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AN EXPERIMENTAL INVESTIGATION OF GLAZED FLAT PLATE PV/T HYBRID SOLAR COLLECTOR SYSTEM IN DUHOK CITY

SEMYANOMEDALYOUSIFI[*] andOMAR MOHAMMED ALI[**]

[*]Dept. of Energy Engineering, Technical College of Engineering, Duhok Polytechnic University, Kurdistan Region-Iraq

[**]Dept. of Mechanical Engineering, College of Engineering, University of Zakho, Kurdistan Region-Iraq

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ABSTRACT

This studycomprises anexperimental investigation of the hybrid photovoltaic thermal (PV/T)solar collector system. The performance of the photovoltaic(PV) panel is enhanced by reducing the temperature of the PV panel by passing cold water through copper pipes welded on a copper sheet plate as a heat exchanger behind the PV panel. The present work uses a flat metal plate of copper as an absorbent plate on the backside of the mono-crystalline PV solar panel. The present work has been validated by comparing the obtained results with previous experimental results from the literature, where fair agreement has been noted. The results display theperformance of the PV/T solar collector during the 2ndof November 2018 and it is achieved a maximum thermal efficiency 40.3%, with a commensurateelectrical efficiency of 14%,and the overall efficiency reached to 54.3%.

KEYWORDS:Photovoltaic thermal collector, Performance, Duhok climate, thermal, electrical efficiency.

2 INTRODUCTION

In the Kurdistan Region, of northern Iraq, energy demand has increased dramatically in the last decade due to population increase, and existing power generation is wholly dependent on fossil fuels, which amounts to burning the country's most lucrative export products, in addition to causingenvironmental pollution and exacerbating climate change(Yuan, Kang, Zhao, & Hu, 2008). The lack of adequate electricity supply and increased demand for energy have also made alternative energy an urgent and necessary requirement, but the lack of support from government, and investors, and the shortage of research and expertise in this field, are major barriers to the development and use of alternative energy sources, both in Iraq and in general.Solar energy is one of the best solutions to reduce energy consumption, and can be used to produce thermal and electrical energy in Iraq due to the daily average sunny periods ranging from 4.2 to 12.3 hours throughout the year,with a mean rate of up to eight hours per day in the Kurdistan,(Y. Al-Douri and F. M. Abed, 2016), (Aziz, 2013).

The daily average global radiation in Duhok reaches a maximum of 22.8 MJ/m^2/day in June and July, then it drops by December to a minimumof 5.3 MJ/m^2/day (Al-Douri & Abed, 2016). Solar cellscan convert only about 10-20% of solar radiation into electricity; some solar radiation is reflected back into the sky, while the remaining solar energy is turned into heat. The photovoltaic thermal (PV/T) collector offers us the opportunity to combine two systems to produce heat and electricity simultaneously in one place, with increased overall system efficiency. The 'waste' heat from electricity generation is used to heat the water or air inside the collector.This also cools solar photovoltaic (PV) cells, which are negatively affected by high temperatures, thus reciprocally increasing electrical efficiency (Razak et al., 2016).PV cells must be cooled to raise the electrical efficiency by passing cool water or air through the back side of the PV panel. Currently, the electrical efficiency produced from silicon-based PVs is about 12-16%,which may reach 19% under Standard Test Conditions STC: 1000 W/m^2, when cell temperature is 25°C (Kim & Kim, 2012). Hybrid collector systems have been found to beattractive and efficient in small buildings with heating loads in terms of economic efficiency,and passive cooling of PV panels is a

semyan.omed@dpu.edu.krd, omar.ali@uoz.edu.krd

suitable method for small and low thermal energy requirements (E. C. Kern & Russell, 1978).

