rate (L/min)	PV/T system		PV module	
	Thermal Exergy (W)	Electrical Exergy (W)	Thermal Exergy (W)	Electrical Exergy (W)
1	-2.557	44.9947	-	47.5517
2	-8.3834	39.1683	-	47.5517
3	-10.72196	36.8297	-	47.5517
4	-11.9897	35.562	-	47.5517
5	-12.942	34.6097	-	47.5517

The exergy analysis was performed using equations (7) to (10) for 1000 W / m^2 solar radiation. The thermal and electrical exergy from about (-2.557 W to -12.942 W) and (44.99 W to 34.6 W) respectively for 1000 W/m^2 solar radiation and flow rate range (1-5) L / min, as shown in Table 3.

4. CONCLUSIONS

By integrating and expressing the efficiencies, the PV/ T system depicted of the outputs (water-based). The (electrical and thermal) efficiency of the PV / T system are included as a main objective. The (thermal and electrical) efficiency together use, which is known as PV/T efficiency was can be used to evaluate the overall performance of the system. Based on the tests carried out on the PV / T system thermal collector, both efficiencies have been shown to increase as the volumetric flow rate increase. Therefore, as the volumetric flow rate increased, the total efficiency (PVT efficiency) increase simultaneously. The water based PV/T collector produced the maximum thermal and electrical efficiency about 94.49% and 14.595%

respectively with 10.67% PV module electrical efficiency. On the other hand, the minimum PV/T thermal and electrical exergy about -12.942W and 34.6W respectively with 47.55 PV module electrical exergy.

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