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Thermal Efficiencies of Photovoltaic Thermal (PVT) with Bi-Fluid Cooling System

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ABSTRACT

Solar radiation can be converted into thermal and electrical energy by using photovoltaic thermal (PVT) system. This system combines the functions of a flat plate solar collector and a PV panel. PV surface and cells play an important role in enhancing the efficiency of PVT systems; that is, the PV efficiency decreases with increasing solar radiation intensity. PVT systems use a small amount of solar radiation to produce electricity and a bulk amount to generate thermal energy that warms the surface of PV cells. A medium that can effectively absorb heat energy from PV collectors should be used to increase the efficiency of electrical energy to a satisfactory level. In this study, a PVT system was fabricated and its performance was evaluated. An experiment was conducted on the PVT with water flow at a mass flow rate from 0.01 kg/s to 0.03 kg/s and air flow rate at a mass flow rate from 0.04 kg/s to 0.10 kg/s. This study highlights the thermal energies efficiencies when bi-fluid (water and air) allowed to flow. The optimal flow rate had been chosen and highest thermal efficiencies for each mass flow rate had been listed in which had been 77.31% has been attained at air and water mass flow rate of 0.06 kg/s and 0.01 kg/s.

1. INTRODUCTION

The harvest of solar energy from the sun is ultimately a promising energy as one of the developments in energy field. Photovoltaic technologies is one of the technology developed by converting solar energy into electrical energy. As time passes by, the investment in improving solar photovoltaic technologies also demanding in contributing to thermal energy production. In this constitution, the solar thermal studies had produced PVT which may generate electrical and thermal energy from one integrated system. In general, PVT is categorised as air- or water-based on the basis of fluid in thermal storage. A PVT system consists of a PV panel, a glass cover, an absorber collector and an insulator [1-5]. PVT had been classified into two categories which as stand-alone PVT and grid-connected PVT [6].

The research in PVT studies had varied and going through lots of enhancement in attaining a system which contributes higher effectiveness for energy production. As the heat absorbed by the solar PV collector, causing the temperature of PV panel itself to rise, the cooling fluid regulates the temperature so that the performances of the PVT system can be yielded effectively [7, 8]. Focusing in coolants for PVT system, conventional fluids such as water and air had been employed for the cooling system. Water with high heat capacity absorbs heat energy and transfers it into a water tank for various uses. These systems are named as hybrid PV/T solar panel, which can simultaneously produce thermal energy and electrical energy. These hybrid PV/T solar panel also produce hot water, which is important for domestic and industrial applications. Hot water is required in laundry, kitchen utensils, bathing and other domestic uses in urban or rural areas. Hot water is also required in hospitals, dormitories, hotels, and industries. Recently, nanofluid as coolants in PVT system was reported [9-13]. Utilizing these fluids had been conducted in separate mode which they allowed to flow independently [14].

The focus in photovoltaic-thermal related studies can be classified into improvements in the design of the cooling system as well as the use of coolant fluids used in such cooling systems [15]. Besides, various types of studies are also conducted to investigate the factors affect the performance of these systems such as weather and climate diversity, design and operating parameters of PVT systems [16]. In addition, the study literature covering all types of energy such as wind energy, bio-mass and also PVs have also been discussed [17]. More research detailed exaggeration and theory analysis has also been carried out on the performance of PVT systems [18]. In addition, a study on evaluation carbon credits and a decrease in the rate of electrical energy produced during heat surplus from solar panels is extracted out of analysis [19].

The use of both fluids such as water and air in one PVT system single has led to an increase in overall performance per unit area of the panel solar used. This has also been shown to contribute to the introduction of more efficient systems in energy production than PVT systems conventional although the solar panels used are the same panel. System PVT of two fluids is expected to be more efficient when both types of fluids are flowed simultaneously [20]. A 2D steady-state analysis had been carried out on a bi-fluid PVT solar collector in which the flow of coolants was alternated [21]. Then, a study in 2013 taking into account aspects of system design and the environment of the study were conducted by Nazari et al. [22]. Waterway which is made of copper and a single air flow has been built as well theoretical studies have been compared with experimental results. The performance of the system is achieved a better level when the fluid is done in parallel with the flow separately. An improved bi-fluid (water and air) PVT system had been designed and developed for its theoretical analysis which resulted satisfactory result for independent fluid flow while high efficiency for simultaneous fluid flow. It was verified that both of electrical and thermal energies generated by bi-fluid PVT system attributed in higher efficiencies during simultaneous operation than independently operated [22].