Examples and tests of thermal and electrical performance have been discussed for hybrid collector systems as a function of collector design factors (Florschuetz, 1979).One-dimensional analyses have been developed by (Raghuraman, 1981)for air flat-plate and liquid PV/Tcollectors to predict the thermal and electrical performance of separatedevices. The peak value of the overall efficiency for the combined PV/T collectors reached 50% for liquid and 40% for air, which are basically lower values than for typical conventional solar thermal collectors.(He et al., 2006) investigated experimentallythe hybrid PV/T system using aluminum metal as an absorber plate with natural circulation of water. The results showed that the thermal efficiency is about 40% and electrical efficiency is9.87%.(Zagorska, Ziemelis, Kancevica, & Putans, 2012)are used (MWPVT- \ 1414) type of solar PV/T collectorduring the summer months from March 1 to November,and tested experimentally over 55 days. The resultsdemonstrated that the solar battery produced 0.418 kWh as an average per day. The highest temperature of cooling water reached 43°C, 16°C higher than the ambient air temperature.

(Erdil, Ilkan, & Egelioglu, 2008) studied experimentally a hybrid PV/T system and PVin a typical house in Northern Cyprus. They compared the two systems to reveal that the PV/T system loses 1% of the electricitygenerated. In contrast, there was an increase in thermal energy in the PV/T collected water. The measurements of electrical characteristics and preheating of water show that the hybrid PV/T system has attractive economic benefits. (Aste, Leonforte, & Del Pero, 2015) developed a mathematical model to estimate the thermal and electrical output of a glazed the PV/T collector is based on water innovated by the authors, and compared it with conventional PV module. The overall efficiency of the PV/T technology in general, is higher than the primary energy produced from a simple PV module. Given that the PV/T technology is capable of producing heat and electricity at the same time.

Experimental investigation of thehybrid PV/T based on waterwith and without phase change material (PCM) at different flow rates is studied by (Preet, Bhushan, & Mahajan, 2017).The results showed that the electrical efficiency of the PV/T-PCM and PV/T is higher than the conventional PV panel, and the greatest increment in the electrical efficiency is 10.66% with PV/T basedon water, and 12.6% with PV/T-PCM based on water,when the flow rate is 0.031 kg/s.(Alobaid, Hughes, Connor, Calautit, & Heyes, 2018)developed a mathematical model to calculate the performance of a PV/Tsystem.The results showed that the average thermal efficiency is 65% and the average electrical efficiency is 13.7%. Discussion of the instrumental factors in system performance and efficiency indicate that increment insolar cells temperature decreases electrical efficiency.

The experimental study of the present work is carried out with glazed PV/T collector using water as a medium fluid, prepared from heat exchangers (typically used for solar heating) and commercial PV modules. High transmittance glass with visible radiation is used to guarantee that the PV silicon cells generated electricity by receiving most of the available solar radiation, leading to increased heat in solar cells. The PV/T panel is tilted with 34.5° to horizontal, and faced south, to obtain maximum solar gain(Khadim, Mahdi, & Ubaid, 2014).

In general, literary references have studied and improved the hybrid PV / T system using different design methods experimentally and numerically. However, it has been observed the studies of the hybrid PV / T system in the Kurdistan Region of Iraq are rare. In addition, the proposed research used the mechanical method to fixation the absorber plate on the backside of the PV panel because most studies use different methods and types of thermal adhesive. The main objective of this work is to utilize heat loss and convert it into thermal energy that heats water while simultaneously increasing the electrical energy efficiency, to gain alternative energy (thermal and electrical) sources in one place. The PV/T collector uses mono c-Si PV cells as solar absorbers amenable to the generally hot, dry, and arid climate of Duhok (Iraq).

