Evaluation of Single-Pass Photovoltaic-Thermal Air Collector with Rectangle Tunnel Absorber

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Abstract: Photovoltaic solar cell generate electric by receiving sun light or solar irradiance. But solar cell recieved heat from solar irradiance as well and this will reduced the efficiency of the solar cell. The heat trap at the solar photovoltaic panel become waste energy. The solution for this was by adding a cooling system to the photovoltaic panel. The purpose of this paper was to cool the solar cell in order to increase its electrical efficiency and also to produce heat energy in the form of hot air. Hot air can be used for drying applications. A single pass PVT with rectangle tunnel absorber has been developed. The rectangle tunnel acted as an absorber and was located at the back side of a standard photovoltaic panel. The dimension of the photovoltaic panel was 120 cm X 53 cm. The size of the rectangle tunnel was 27 units of tunnel bar with the size of 1.2cm X 2.5cm X 120 cm (width X tall X length) and 12 units with 1.2cm X 2.5cm X 105.3cm (width X tall X length). The rectangle tunnel was connected in parallel. The PVT collector has been tested using a solar simulator.

Results: Electrical efficiency increased when the solar cell was cool by air flow. Solar photovoltaic thermal collector with rectangle tunnel absorber has better electrical and thermal efficiency compared to solar collector without rectangle tunnel absorber. Photovoltaic, thermal and combined photovoltaic thermal efficiency of 10.02 %, 54.70 %, 64.72 % at solar irradiance of 817.4 W/m², mass flow rate of 0.0287 kg/s at ambient temperature of 25 °C respectively has been obtained. Conclusions: The hybrid photovoltaic and thermal with rectangle tunnel as heat absorber shows higher performance compared to conventional PV/T system.

Keywords: Photovoltaic thermal, rectangle tunnel absorber, thermal efficiency

A     Area of air flow (m²)
A₀    Area cover by solar cell (m²)
Aₚ    Area of solar panel (m²)
Cₚ    Specific heat capacity for air (Jkg⁻¹°C⁻¹)
Iₘ    Maximum current (A)
ṁ     Mass flow rate (kg/s)
ηₑl   Electrical efficiency (%)  
ηₘₜ   Thermal efficiency (%)  

Pₘ    Power maximum (W)
S     Solar radiation (W/m²)
Vₘ    Maximum voltage (V)
Vₐv   Air flow velocity (m/s)
1 Introduction

Efficiency of solar cell will drop when the temperature of it increases. The efficiency of the system will lose about 0.3% when cells temperature increased by 1°C [1]. Air can be used to cool the surface temperature of the photovoltaic panel. The air will pick up the surface heat and can be used for domestic of application including drying and other industrial process heat application.

A special type of solar collectors was design to collect electric energy and thermal energy simultaneously known as Photovoltaic-Thermal (PV/T) solar collector. Solar hybrid PV/T system can generate more energy per unit area compared to system of solar panel and thermal collector separately side by side [2]. The purpose of using hybrid solar photovoltaic-thermal system is to prevent the electrical efficiency to drop and to collect thermal energy in water or air as heat carrier. The first photovoltaic-thermal hot air collector application was tested at Solar Test House in Institute of Energy Conversion, University of Delaware at 1973 [3].

Solar energy includes system of drying is very attractive application and cost competitive such as drying of cocoa, ginseng, rubber, noodle, coffee beans, fruits, or fish, and prawns. Herbs like herbal tea and ginseng need long period of drying and if not dry under suitable condition, the herbs will spoil. 30-40% of agriculture like fruits and vegetables are expected spoil in developed country and in India alone spoil fruits worth more than US $ 1.5 billion annually [4]. Hence, suitable drying systems were to ensure the production quality. Solar drying system can provide better quality of drying compared to open sun drying under direct sunlight at the open air which was subject to insect infection and other contaminations [5].

Single pass solar collector with open channel absorber has been studied by earlier researcher [6, 7]. The double pass solar collector with upper and lower channels has been fabricated by other researchers [8, 9]. Comparison of single pass and double pass collector has been done and double pass solar collector shows better performance [10]. Further research has been conducted by combining heat conductor into solar collector such as v-groove, porous media, and fins [11, 12]. Purpose of adding heat conductor into solar collector was to enhance the heat extraction of collector and thus increase the efficiency of the collector. In this paper, rectangle tunnel absorber is added into the photovoltaic thermal collector as heat conductor.

A PV/T solar collector by combining photovoltaic panel and rectangle tunnel absorber as heat conductor was fabricate and tested in this experiment. A PV/T combined single pass solar photovoltaic with rectangle tunnel system. Using single pass system instead of double pass system was to avoid using large amount of area. This design was to maintain the electrical efficiency of the solar panel and to produce hot air by extract heat from solar panel.

