WATER BASED PHOTOVOLTAIC THERMAL (PVT) COLLECTOR WITH SPIRAL FLOW ABSORBER: AN ENERGY AND EXERGY EVALUATION

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ABSTRACT
The inspiration of combining photovoltaic(PV) and solar thermal collector to provide electrical and heat energy is not new, however it is an area that has received only limited attention. With concern growing over energy sources and their usage, photovoltaic thermal (PVT) has become an area which is receiving much more attention. It comprised of the PV efficiency and thermal efficiency. The total of the both efficiencies, which is known as PVT efficiency was used to evaluate the overall performance of the system. Based on the testing performed on the collector, it was shown that both efficiencies increased when the mass flow rate increased. Therefore, the total efficiency (PVT efficiency) and primary-energy saving efficiency increased simultaneously when the mass flow rate increased. The water based PVT collector with Spiral flow absorber produced PVT efficiency of 58% to 64% with 10% -12% PV efficiency and of 42% -50% thermal efficiency, also it produced primary-energy saving efficiency from about 75% to 84% at the mass flow rate from 0.012 kg/s to 0.040 kg/s and solar radiation of 700W/m². On the other hand, the PVT exergy is between 100 to 170 W with thermal exergy of 50 to 120 W and electrical exergy of 60 to 63 W. Again, the entropy generation is between 92 and 129 W showing that it decreased with increased mass flow rate.

KEYWORDS: Exergy, Analysis, Spiral Flow Absorber, Photovoltaic Thermal (PVT) Collector.


1. INTRODUCTION
According to some experts, oil has already started to peak. Gas and coal reserves are bigger than oil, and 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 dependency on fossil fuels (Nwaeto and Placid, 2018). 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 (Ibrahim et al. 2010; Madu and Uyaelumuo, 2018).

The inspiration of combining photovoltaic (PV) and solar thermal collector to provide electrical and heat energy is not new, however it is an area that has received only limited attention. With concern growing over energy sources and their usage, photovoltaic
thermal (PVT) has become an area which is receiving much more attention. PVT solar collectors convert solar radiation directly to both electrical and thermal energies. A PVT collector basically combines the functions of a flat plate solar collector and those of a photovoltaic (PV) panel. The research on PVT started during the mid-1970s, with the focus on PVT collectors, and the main aim with increase of the PV efficiency. Domestic application was regarded as the main market. Initially the focus was on glazed collectors, both air based and water based. Due to these problems, the cost for a complete system of PVT is incredibly high and unaffordable to the industrial and residential owners. One of the most attractive application of PVT air or water based collectors are building integrated photovoltaic thermal (BIPVT) which has undergone rapid developments in recent years; however PVT air based system have been more developed. PVT system is a promising system to generate both energies due to its higher reliability system with lower environment impact. Generally, PVT water collector system consists of the PV module, absorber collector in the formed of tubes, the glass cover (transparent) and insulated container. It is expected that over the next few years, there will be a rapid growth in BIPVT publications and products (Touafek, Haddadi and Malek, 2013). Recently, performance analysis has been carried out exergy analysis on PVT collector. The main objectives of this paper is energy and exergy analyses of water based PVT collector with Spiral flow absorber, and investigate the effects of mass flow rate on energy and exergy efficiency.

2. METHODOLOGY

Figure 1 shows the Spiral flow absorber of water based PVT collector. Figure 2 shows the experiment set-up of a water based PVT collector with Spiral flow absorber. A standard PV module represented as a flat plate single glazing sheet of poly crystalline silicon has been laminated and bonded with a high temperature silicone adhesive and sealant. The absorber collector, consist of a single unilateral channel for the water to flow is inserted underneath the standard photovoltaic (PV) module. The size of the PVT collector is 0.65 wide and 1 m long. An indoor testing facility and an experimental setup of the PVT collector were constructed. The simulator was used 23 halogen lamps, each with rated of 500 W. The PVT collector has been exposed to the solar radiation of 800 W/m². When the load is applied to the collectors, the changes of current and voltage are recorded for each solar radiation selected. For mass flow rate, during this testing, the mass flow rate of 0.011 to 0.041 kg/s are set and any changes to the collector due to these mass flow rates are recorded. Data collected and stored in the ADAM Data Acquisition System for every 1 minute and later used to calculate the PV and thermal efficiency for the collector. The water inlet and outlet for this testing are control and circling back to the storage tank to form a close-loop system.