3 THE EXPERIMENTAL SETUP

3.1 Photovoltaic/ Thermal Collector

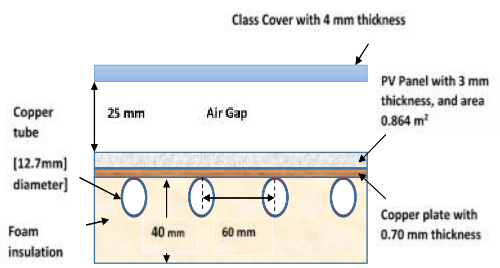
Figure 1presents the cross-sectionof the PV/T collector. Figure 2showsthe PV/T collector that tested for its performance. The PV/T collector used in this experiment includes an iron frame consisting of a transparent glass cover with an upper surfaceof 4 mm thickness, and a PV panel made from mono c-Si. The PV panel is directly and firmly attached to the absorber plate (copper sheet) by mechanical fixing, and the plate isattached to longitudinal circular copper tubesby welding, to enable cooling water to pass through. A special layer of thermal insulation (foam)is used at the bottom and sides,with 40 mm thickness to reduce heat loss from the bottom and sides to the outer environment. The glass cover had high transparency to reduce heat losses. Temperature sensors are used to measure the temperature of the wind convection from the top surface of the PV to the ambient air. The model of the water-based PV/T system is designed using locally available materials.

Table (1): shows the location of the tested PV/T collector, with the date and timeof

Table 1Experimental conditions

Location	Duhok, Kurdistan Region, Iraq
Meteorological conditions	Latitude of 36°51'41.0"N Longitude of 42°58'40.5"E
Day, month	2nd November, 2018
Time	8:30 am to 4:30 pm

experimentation.



3.2 Experimental rig

The schematic diagram of the PV/T system is shown in Figure 3. The PV/T collector has an area of 0.864 m2, and the system is equipped with a 100-liter water tank consisting of two layers of stainless steel (with insulating foam between layers). The temperatures of the collector water inlet and outlet, glass cover, air gap, PV panel, the absorber plate, insulation, and ambient air are measured using thermocouples type K. The water flow rate is 0.040 kg/s and it is circulated by a centrifugal pump with power 60 watts. The water flow is controlled by ShunhuanLiu Lang Jibiao (SHLLJ). The liquid flowmeter with accu thewater flow rate is from BijingFortec Environmental Company. Solar radiation was measured using Solar Radiation Sensor RK200-04 with range 0-1500 W/m2 and Spectral range 300～1100nm. Also, airspeed is measured by wind speed sensor RK100-01, with accuracy ±0.5 m/s. All signals Including the electricity produced from the PV/T collector is logged with the equipped data logger NAPUI130D (16 CH), with variable time intervals and accuracy ±0.2%. The PV/T collector is installed on the roof of a building in Duhok Polytechnic University, located in Duhok Governorate,in the Kurdistan Federal Region of northern Iraq.

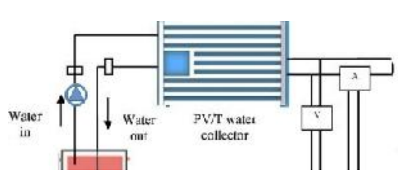


Fig. 3): Schematic diagram of the PV/T system

3.3 Data Reduction

The performance of the PV/T collector can be described in terms of numerous forms of efficiency. Thermal efficiency (η_{th})is the ratio of the useful thermal profit of the collector to the solar radiation on the collector's area during a certain period of time. The electrical efficiency (η_e) is the ratio of the useful electrical power to the solar radiation on the collector's area during a certain period of time. The overall efficiency ($\eta_{overall}$) is the summation of the thermal and electrical efficiency, whichis usually used to evaluate overall efficiency performance (Tiwari, Tiwari, & Shyam, 2016).

The electrical efficiency (η_e), of the PV/T collector can be obtained using:(Preet et al., 2017),

(Alobaid et al., 2018)

$$\eta_e = \left(\frac{FF * I_{sc} * V_{oc} * \beta_c}{A_c * G}\right) \quad (1)$$

Where FF isthe fill factor, $V_{oc}$is the open circuit voltage, $I_{sc}$is the short-circuit current, A_c is the PV area, and $G$is the solar intensity (incident on the PV module). FFcan be estimated from equation 2, and packing factor (β_c) can bedeterminedas shown in equation 3.

$$FF = \left(\frac{P_{max}}{I_{sc} * V_{oc}}\right) = \left(\frac{I_{max} * V_{max}}{I_{sc} * V_{oc}}\right) \quad (2)$$

$$\beta_c = \frac{area\ of\ the\ solar\ cells}{area\ of\ the\ PV\ panel} \quad (3)$$

