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Experiment study of water based photovoltaic-thermal (PV/T) collector

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ABSTRACT

Solar radiation can be converted to the electrical energy and thermal energy by photovoltaic panel and solar collector. In this experiment, PV/T collector was designed, fabricated and tested its performance. The experiment conducted on PV/T collector with water flow at mass flow rate 0.012 kg/s to 0.0255 kg/s. The water flow with the stainless stell absorber help the PV/T collector in increasing the convection of thermal heat transfer. The power output increase with increase of radiation. The efficiency of PVT varies with different intensity of radiation which stated in this experiment for 750 W/m^2 and 900 W/m^2. The analysis of energy and exergy are excuted and results show energy output for water based PV/T collector are 346 W for solar radiation 700 W/m^2 and 457 W for solar radiation 900 W/m^2. Meanwhile the total exergy output compared to the PV panel without stainless stell absorber, which the exergy increased by 22.48% for 700 W/m^2 and 20.87% for 900 W/m^2.

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1. INTRODUCTION

Many researches towards the solar energy occur all over the word to the concern of global crisis on oil and gas prices. According to some experts, oil has ready started to peak. Gas and coal reserves are bigger than oil, will tend to be progressively replaced by the former, which should attenuate a price explosion. Nevertheless this process will push energy prices higher, until sustainable sources replace dependency on fossil fuels as major source of energy. The sustainable energy such as solar energy has been identified as one of the promising source of energy to replace the de-pendency on fossil fuels. Solar energy is a clean energy which has the potential to meet a significant proportional of the world’s energy needs. It can be broadly classified into two systems; photovoltaic (PV) energy system which converts solar energy into electrical energy, and thermal energy system which converts solar energy into thermal energy. The PV is one of the technology used to harness solar energy. Recently, the integration of photovoltaic and solar thermal collector provide the system to produce heat and electrical energy from solar energy simultaneously. The problem of temperature of PV surface raising causes the efficiency to decerease was overcome by adding a heat recovery system to a photovoltaic module. Generally, type of PV/T devided based on fluid in thermal storage, air based or water based. PV/T consist of PV module, glass cover, absorber collector and the insulator [1]-[10].

The researcher have evaluated range of parameters such as design of tube collector, type of insulator and type of PV in order to increase of PV efficiency. Chow et al. [11] investigated energy and exergy analysis of a PV/T water based collector system with and without glass cover, Bahaidarah et al. [12] performed an evaluation of a PV module by back surface water cooling and concluded that PV panel efficienecy increased by 9% under water active cooling. Many experiment studies focused on the size, arrangement and type of fluid used for cooling in PV/T.

Exergy analysis has become an essential tool in the system design, analysis, and optimization of thermal systems [13]-[20]. The main objective of this study is to investigate the efficiencies of water based PV/T collector base on energy and exergy analysis. The effect of different mass flow rate on the generation electrical and thermal energy is evaluated too. The overall energy and exergy output are calculated from thermal and electrical energy presented.

2. MATERIAL AND METHODS

The set up of PV/T system during the indoor experiment under solar simulator is shown in Figure 1. A standard polycrystalline 80 W photovoltaic module represented as a flat plate unglazed sheet attached on the top. The collector made up of single unilateral channel for the fluid to flow is inserted underneath the PV module. The size of PV/T collector surface is 0.5 wide and 1.2 m long. K-type thermcouple used with data logger to collect the inlet and outlet fluid and that PV panel surface temperature. The change of temperature during the experiment can be tracked and recorded in short step time (1 minute). The total incident radiation on the system is measured by pyranometer. A flow meter (1-4 G/M) mounted at the opening of fluid inlet for controlling of mass flow rate.

The experiment was conducted under indoor testing facility using solar simulator. The simulator consist of 40 halogen lamps and the intensity of solar radiation controlled by variable voltage controller. The PV/T system has been exposed to the solar radiation of 900 W/m^2 for 40 minutes before collecting data to ensure the equilibrium state of radiation. The change of voltage are recorded using electric load under different mass flow rate and volume concentration of nanofluid. The mass flow rate of water was set to the range of 0.01 to 0.0255 kg/s. The temperature of the system collected from thermocouple stored in the ADAM Data Acquisition System for every 1 minute and later used to calculate the electrical and thermal efficiency for the collector. The water was circulated around the system using the pump and heat exchanger used for cooling the fluid in the cloosed loop system.