The objective of this paper was to study that electrical efficiency and thermal efficiency of the photovoltaic thermal collector increased after adding rectangle tunnel absorber to the single pass solar collector system. Different mass flow rates have been tested on the collector to observe the effect of mass flow rate to the efficiency of collector.

2 Experiment set up

A solar panel model of SHARP NE-80E2EA which can produce 80W power when tested under 1000 W/m² solar irradiance and room temperature of 25°C was prepared. 27 units of rectangle tunnel bars with the size of 1.2cm X 2.5cm X 120 cm (width X tall X length) and 12 units with 1.2cm X 2.5cm X 105.3cm (width X tall X length) was prepared. The tunnel bars was placed at the back surface of solar panel as heat conductor. The solar panel was insulated with polyethylene to prevent heat loss. Ducting is design and fabricates to connect a blower to the photovoltaic air collector. The solar PVT collector was tested under 23 simulator halogen lamps. Regulators were used to control the brightness or solar irradiance from simulation lamps. Heaters made of 2 halogen lamps were placed inside the ducting to stabilize air temperature that going into the collector.

3 Experimental procedures

The experiment was run under 2 different solar irradiance values. Each solar irradiance was tested with 5 different mass flow rates. The photovoltaic thermal collector was tested with and without rectangle tunnel to compare the different. Solar irradiances from simulation lamps were set to 385.2 W/m² and 817.4 W/m². Mass flow rates were set to 0.0110 kg/s, 0.0287 kg/s, 0.0409 kg/s, 0.0552 kg/s, and 0.0754 kg/s. The test was run by setting the solar radiation to certain power and flow the air through the solar collector and slightly increase the mass flow rate for 5 times and collect data for each mass flow rate. Data like current, I (A), voltage, V (Volt), short circuit current, Isc (A) dan open circuit
voltage, $V_{oc}$ (Volt) and temperature, $T$ ($^\circ$C) is measure every 90 minutes. Data collected was used to determine the electrical efficiency and thermal efficiency of both collectors.

A pyranometer was used to determine solar irradiance. Multimeter was used to collect data like current, $I$ (A), voltage, $V$ (Volt) and temperature, $T$ ($^\circ$C). J type thermocouples were connected to multimeter as a temperature indicator. Ananometer DTA 4000 used to determine the air flow velocity in the solar collector.

4 Results and Observations

The purpose of this experiment was to improve the cooling system by carrying out as much heat as possible from solar photovoltaic PVT collector made for this experiment. So, this experiment was to increase both the electrical and thermal efficiency.

Air flow mass can be calculate from the equation below:

$$\dot{m} = \rho AV_{av}$$  \hspace{1cm} (1)

Air flow mass, $\dot{m}$ was needed to calculate the thermal efficiency of the PVT system. Density, $\rho$, area of air drain input, $A$ was standard value in this experiment. Air velocity, $V_{av}$ was determine using voltage regulator and blower.

$I_{sc}$ dan $V_{sc}$ can be achieve from connection of circuit directly from multimeter to solar panel. While $I_{m}$ dan $V_{m}$ can be achieve from connection of circuit by connect solar panel to Voltmeter and then Ampmeter while connect a Reostat, $R_p$ parallel to that Voltmeter. Where $I_m$ and $V_m$ were from power maximum, $P_m$. Power, $P$ was the result of current, $I$ times voltage, $V$.

$$P_m = I_m V_m$$  \hspace{1cm} (2)

Performance of the system PVT can be seen from electrical and thermal efficiency. Electrical efficiency, $\eta_{el}$ and thermal efficiency, $\eta_{therm}$ was shown as below:

$$\eta_{el} = \frac{I_{m}V_{m}}{A_cS} \times 100 \%$$  \hspace{1cm} (3)

$$\eta_{th} = \frac{\dot{m}C_p(T_o - T_i)}{A_pS} \times 100 \%$$  \hspace{1cm} (4)
5 Error Analysis

Every apparatus have their limitation of precise when collecting datas. This makes the apparatus have their own error and this error will affect the result of calculation. An equation to calculate error was needed when the equation contain 2 values or above with error. Deferentiation can be used to calculate error equation.