Where I_{max} is maximum power current and V_{max} is the maximum power voltage.The thermal efficiency can be calculated using following equation:

$$\eta_{th} = \left(\frac{Q_u}{A_c * G}\right) \quad (4)$$

The overall efficiency can be calculated from ie equation.

$$\eta_{overall} = \eta_{th} + \eta_e \quad (5)$$

Where $\dot{Q}_u$ is the rate of output useful energy, whichcan be obtained from the following equation:

$$\dot{Q}_u = A_c F_R[(\alpha\tau)G - U_L(T_{fi} - T_{amb})] \quad (6)$$

Where T_{fi} is the inletfluid temperature, T_{amb} is the ambienttemperature, and $(\alpha\tau)$ is the transmittance-absorptance product.Based on several equations proposed by (John A Duffie & Beckman, 2013), U_L is the overallheat-loss coefficient and F_R is the collector-efficiency factor. Thus, by substituting the parameters listed in table 2 into the above equations, it is possible to compute the thermal and electrical efficiencies.

The experimental uncertainties for thermal and electrical efficiencies has been estimated (Holman, 2012).The thermal and electrical efficiencies are functions of the independent variables T_{amb}, T_{fi}, G and I_{sc}, V_{oc}, G, A_c respectively. From equations (4) and (6), the uncertainty of the thermal efficiency $\omega_{\eta_{th}}$ can be calculated using:

Area of the PV/T collector, A_c	0.864 m^2
Glass thickness, δ_g	0.004 m
Glass thermal conductivity, K_g	0.9 W/m k
Glass cover emissivity ε_g	0.88
Reference cell efficiency, η_{ref}	17.8 %
PV thermal conductivity, K_{PV}	140 W/m k
PV Panel emissivity, ε	0.93
Absorber plate thermal conductivity, K_{abs}	385 W/m k
Tube outside diameter, D_o	0.0127 m
Tube inside diameter, D_i	0.010 m
Number of tubes	10
Stefan Boltzmann constant, σ	5.67*10^{-8} $W/m^2.k^4$
Transmittance–absorptance product $(\tau\alpha)$	0.805

$$\omega_{\eta_{th}} = \left[\left(\frac{\partial \eta_{th}}{\partial G}\omega_G\right)^2 + \left(\frac{\partial \eta_{th}}{\partial T_{fi}}\omega_{T_{fi}}\right)^2 + \left(\frac{\partial \eta_{th}}{\partial T_{amb}}\omega_{T_{amb}}\right)^2\right]^{0.5} \quad (7)$$

From equation (1) the uncertainty of electrical efficiency ω_{η_e} can be calculated using:

$$\omega_{\eta e} = \left[\left(\frac{\partial \eta_e}{\partial G} \omega_G\right)^2 + \left(\frac{\partial \eta_e}{\partial I_{sc}} \omega_{I_{sc}}\right)^2 + \left(\frac{\partial \eta_e}{\partial V_{oc}} \omega_{V_{oc}}\right)^2 + \left(\frac{\partial \eta_e}{\partial W} \omega_W\right)^2 + \left(\frac{\partial \eta_e}{\partial L} \omega_L\right)^2 \right]^{0.5} \quad (8)$$

Where $\omega_{T_{fi}}$,$\omega_{T_{amb}}$ are temperature uncertainty ofinlet fluid and ambient air respectively and equal to ± 1°C.ω_G is pyranometer uncertainty and equal to ± 1W/m^2,ω_L, ω_W are length and width uncertainty = 0.002 m, $\omega_{I_{sc}}$,$\omega_{V_{oc}}$ are the current and voltage uncertainty = ± 2%. By solving equations (7) and (8) the uncertainty of thermal efficiency is $\omega_{\eta_{th}}$= ± 3.02%. And the uncertainty of electrical efficiencyω_{η_e} is estimated equal to ± 0.745%.