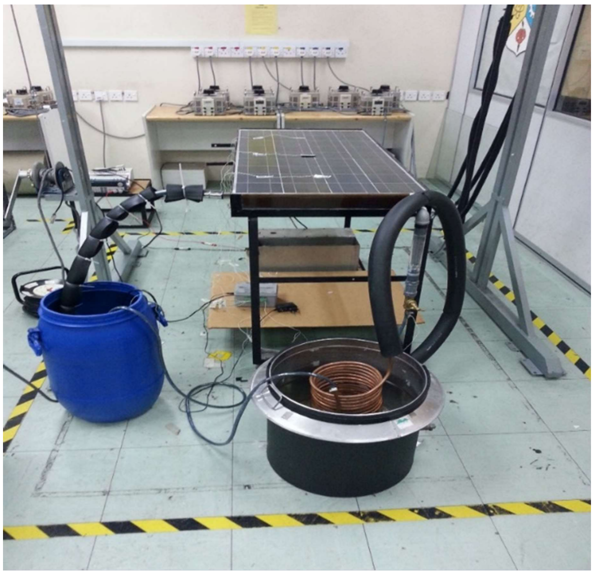

Figure 1. The set up of water based PV/T collector under solar simulator

The energy and exergy analysis were used to evaluate the overall performance of the PV/T collector. The energetic and exergetic analysis measures quantity and quality respectively. The energy analysis comprised of thermal efficiency and electrical efficiency. The ratio of electrical and thermal energy gain to the solar radiation incident on the PV/T system described the efficiencies. The total efficiency of PV/T performance can be expressed as below [21], [22].

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

The thermal efficiency can be calculated as

$$\eta_{th} = \frac{Q_u}{IA_c} \tag{2}$$

Where the rate of useful thermal energy can be calculated as follows

$$Q_u = m_f C_p\left(T_{f,out} - T_{f,in}\right) \tag{3}$$

Where m_f is the fluid mass flowa rate, C_p is the fluid specific heat capacity and $T_{f,in}$ and $T_{f,out}$ are the fluid inlet and outlet temperatures. The electrical efficiency of the PV module which is a function of PV module temperature given by [2] [10]:

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

Where η_r is the reference efficiency of PV module (η_r= 0.12), β is the temperature coefficient (β =0.0045 °C), T_c is cell temperature and T_r is the reference temperature. The rate of electrical energy gained from PV/T collector is given as

$$\dot{E}_{el,net\ electrica} = \eta_{el} \times A_{pv} \times I \tag{5}$$

Considering the electrical energy is a high-grade form of energy gain, the net electrical energy should be converted to the thermal energy using convevrsion effeciency of thermal power plant, C_{power} as follows

$$\sum Q_{u,overall} = \sum Q_{u,overall} + \frac{\sum \dot{E}_{el}}{0.38} \tag{6}$$

Where C_{power} can be taken as 0.38 for good quality of coal.

Thermal energy cannot produce work until a temperature difference exist between a heat source and a heat sink while electricale energy can ber completerly transform into work. The exergy analysis include Carnot efficiency for a qualitative and standardized evaluation of the hybrid performance. The overall exergy output of the PV/T system can be express in the form given

$$\sum Ex_o = \sum Ex_{th} + \sum Ex_{pv} \tag{7}$$

where

$$Ex_{th} = Q_u\left(1 - \frac{T_a+273}{T_o+273}\right) \tag{8}$$

and

$$Ex_{pv} = \eta_c A_c N_c I_{ex} \tag{9}$$

where

$$I_{ex} = Ex_{in} = IA\left[1 - \frac{4}{3}\left(\frac{T_a}{T_s}\right) + \frac{1}{3}\left(\frac{T_a}{T_s}\right)^4\right] \tag{10}$$

where I is solar radiation, T_a is ambient temperature and T_s is sun temperature ($T_s = 5777K$), and from equation above, we can calculated exergy efficiency.