Figure 1: Spiral flow absorber
3. ENERGY ANALYSIS

The performance of water based PVT collector can be depicted by the combination of efficiency expression (Daghigh et al., 2011). It comprised of the thermal efficiency ($\eta_{th}$) and the electrical efficiency ($\eta_{PV}$). These efficiencies usually include the ratio of the useful thermal gain and electrical gain of the system to the incident solar irradiation on the collector’s gap within a specific time or period. The total of the efficiencies, which is known as total efficiency or PVT efficiency ($\eta_{PVT}$) is used to evaluate the overall performance of the system (Ibrahim, Othman, Ruslan, Mat and Sopian, 2011).

$$\eta_{PVT} = \eta_{th} + \eta_{PV}$$  \hspace{1cm} [1]

Considering that electrical energy is a high grade form of energy gain, primary energy saving efficiency is proposed as another performance evaluation method to recognize the energy grade difference between electricity and thermal, which is given by: (He, Zhang and Ji, 2011).

$$E_f = \frac{\eta_{PVT}}{\eta_{p}} + \eta_{th}$$  \hspace{1cm} [2]

Where ($\eta_p$) taken as 38% is the electric-power generation efficiency of the conventional power plant (Zhang, et al., 2012). The evaluation indicator of primary-energy saving efficiency concerns both of the quality and quantity of the energy that the PVT system converts solar energy too. The thermal efficiency of the collector is expressed as

$$\eta_{th} = F_R (\tau \alpha)_{PV} - F_R U_L \frac{T_i - T_a}{G_T}$$  \hspace{1cm} [3]

Electrical efficiency of the PV module ($\eta_{PV}$), which is a function of module temperature is given by Ji et al (2007):
where $\eta_r$ is reference efficiency of PV module ($\eta_r = 0.12$), $\beta$ is temperature coefficient ($\beta = 0.0045^\circ\text{C}$), $T_c$ is cell temperature and $T_r$ is reference temperature.

### 3.1 Exergy Analysis

Exergy analysis is a useful method to establish strategies for the design and operation of many industrial processes where the optimal use of energy is considered an important issue (Chow, Ji and He, 2007). This information is effective in determining the plant and the operation cost, the energy conservation, the fuel versatility and the pollutant. In the recent years, exergy analysis has been widely used for the performance evaluation of thermal systems. If the effects due to the kinetic and potential energy changes are neglected, the general exergy balance can be expressed in rate form as given by Vokas et al. (2006).

$$\sum Ex_m - \sum Ex_o = \sum Ex_d$$  [5]  
Or

$$\sum Ex_m - \sum (Ex_{ph} + Ex_{PV}) = \sum Ex_d$$  [6]  
Where

$$Ex_m = A_c N_c I \left[1 - \frac{4}{3} \left(\frac{T_a}{T_z} + \frac{1}{3} \left(\frac{T_a}{T_z}\right)^4\right)\right]$$  [7]  
$$Ex_{th} = Q_u \left(1 - \frac{T_a + 273}{T_o + 273}\right)$$  [8]  
$$Ex_{PV} = \eta_c A_c N_c I$$  [9]  
$$Ex_{PVT} = Ex_{th} + Ex_{PV}$$  [10]  