4 RESULTS AND DISCUSSION

A 150-watt commercial PVpanelisassembled with the PV/T collector to maximize the benefits of sunlight and convert the heat dissipation into hot water. The maximumoverall efficiency from the collector is 54.3%, which is more efficient if the sunlight is used only to produce electricity or to produce hot water in the traditional way. The research showed that the electrical and thermal conversion PV/T collector is affected by solar radiation intensity, ambient temperature, wind speed, direction and angle, mass flow rate, and the water entering and exiting from the collector. There are other factors such as the tubes and absorbing plate metals, and other. This paper focuses on changes in the efficiency of the collector and the variation in temperature that affected the PV panel.

The current research finding is compared to the finding of Bhattarai et al.,2012 experimental study because both share the same PVT collectors' components (glass cover, air gap, absorber plate and tubes metal, and heat transfer medium).

Figure 4 demonstrate the thermal efficiency result under zero reduced temperature between Bhattarai et al.,2012 and this study. Although both curves have the same trend, there is asimpledifference in thermal efficiency between them. The maximum difference is 16.3% at zero condition and it decreases gradually to 5.1% when the (T_{in} –T_{am})/ G reachs to the maximum value. There are several reasons of this variation such as climate, location, mass flowrate, area of the PV/T collector and timing.

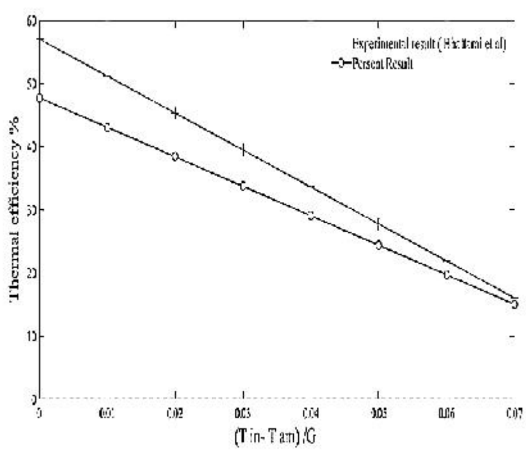


Fig.4 Comparison of experimental result of thermal efficiencies according to reduced temperature

Figure 5 shows the electrical efficiency curves of Bhattarai et al.,2012 and this study model under zero reduced temperature. It has been observed thatboth curves have the same trend too and the maximum difference between them is 3.8% at zero temperature due to using a different type of PV cells.

Figure 6 illustrate the overall efficiency curves in Bhattarai et al.,2012 and present model under zero reduced temperature. The curves have the same trend and the maximum difference between them is 12.5% at zero temperature. This variation was due to the same reasons mentioned earlier in figures 5 and 4.

Figure 7 shows readings and changes every 30 minutes over 8 hours for collector components. As the solar radiation intensity changes during that period, an increase in temperature is observed for the parts of the hybrid PV/T collector. Thermal energy is transferred from the glass cover to the liquid, passing through the copper tubes through several processes of heat transfer. The temperature of the water in the tank increases from 29°C to more than 45°C. A slight increase in ambient temperature is observed, which did not exceed 27°C. During the first three hours, the PV cell temperature rises to 72°C, then it decreases gradually by increasing the temperatures of the fluid that returns from the tank to the coolant temperature, utilized from the heat exchanger. The collector (T_{in}) and PV cells (T_{PV}) areequal at the end of the day. Note that the temperature of the glass did not increase significantly because of the impact of air passing through, with wind speeds of up to2.3 m/s.

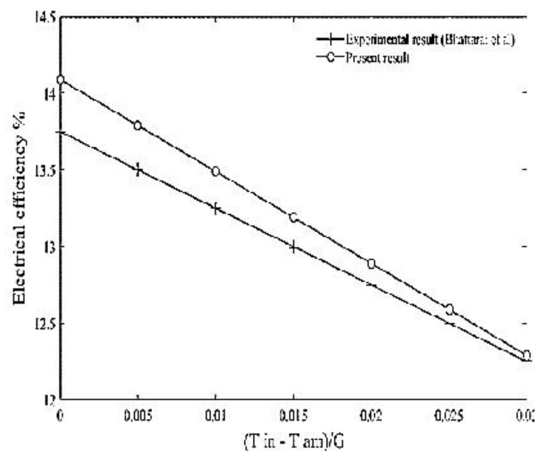


Fig. (5): Comparison of electrical efficiencies according to reduced temperature
$(T_{in} - T_{am})/G$ in (Bhattarai et al., 2012) result.