3. RESULT AND DISCUSSION

In this study, the effect of mass flow rate and solar radiation on the performance of PV/T collector are obtained. The experimental results for the variation of temperatures (ambient, inlet, outlet and PV) under different mass flow rate are shown in Figure 2 and Figure 3. The surface PV temperature reduction are higher with increasing mass flow rate. At 700 W/m^2, the surface reduction recorded at 0.026 kg/s compared to that of PV is 15.28 °C, while the surface reduction at 900 W/m^2 is 8.48 °C.

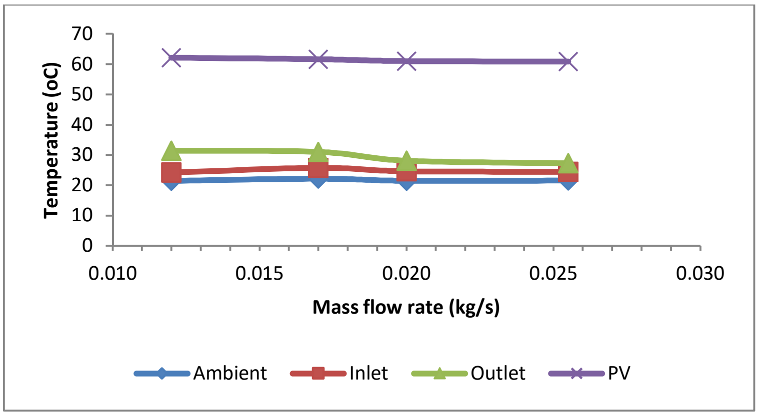

Figure 2. Temperatures (ambient, inlet, outlet, and PV) of water based PV/T collector for a solar radiation of 700 W/m^2

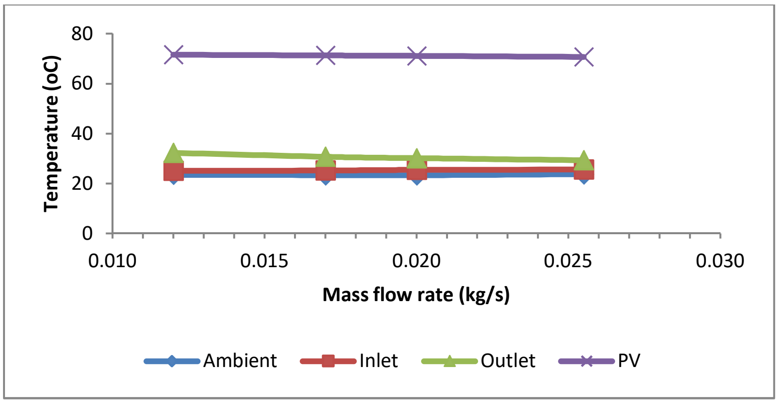

Figure 3. Temperatures (ambient, inlet, outlet, and PV) of water based PV/T collector for a solar radiation of 900 W/m^2

Table 1 and Table 2 shows thermal, electrical and PVT efficiencies calculated at solar radiation 700 W/m^2 and 900 W/m^2 under mass flow rate range from 0.012 kg/s to 0.0255 kg/s. The thermal efficiency produced from about 57 to 65% at 700 W/m^2. The thermal efficiency increase about 2% from 700 W/m^2 to 900 W/m^2 solar radiation. This result indicated that higher mass flow rate increase the heat transfer rate from the fluid to the surface PV module. The electrical and PVT efficiency produced from about 10.33 to 10.40% and 67 to 75% at 700 W/m^2, respectively. For 900 W/m^2, electrical and PVT efficiency produced from about 9.80 to 9.85% and 70 to 77% at 700 W/m^2, respectively.