Satisfactory results on thermal energy, electricity and performance equations total terms for separate and simultaneous fluid flows. At the flow rate optimal mass, as much as 76% of the thermal performance of the system as a whole achieved [23]. A hybrid PVT system in which a PV panel used as a transparent was also conducted in 2016. The Hottel Whillier Bliss equation was used to validate the performance system. Experiment results of 17% and 76% of the overall electrical energy and thermal efficiency are at radiation of 800 W/m^2 and 0.02 kg/s fluid mass flow rate as optimal flow [24]. A study to examine the performance of the last two PVT systems implemented and found a system with this design generates electrical energy and high terms [25]. As a conclusion to this sub-topic, the study on the PVT system using two fluids summarized in the table below based on the method of the study conducted.

A research conducted by Jarimi et al. [26] was highlighting the importance of finding ideal mass flow rate for a PVT system. This study implied that it was essential for a system to be operated with optimal flow rate of coolants for an effective performance.

In this study, thermal energy is the main focus to be analyzed for the bi-fluid PVT system. Flexible monocrystalline solar panel had been chosen as the solar collector which integrated with a glaze as to complement air duct for the air flow and spiral absorber for the water flow channel. Moreover, maximum thermal energy gained at each mass flow rate of both fluids will be reviewed and optimum flow rate will be further discussed.

2. MATERIALS AND METHOD

2.1 Material

PVT system with integration of bi-fluid required a piping system for the flow of water and an air flow channel. In Figure 1, the experimental set up has been shown which it was placed at the outdoor, located at the rooftop of Physics Building, Universiti Kebangsaan Malaysia. A 0.57 m^2 of flexible monocrystalline photovoltaic (PV) panel had been used in which the absorption of solar radiation took place. This outdoor research had been conducted to obtain the efficiencies of thermal energy generated by the system. Figure 2 portrays the labelling of the setup diagram thoroughly. In the setup, a glaze (mirror) had been installed on the top of the collector, followed by the air flow duct in between the glaze and the flexible PV panel which sandwiched to the spiral absorber beneath it. The installation of glaze to the PVT system acted as great attributable to gain high thermal energy. It had been proved by Chow et al. [27] whom verified the improvement of using glass cover on PVT system. Meanwhile, for the thermal system, two type of coolants (bi-fluid; water and air) had been utilized with different parameters in their single flow channel.

An 80W of amphibious pump had been used to assist the water pumping so that it was put in the tank where the cooled water flowed from the cooling tank. 1-4 G/M of flow meter had been mounted at the channel inlet to control the mass flow rate of water. In the cooling tank, a heat exchanger was placed in the water outlet tank to cool down the water flowed out of the water channel.

As for the flow of air above the flexible panel and water throughout the spiral absorber beneath the flexible panel had been aided with other equipment to ensure smooth flow of fluids (Figure 3). The air flow was thrusted by using 240 V Axial AC fan that were installed at the closed end of collector and regulated by using a dimmer. The air that collected the heat throughout its way then discharged at the open-end of collector.

Figure 1. The experimental setup of PV with bi-fluid cooling system

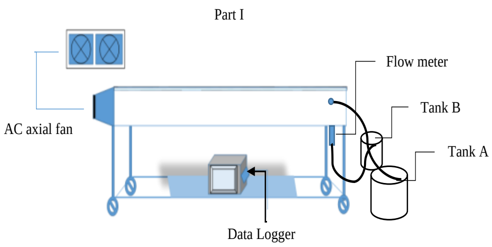

Figure 2. Schematic diagram of outdoor experimental setup

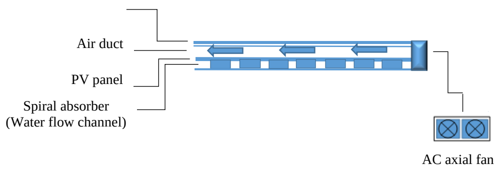

Figure 3. The part I (as in Figure 2) interior diagram

The main data's parameter was the temperature which constituted the temperature of 32 parts of systems. Thermocouple type-K had been installed by pasting them at each 32 parts and then connected them to data logger with integration of PC and ADAM software. The readings had been started as soon as the system exposed to solar radiation and operated for an hour, at each different parameter of simultaneous utilization of bi-fluids. For each pair of parameters of water and air mass flow rate, the experiment had been repeated for three times.