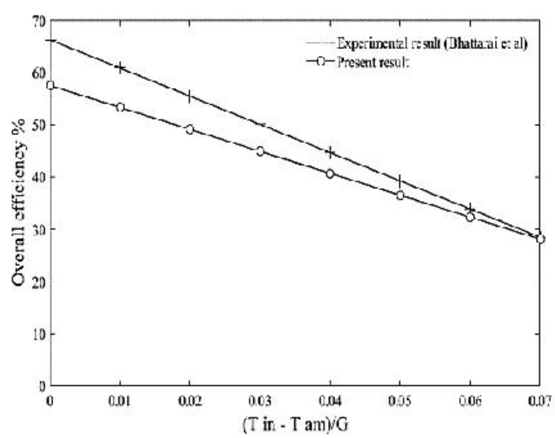


Fig. (6): Comparison of experimental result of overall efficiencies according to reduced temperature $(T_{in} - T_{am})/G$ in (Bhat

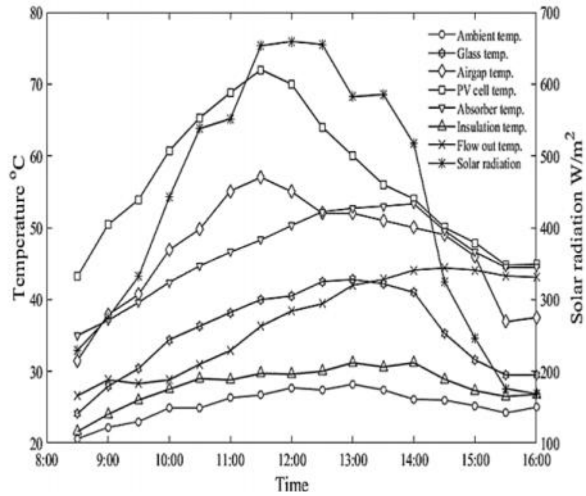


Fig. (7): Temperature variation every 30 minutes for specific parts during PV/T collector operation

Figure 8 compares electrical and thermal efficiency and the difference that occurs during the increase of heat within the collector every 30 minutes over 8 hours. The maximum thermal efficiency is 40.3% during the day and the minimum electrical efficiency is 12.5% contemporaneously. As the electrical efficiency increases, the thermal efficiency decreases dramatically due to the reduction in the intensity of solar radiation. The second day of November 2018 was a warm day, maximum ambient temperature is 27 °C, with an average air speed of 2.3 m/s. The fluid flow rate is set to 0.04 kg/s. The temperature of the inlet and outlet fluid from the collector is recorded with solar radiation intensity every 30 minutes.

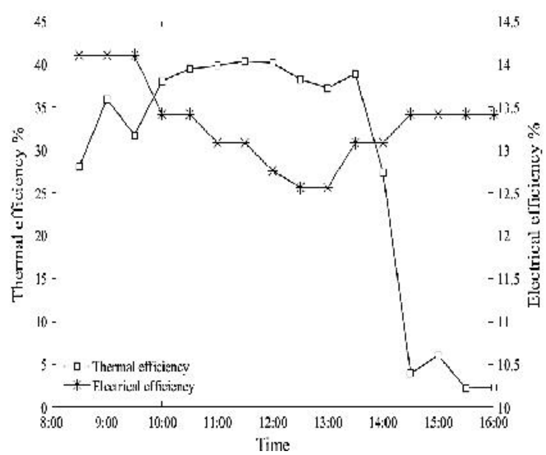


Fig. (8): Change in electrical and thermal efficiency during PV/T collector operation

Figure9 shows the variation in the temperatures of the inlet and outlet fluid from the collector. The largest difference between them is5.5°C, between 9:30 to 11:30 am, due to the increasing temperature of the absorbent plate at that time. The smallest difference between them is0.9°C due to a decrease in the temperature of the absorbent plate. Theinlet and outlet temperature increase at constant rate, and the maximum temperature is 44.4°C for the inlet and45.8°C for the outlet, whilethe maximum water tank temperature reached45.8°C.