Table 1. Energy Analyisis of Water Based PV/T Collector at Solar Radiation of 700 W/m^2

m	Efficiency (%)		
(kg/s)	Thermal	Electrical	PVT
0.012	57.012	10.328	67.340
0.017	61.156	10.357	71.513
0.020	63.624	10.391	74.015
0.026	64.984	10.399	75.383

Table 2. Energy Analyisis of Water Based PV/T Collector at Solar Radiation of 900 W/m^2

m	Efficiency (%)		
(kg/s)	Thermal	Electrical	PVT
0.012	59.789	9.799	69.588
0.017	63.000	9.815	72.815
0.020	64.230	9.825	74.055
0.026	66.912	9.849	76.761

The thermal and electrical output are calculated from (3) and (5) for the both cases of solar radiation. The thermal and electrical output for 700 W/m^2 radiation are 299.73W and 46.67 W. For 900 W/m^2 radiation, the thermal and electrical output are 398.32W and 59.15 W, as shown in Table 3. The reference system in this experiment is referred to PV panel wihout cooling system. From Table 3, the reference PV electrical efficiencies is 9.37% for 900 W/m^2. The increase in electrical efficiency compared to the reference system is 5.05% at 900 W/m^2 solar radiation.

Tables 3. Energy Analysis of PV Panel and Water Based PV/T Collector

	Solar Radiation (W/m^2)	η_{th} (%)	η_{el} (%)	Thermal Output (W)	Electrical Output (W)
Distilled Water	700	64.98	10.39	299.73	46.67
	900	66.91	9.84	398.32	59.15
PV (reference)	700	-	9.55	-	42.84
	900	-	9.38	-	56.31

The exergy analysis was conducted using (7) to (10) for the both cases of solar radiation. The thermal and electrical exergy for 700 W/m^2 radiation are 5.786 W and 46.534 W. For 900 W/m^2 radiation, the thermal and electrical output are 8.858W and 58.828 W, as shown in Table 4. The PVT exergy are 52.32 W and 67.68 W for 700 W/m^2 and for 900 W/m^2 respectively.

Tables 4. Exergy Analysis of PV Panel and Water Based PV/T Collector

Solar Radiation (W/m^2)	Exergy thermal (W)	Exergy electrical (W)	Exergy PVT (W)
700	5.786	46.534	52.32
900	8.858	58.826	67.68

4. CONCLUSIONS

The performance of water based PV/T collector can be depicted by the combination of efficiency expression. It comprised of the PV efficiency and thermal efficiency. The total of the both efficiencies, which is known as PV/T efficiency was used to evaluate the overall performance of the system. Based on the testing performed on the collector, it was proved that both efficiencies increased when the mass flow rate increased. Therefore, the total efficiency (PV/T efficiency) increased concurrently when the mass flow rate increased. The water based PV/T collector produced PV/T efficiency about 67 to 77% with 9.8 to 10.4% PV efficiency and of 57-67% thermal efficiency. On the other hand, the PV/T exergy is between 52 W and 68 W with thermal exergy of 5.8W to 8.9W and electrical exergy of 46.5 to 58.8W.

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BIOGRAPHIES OF AUTHORS

Nur Farhana Mohd Razali, M.Sc graduated with the M.Sc in Renewable Energy from Solar Energy Research Institute (SERI), Universiti Kebangsaan Malaysia (UKM), Malaysia. The M.Sc thesis was about the Exergy Analysis of Nanofluids Based Photovoltaic Thermal (PVT) Collector. Her M.Sc thesis under supervisor by Ahmad Fudholi Ph.D (main supervisor) and Prof Dr. Mohd Hafidz Ruslan (co. supervisor). She received “Excellent Thesis” Award from SERI UKM in 2017. More than 5 papers currently accepted manuscript in journals in Scopus index. She was appointed a Graduate Research Assistant (GRA) under Fundamental Research Grant Scheme (FRGS/1/2014/ST02/UKM/03/1) under project leader by Ahmad Fudholi Ph.D during his Master’s degree.