2.2 Method

The experiment began at around 9 in the morning till 4 in the evening. The solar radiation recorded had varied in trends of radiation as the weather for each day were different. The results obtained from this research had been influenced by lots of conditional factors such as outdoor wind velocity, sun radiation and ambient temperature that cannot be regulated and considered as vital circumstances for each result.

The setup had been exposed and the time for the sunlight to radiate upon the collector was recorded. In the meantime, the flow of cooling fluids (water and air) had been regulated and allowed to flow. The readings of solar radiation were recorded automatically as well as the temperature of 32 parts of the location of thermocouples by the data logger. The fluids were simultaneously flowed through their respective channel which was perpendicular to each other in direction of the inlet and outlet fluids.

In between of the system operation, the flow of water had been turned off and the glass cover had been shielded from receiving sunlight. The system had been said to be rested in order to revive the system for second sun exposure. The air flow continued till the end as in the resting time for the set up, it helped to cool down the system and aided for short preparation time. Till the temperature of PV and glass were thoroughly same as before experiment had been started, then the procedure for the operation were repeated up to three times.

From the collected data, thermal energy generated by the system had been analyzed. It was examined based on the parameter of different mass flow of working fluids which were water (0.01 kg/s, 0.015 kg/s, 0.02 kg/s, 0.025 kg/s and 0.03 kg/s) and air (0.04 kg/s, 0.06 kg/s, 0.08 kg/s and 0.1 kg/s). The solar radiation radiated upon the panel, measured by Pyranometer EPLEY connected to multimeter, showed uneven distribution of solar radiation's readings as the source of the solar in the experiment was from the sun.

The efficiencies of thermal energy contributed by the PVT system was calculated by using the formula from Baljit et al. [28].

$$\eta_{th} = \frac{\dot{m}_f C_{p,f}(T_{f,out} - T_{f,in})}{A_C I} \quad (1)$$

where, $\dot{m}_f$ is mass flow of fluid, $C_{P,f}$ is specific heat capacity of fluids, A_C is area of collector, and I is solar irradiance.

Meanwhile, for bi-fluid the total thermal efficiency is [28]:

$$\eta_{th} = \frac{\dot{m}_{air} C_{p,air}(T_{air,out} - T_{air,in}) + \dot{m}_w c_{p,w}(T_{w,out} - T_{w,in})}{A_C I} \quad (2)$$

Meanwhile, this paper focuses to discuss the optimal mass flow rate of coolants utilized by the system. The thermal efficiencies obtained, will be analyzed for fixed air flow with varied water flow rate.

3. RESULTS AND DISCUSSION

An outdoor experimental study had been carried out in order to have a real-situation test for a bi-fluid PVT system. The data collected that will be discussed focuses on the thermal efficiency gained by the bi-fluid PVT system. Data assemblage started as soon as the experiment started and ended as soon as the system had been covered from the sunlight which took place at 9 a.m. to 4 p.m., thoroughly.

Table 1. Optimal mass flow rate in attaining maximum average thermal efficiencies

Mass flow rate (kg/s) Air	Mass flow rate (kg/s) Water	Thermal efficiencies (%)	Average thermal efficiencies (%)
0.04	0.025	60.56 77.17 49.79	62.51
0.06	0.01	96.14 62.75 73.03	77.31
0.08	0.01	62.97 68.92 75.59	68.16
0.1	0.015	50.96 64.49 62.97	59.47

At each air mass flow rate, ranging from 0.04 kg/s to 0.1 kg/s had been resulted to have high thermal energy gain at different water mass flow rate. It had been summarized in Table 1 which presented optimal mass flow rate for both water and air for this simultaneously flow operation. The maximum efficiencies were recorded during the flow of pair mass flow rate of bi-fluid (water and air) as in the Table 1. The highest thermal energy efficiencies by averaging the thermal efficiencies calculated from 3 repeated experiment for the same parameter. At 0.06 kg/s or air flow rate and 0.01 kg/s of water mass flow rate, it had been resulted the highest average thermal efficiency which was 77.31%. By taking into consideration of the solar radiation absorbed by the PV collector, the solar radiated upon recorded were 645 W/m^2 to 810 W/m^2.