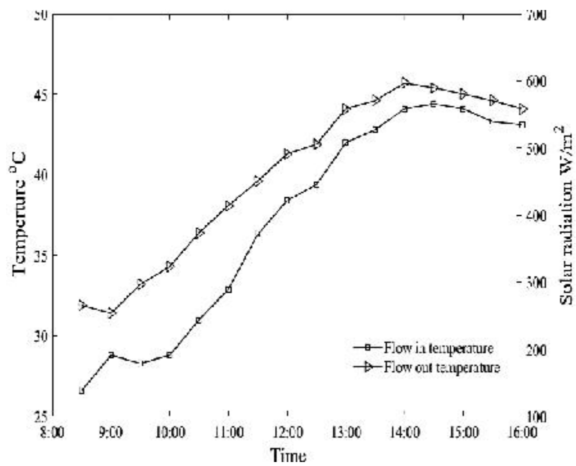


Fig. (9): Recorded inlet and outlet fluid temperature on November, 2018

Figure 10 shows the variation of the overall efficiency of solar PV/T collector, and the maximum value reached to 54.3%. Overall efficiency is almost stablefrom 10 am to 2:30 pm, and then began to drop dramatically to reach its lowest limit of 15.3% at 4.00 pm (when sunset started).

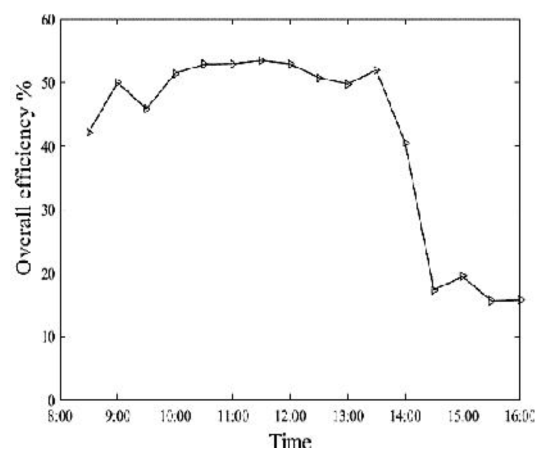


Fig. (10): Variation of overall efficiency over time

Figure 11 clearly displays the useful energy directly affected by solar radiation intensity. It is noticeable that the useful energy (Q_{useful}) increases with increasing solar radiation and itreached to 289.1 W, when the solar radiation is 659.2 W/m^2.

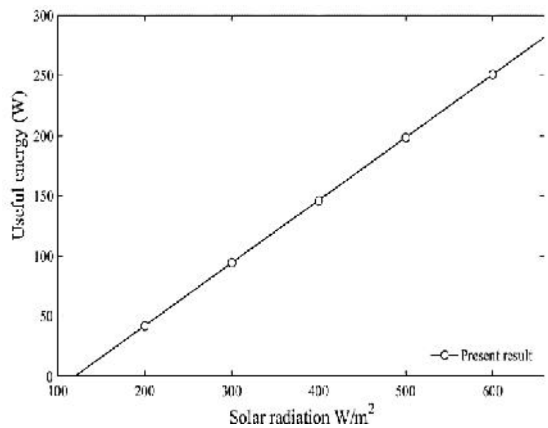


Fig. (11): Variation of useful energy with solar radiation

5 CONCLUSION

Thisstudy investigated a hybrid PV/T solar collector system in Duhok city. The experimental rig isdesigned and manufactured by the researchers. A flat copper plate isused as an absorbent plate on the backside of the solar PVpanel manufactured from mono-crystalline.Copper tubes areused to pass water through it at the bottom of the absorbent plate.The results display the performance of the hybrid collector for a one day. The maximum thermal efficiency obtained is40.3%, andthe electrical efficiency is improved to reach 14%. The studyachieved a net increase in overall efficiency, reaching 54.3%. Also, the experimental resultsindicate the effect of solar radiation generally on electricalefficiency, and the effect of clouds on thermal efficiency.The comparison showed satisfactory results although there was some variation due to the difference in climate, location, and timing.