Ahmad Fudholi, Ph.D, M.Sc obtained his S.Si (2002) in physics. He was born in 1980 in Pekanbaru, Indonesia. He has working experience about 4 years (2004-2008) as Head of Physics Department at Rab University Pekanbaru, Riau, Indonesia. A. Fudholi started his master course in Energy Technology (2005-2007) at Universiti Kebangsaan Malaysia (UKM). His M.Sc thesis was on Wind/PV Hybrid System and the Ph.D thesis was about the Finned Double-Pass Solar Collectors for Drying of Seaweed. His M.Sc and Ph.D thesis under supervisor by Prof Dato’ Dr. Kamaruzzaman Sopian. After his master he became Research Assistant at UKM up to 2012. After his Ph.D (2012) in renewable energy, he became Postdoctoral in Solar Energy Research Institute (SERI) UKM up to 2013. He joined the SERI as a Lecture in 2014. More than USD 310,000 research grant (13 grant/ project) in 2014–2017 was involved. More than 25 M.Sc project supervised and completed. Until now, he managed to supervise 5 Ph.D (4 main supervisor and 1 Co. supervisor), 3 Master’s student by research mode, and 5 Master’s student by coursework mode, he was also as examiner (3 Ph.D and 1 M.Sc). His current research focuses on renewable energy, especially solar energy technology, micropower system, solar drying systems, and advanced solar thermal systems (solar assisted drying, solar heat pump, PVT systems). He has published more than 100 peer-reviewed papers, which 25 papers in ISI index (20 Q1, impact factor more than 3) and more than 60 papers in Scopus index, 16 more currently accepted manuscript, 20 more currently under review, and 2 book chapters. Addition, he has published more than 70 papers in international conferences. His total citations of 756 by 493 documents and h-index of 14 in Scopus (Author ID: 57195432490). His total citations of 1363 and h-index of 19 in google scholar. He is appointed as reviewer of high impact (Q1) journal such as Renewable and Sustainable Energy Reviews, Energy Conversion and Management, Applied Energy, Energy and Buildings, Applied Thermal Engineering, Energy, Industrial Crops and Products, etc. He is appointed as reviewer of reputation journals such as Drying Technology, International Journal of Green Energy, Biosystem Engineering, Journal of Sustainability Science and Management, Journal of Energy Efficiency, Sains Malaysiana, Jurnal Teknologi etc. He is also appointed as editor journals. He has received several awards such as Gold Medal Award at the International Ibn Al-Haytham's Al-Manazir Innovation and Invention Exhibition 2011, Silver Medal Award at the International Technology EXPO (ITEX) 2012, Silver Medal Award at the Malaysia Technology Expo (MTE) 2013, Bronze Medal Award at International Exposition of Research and Invention (PECIPTA) 2011, also 2 Bronze Medal Award at PECIPTA 2017. He was also invited as speaker: Workshop of Scientific Journal Writing; Writing Scientific Papers Steps Towards Successful Publish in High Impact (Q1) Journals.

Prof. Dr. Mohd Hafidz Ruslan currently is the Deputy Director and Head of Postgrade Studies of the Solar Energy Research Institute (SERI) UKM, Malaysia. His current research focuses on solar energy, especially solar thermal technology, heat pump system, solar water heating and solar drying systems. He has published more than 150 peer-reviewed papers in ISI and Scopus index. Addition, he has published more than 100 papers in international conferences. His total citations of 1541 by 1077 documents and h-index of 22 in Scopus index (Author ID: 6504666472). His total citations of 2564 and h-index of 27 in google scholar index.