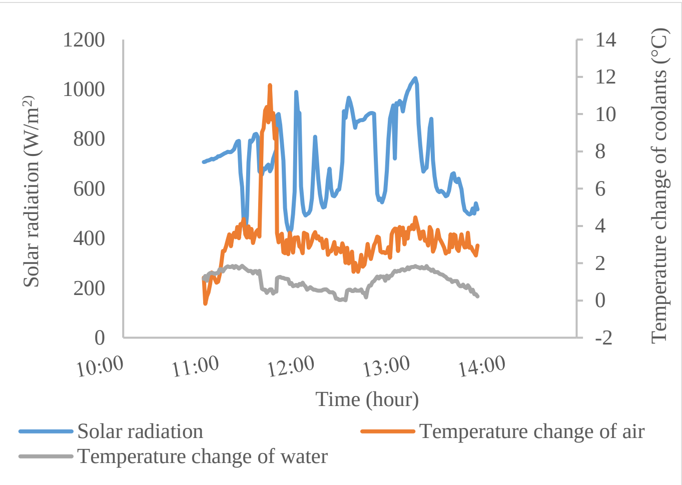

Figure 4. Temperatures and solar radiation against time for water mass flow rate of 0.03 kg/s

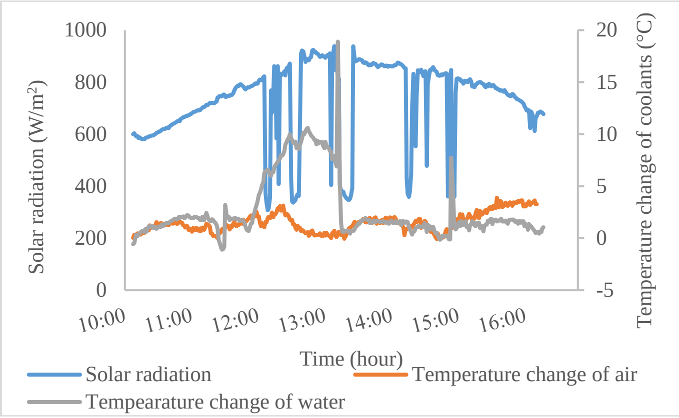

Figure 5. Temperatures and solar radiation against time for water mass flow rate of 0.025 kg/s

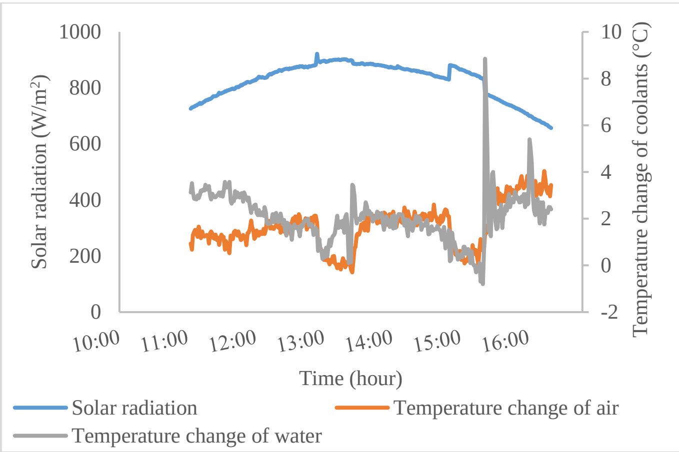

Figure 6. Temperatures and solar radiation against time for water mass flow rate of 0.02 kg/s