Where $Ex_{in}$ is input exergy (radiation exergy), $Ex_o$ is output exergy, $Ex_{th}$ is thermal exergy, $Ex_{PVT}$ is photovoltaic/thermal exergy, $A_c$ is collector area, $N_c$ is collectors number, $I$ is solar radiation, $T_a$ is ambient temperature and $T_s$ is sun temperature ($T_s = 5777K$). The exergy destruction ($Ex_d$) or irreversibility may be expressed as:

$$Ex_d = T_a S_{gen}$$  [11]  
The exergy efficiency ($\eta_{ex}$) of the second law efficiency may be expressed as

$$\eta_{ex} = 1 - \frac{Ex_d}{Ex_m}$$  [12]  

### 4. RESULTS AND OBSERVATIONS

Table 1 shows the summarized of comparison present study with other absorber collector designs (Zhang et al., 2012). The performance study to evaluate and understand the integration of PV and thermal system has been conducted. The study has compared the conventional solar water heater the PVT system known as integrated photovoltaic/thermal system (IPV/TS). It can be concluded that the solar PVT collector made from corrugated polycarbonate module produced good thermal efficiency. Further improvement could be achieved by proper insulation for the PVT design. The study managed to achieve the PV efficiency of 9% with 38% thermal efficiency in total efficiency (PVT efficiency) of 47%. The test results shows high efficiency on combined system achieved with primary energy saving for daily exposure approaches 65% at zero reduced temperature operation.

In this experiment, sensitivity study of the system has been performed and proved that by combining the system, the installation area produce more energy per unit surface area than one PV module and one hot water system.
Figure 3 shows PV, thermal, PVT and primary energy saving efficiencies for water based PVT collector with Spiral flow absorber under mass flow rate ranging from 0.012 kg/s to 0.040 kg/s and solar radiation at 700 W/m². The collector produced PVT efficiency of 58 to 68% with 10-12% PV efficiency and of 42-50% thermal efficiency, also it produced primary-energy saving efficiency from about 75% to 84% at the mass flow rate from 0.012 kg/s to 0.040 kg/s. Figures 4A and 4B shows the variation of exergies and entropy generation of the water based PVT collector with Spiral flow absorber. Figure 4 clearly shows that thermal and PVT exergy increase as the mass flow rate increases, and PV exergy show very slow increase. The PVT exergy is between 100 W and 170 W with thermal exergy of 50 to 120 W, and electrical exergy of 60 to 63W. On the other, entropy generation of collector decreased with increased mass flow rate. The entropy generation is between 92 and 129 W. Figure 5A and 5B shows the variation of efficiency and outlet temperature of the water based PVT collector with Spiral flow absorber. The energy and exergy efficiency of PVT collector increase as the mass flow rate increases. The PVT exergy is between 100 W and 170 W with thermal exergy efficiency of 50 to 120 W, and electrical exergy efficiency of 24 to 38%. On the other, outlet temperature of collector decreased with increased mass flow rate. The outlet temperature is between 53 and 66°C.

![Figure 3: Changes of efficiencies for Spiral flow absorber over various mass flow rates at solar radiation of 700 W/m²](image-url)
Figure 4A: Changes of exergies over various mass flow rates at solar radiation of 700 W/m$^2$

Figure 4B: Entropy generation over various mass flow rates at solar radiation of 700 W/m$^2$
5 CONCLUSION

The efficiencies have been obtained. The water based PVT collector with Spiral flow absorber produced PVT energy efficiency of 58 to 64% with 10-12% PV efficiency and of 42-50% thermal efficiency, also it produced primary-
energy saving efficiency from about 75% to 84% at the mass flow rate from 0.011 kg/s to 0.040 kg/s and solar radiation of 800W/m². On the other hand, the PVT exergy efficiency is between 25% and 42% with thermal exergy of 50 to 120 W and electrical exergy of 60 to 63 W. The entropy generation of collector decreased with increased mass flow rate. The entropy generation is between 92 and 129 W.

REFERENCES