Due to the electricity problems in the Kurdistan region and itsabundance of solar energy, it is possible to exploit this energy by using the hybrid PV/T collector as a successful alternative and a sustainable solution for low heat applications, such as preheating household water, in Duhok city.

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بوخته

ڤەکولیندنەکا تاقیگەهی بو سیستەمی کومکرنا ووزا خورێ هاتە کرن ب ڕێکا سیستەمێ (PV/T)ل دهوکی، ل هەریما کوردستانا عیراقێ. ئەڤ ڤەکولیندنە باشکرنا کارێ بوردێ کەهروموگناتیسی(PV)دیار دکەت ب ڕێکا کیم کرنا پلا گەرماتیێ یا خانەیێن وێ ئەو ژی بریکا دەرباسکرنا ئاڤا تەزی وەك ڤەگوهێزەك بو گەرماتیێ دناف بوریێن سفری دا ئەویت هاتینە جێگیرکرنا ب پلێتەکێ کانزایی یی سفری کو هاتیە بکار ئینان وەك ڤەگوهێزەك بو گەرماتیی. ئەڤ پلێتێ سفری هاتە جێگیر کرن ب لایێ پشتێ یی بوردێ کەهروموگناتیسی ڤە ب ڕێکا میکانیکی. ئەنجامێن ڤێ ڤەکولینێ هاتنە بەراوردکرن دگەل ڤەکولینەکا بەری نوکە هاتیە ئەنجامدان و ئەنجام د پەسەند بون.بوردێ کەهروموگناتیسی ئەوێ هاتیە بکار ئینان پێك دهێت ژ خانەیێن ئیکانە یێن کریستالی (MONO C-SI)ئەنجام دیاردکەن کو کومکەرا ووزا خورێ یا (PV/T) دماوێ هەیڤا چرییا دووێ سالا 2018 شییا بلند ترین شیانێت گەرماتیێ تومارکرن ئەوژی گەهشتە 40.3% و شیانێت کارەبێ گەهشتە 14% و شیانین گشتێ بو 54.3%

الخلاصة

اجريت دراسة تجريبية لمجمع للطاقة الشمسية من خلال نظام هجين كهروضوئي حراري (PV/T) في محافظة دهوك من اقليم كردستان العراق. توضح الدراسة تحسن أداء اللوحة الكهروضوئية(PV)عن طريق تقليل درجة حرارة خلاياها وذلك من خلال تمرير الماء البارد كوسيط ناقل للحرارة من خلال أنابيب نحاسية تم تثبيتها على صفيحة معدنية مسطحة من النحاس والتي استخدمت كمبادل حراري . هذه الصفيحة النحاسية تم تثبيتها بطريقة ميكانيكية على الجانب الخلفي للوحة الكهروضوئية. تمت مقارنة النتائج لهذا البحث مع دراسة تجريبية سابقة وكانت النتائج مقبولة، حيث لوحظ ان النتائج قريبة من بعض .اللوح الكهروضوئي المستخدم يتكون من خلايا احادية البلورية (mono c-Si). تشير النتائج إلى أن أداء المجمع الهجين(PV/T) خلال شهر نوفمبر 2018. حقق أقصى كفاءة حرارية و التي وصلت 40.3 ٪، مع كفاءة كهربائية وصلت الى 14 ٪ ، وبلغت الكفاءة الإجمالية 54.3 ٪.

semyan.omed@dpu.edu.krd, omar.ali@uoz.edu.krd