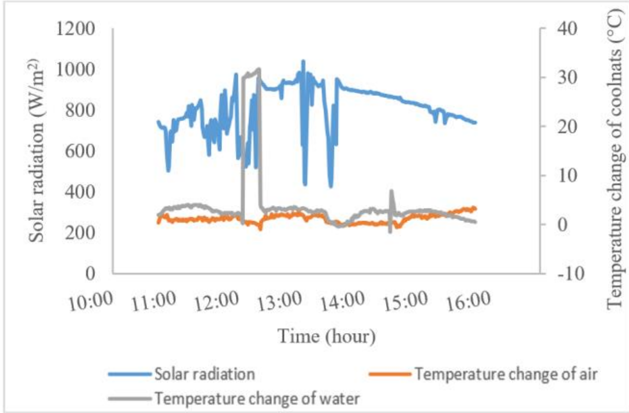

Figure 7. Temperatures and solar radiation against time for water mass flow rate of 0.015 kg/s

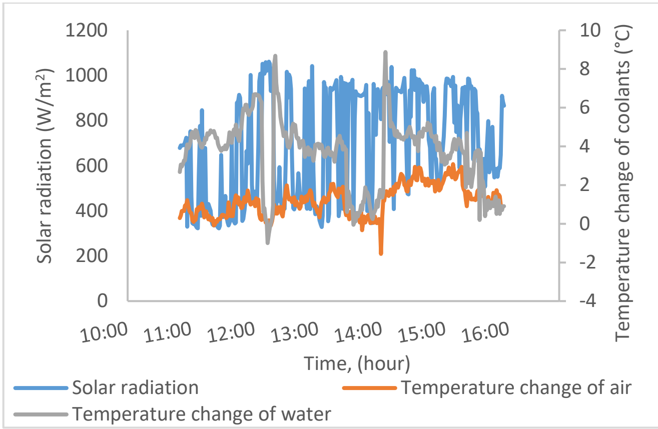

Figure 8. Temperatures and solar radiation against time for water mass flow rate of 0.01 kg/s

Table 2. Thermal efficiencies attained by PV with bi-fluid cooling at air mass flow of 0.06 kg/s

m (kg/s)	Solar Radiation (W/m^2)	To-Ti (^{o}C)	Thermal efficiencies (%)		Average thermal efficiencies (%)
			Air	Water	
0.03	625.96	1.1	0.9	50.82	54.74
	599.59	1.2	1.24	67.25	
	697.22	1.45	0.75	46.15	
0.025	694.44	0.88	1.91	64.35	59.01
	628.51	1.97	1.51	77.62	
	743.62	1.84	0.35	35.08	
0.02	825.515	1.46	2.5	63.64	65.93
	857.095	2.6	1.02	49.96	
	690.765	2.2	2.34	84.2	
0.015	810.71	1.55	2.25	51.1	60.96
	929.59	1.87	2.72	59.19	
	762.85	4.27	2.32	93.49	
0.01	646.68	1.37	6.42	96.14	77.31
	810.54	2.18	3.73	65.97	
	779.22	2.93	3.47	78.19	

As the highest thermal energy was achieved by allowing 0.06 kg/s of air, thus the further discussion had been on the same air flow rate (0.06 kg/s) with varied water mass flow rate. Hence, the trend of solar radiation along with the temperature differences against the time of operation had been illustrated in Figures 4 to 8. The temperature difference between the outlet and inlet fluids may affect the performances of PVT system in generating energy. As can be concluded from the Table 2, at the highest thermal efficiency presented high temperature difference between outlet and inlet fluids (water and air) which regulates and extract excess heat for the system to work effectively.

4. CONCLUSIONS

The experiment to investigate the optimal mass flow rate of cooling fluids, integrating to the PVT system had been conducted. By varying both mass fluids of coolant which were water and air, the result had shown that the highest thermal efficiency had been attained by PVT system with 0.06 kg/s and 0.01 kg/s of air and water mass flow rate. Then, the discussion on the result of thermal efficiencies had been narrowed down for further discusses on the fixed air flow with different water flow rate (0.03 kg/s, 0.025 kg/s, 0.02 kg/s, 0.015 kg/s, 0.01 kg/s). Amongst the varied flow, 0.01 kg/s of water flow rate had shown highest thermal efficiency which was 77.31 at temperature difference of coolants (water and air) were between 3.47°C to 6.42°C and 1.37°C to 2.93°C. Thermal energy efficiency is the highest recorded when the temperature difference of both the outgoing and incoming fluids is the highest. This proves that the residual temperature absorption is absorbed the fluid affects the energy generation efficiency due to the temperature of the photovoltaic panel can be well balanced and controlled.

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