Prof Dato' Dr. Kamaruzzaman Sopian graduated with the BS Mechanical Engineering from the University of Wisconsin-Madison in 1985, the MS in Energy Resources University of Pittsburgh in 1989 and PhD in Mechanical Engineering from the Dorgan Solar Laboratory, University of Miami at Coral Gables in 1997. His MS thesis was on Solar Absorption Cooling System and the PhD dissertation was about the Double-Pass Photovoltaic Thermal Solar Collectors. Upon graduation, he has been appointed as an Assistant Professor at the Department of Mechanical and Materials Engineering, Universiti Kebangsaan Malaysia (National University of Malaysia). He was promoted to the post of Professor of Renewable Energy in the Department of Mechanical and Material Engineering, at the Universiti Kebangsaan Malaysia (the National University of Malaysia) in 2001 and currently is the Director of the Solar Energy Research Institute in the same university since 2005. He has been involved in the field of renewable energy for more than 25-years. His main contributions are in solar radiation modeling and resource assessment, advanced solar photovoltaic systems (grid-connected photovoltaic, solar powered regenerative fuel cell, solar hydrogen production, thin film silicon solar cell) and advanced solar thermal systems (solar cooling, solar heat pump, solar assisted drying, combined photovoltaic thermal or hybrid collector). He has secure research funding from the Malaysian Minstry of Science and Malaysian Ministry of Education and industry for more than USD 6 million. He has conducted renewable enery courses the Asian School of Energy (2007 - 2014) funded by ISESCO, COMSAT, TIKA and UNESCO. He has published over 800 research papers in journals and conferences (SCOPUS h index = 52, no. of citation = 9082) (Google Scholar h index = 63, no. of citation = 15196). A total of 32 MSc (coursework), 15 MSc (research mode) and 40 PhD candidates from various countries such as Bangladesh, Iran, Iraq, Algreria, Libya, Indonesia, Nigeria, Oman, Yemen, Malaysia and Jordan have graduated under his supervision. He has delivered keynotes and planery speeches at national and international conferences on renewable energy in Malaysia, China, India, Iraq, Iran, France, Greece, Morroco, United Kingdom, United States, Hungary, Egypt, Libya, United Arab Emirates, Syria, Saudi Arabia, Bahrain, Indonesia, Thailand, Philiphines, Japan, Singapore, Germany, Holland, Italy, Maldives, and Combodia. He has undertaken short assignments in about 10 countries for international agencies and programs such as UNDP-GEF, UNIDO, ASEAN EU-Energy Facility, ASEAN-Australia Economic Co-operation Program, ASEAN-CIDA (Canada International Development Agency), JSPS-VCC, British Council CHICHE, ISESCO and UNESCO related to renewable energy technology. He has been appointed as the Honorary Professor of Renewable Energy, at the Faculty of Built Environment, University of Nottingham, United Kingdom (2009 -2013). In addition, he has been appointed as the associate editors of the Journal of Renewable Energy (2005 – 2010) and Journal of Sustainable Cities and Society published by Elsevier Ltd, and Journal of Energy, Hindawi. Journal of Sustainable Energy and the Environment (Thailand), Jordan Journal of Mechanical and Industrial Engineering (JJMIE) (Jordan), International Journal of Thermal and Environmental (Canada) and Palestine Technical University Research Journal (Palestine). He won several international awards for his academic contribution in renewable energy including the IDB (Islamic Development Bank) S&T Prize 2013, World Renewable Energy Network Pioneer Award 2012, Malaysia Green Technology Award 2012, and the ASEAN Energy Awards (2005, 2007, 2013 and 2014). He has 4 patents, 20 patents pending, 6 copyrights, and 1 trademark for his innovation in renewable energy technology. The innovation and invention in renewable energy technology have won 80 medals in national and international innovation and invention competitions including special innovation awards such as Prix de L 'Environnement by the Swiss Society for Environmental Protection, 2001, Geneva, Sustainable Development Award INNOVA 2007, Special Prize, Korea Invention Promotion Association at the INPEX Pittsburgh 2008 and Energy and Environmental Award, at INNOVA 2013 in Brussels. His Royal Highness The Sultan of Perak conferred the Paduka Mahkota Perak (PMP) in 2003 and the Dato' Paduka Mahkota Perak (DPMP) in 2013. He was conferred as a Fellow of the Malaysia Academy of Sciences (FASc) in 2011. Promoting renewable energy technology to the communities and industries has always been his passion. He has developed and delivered solar dryers for fish and seaweeds in Karkor Cambodia and Semporna Malaysia respectively. In addition, he has developed a cottage industry for manufacturing of photovoltaic panels in Kuala Trengganu. He has also delivered the first pico hydro system for an orang asli community in Kampung Tuel, Kelantan. He has designed and commissioned the first large scale solar assisted hot water system for a 1000 bed hospital in Malaysia and also a solar assisted drying system for old palm fronds for a palm oil factory in Malaysia.