For mass flow rate’s equation, which was density of air X area of air flow X air velocity. Density of air can be excluded from error equation because its a constant value. Equation to calculate error for mass flow rate was shown below:

\[
\delta m = \left[ \frac{\delta A + \delta V}{V} \right] \delta m
\]  

(5)

For electrical efficiency, which was current maximum X voltage maximum divided by cells surface area X solar irradiance. All this values was calculated by apparatus and so had errors.

\[
\delta (I_{m} \times V_{m}) = \left[ I_{m} \times \delta (V_{m}) \right] + \left[ V_{m} \times \delta (I_{m}) \right]
\]  

(6)

\[
\delta (A_{c} \times S) = \left[ A_{c} \times \delta (S) \right] + \left[ S \times \delta (A_{c}) \right]
\]  

(7)

\[
\delta n_{el} = \frac{\left[ (A_{c} \times S)\delta (I_{m} \times V_{m}) \right] - \left[ (I_{m} \times V_{m})\delta (A_{c} \times S) \right]}{[A_{c} \times S]^2}
\]  

(8)

For thermal efficiency equation, specifc heat for air, Cp was a constant value and not determine using any apparatus. Thus, Cp can be ignore when calculating error for thermal efficiency. Below are the data needed for thermal efficiency error calculation:

\[
\text{nt h} = \frac{\delta \times \Delta T}{A_{p} \times S}
\]  

(9)

\[
\delta (\text{nt h}) = \left[ \frac{\delta (\text{nt h})}{\text{nt h}} \right] + \left[ \frac{\delta (\Delta T)}{\Delta T} \right] + \left[ \frac{\delta (S)}{S} \right]
\]  

(10)

\[
\delta (A_{p} \times S) = \left[ A_{p} \times \delta (S) \right] + \left[ S \times \delta (A_{p}) \right]
\]  

(11)

\[
\delta n_{th} = \frac{\left[ (A_{p} \times S)\delta (\text{nt h}) \right] - \left[ (\text{nt h})\delta (A_{p} \times S) \right]}{[A_{p} \times S]^2}
\]  

(12)

The error for mass flow rate was 0.0052 kg/s for example (754±52) X 10^{-4} kg/s. Error for electrical efficiency around 4.04 % to 4.43 % and for thermal efficiency was around 0.28 % to 0.49 %. Error for thermal efficiency was lower then electrical efficiency and its because the mass flow rate used in thermal calculation had smaller error compare to current and voltage used in electrical.

Figure 7 shows that surface temperature of photovoltaic panel drops when increasing the mass flow rate. Solar photovoltaic thermal collector with tunnel has lower temperature compare to collector without tunnel. This shows that collector with tunnel can help carry more heat out of the solar collector.

Figure 8 shows I-V curve for collector with and without tunnel at 0.0552 kg/s mass flow rate and solar radiation of 817.4 W/m². Figure 8 shows that collector with tunnel has higher power maximum compared to collector without tunnel. Collector
with tunnel have power maximum of 22.45 W and collector without tunnel has only 20.66 W.

From Figure 7 and Figure 8 can be noticed that photovoltaic cells that have lower temperature can archived higher open circuit voltage \( (V_{oc}) \), short circuit current \( (I_{sc}) \), and also power maximum \( (P_m) \). This result shows that lower temperature of photovoltaic cells can increase the power output and increasing in cells temperature will lower the power output and the efficiency as well.

0.04 kg/s. For collector with tunnel, thermal efficiency reached steady stage after 0.07 kg/s of mass flow rate. From Figure 7 and figure 10 above, the thermal efficiency can increase about 30% if temperature of photovoltaic module drops about 20°C.

Fig. 9: Electrical efficiency of both collectors

Figure 9 shows the electrical efficiency increase when the mass flow rate increases. But the electrical efficiency only increase to certain mass flow rate and then archived static stage after 0.07 kg/s of mass flow rate. Photovoltaic thermal collector with tunnel shows better efficiency in electrical compare to collector without tunnel because solar panel has lower temperature for solar collector with tunnel.

Fig. 10: Thermal efficiency of both collectors

Thermal efficiency over mass flow rate above shows about the same increase with electrical efficiency but only has much higher efficiency. Thermal efficiency for collector without tunnel reaches steady stage when the mass flow rate over

6 Conclusions
Solar cells generate more electricity when receive more solar radiation but the efficiency drops when
temperature of solar cells increase. Hybrid photovoltaic and thermal collector can solve the problem. Photovoltaic thermal collector with tunnel shows better performance in cooling, electrical and thermal efficiency. Efficiency of the collector will increase with the increase of mass flow rate or the air flow velocity. The efficiency archived steady stage when reach to certain mass flow rate or can be said that the system reach maximum performance. At mass flow rate of 0.0754 kg/s, electric efficiency can archive 10.06 % and thermal efficiency was 75.16%. Errors in Figures 9 and 10 were because of the rheostat used in the experiment was inconsistent.

Recommendations for this experiment were that minimise the error of the apparatus used. The solar collector can be change to double pass collector to compare its performance with single pass system. Rectangle tunnel absorber can be change to fin or porous media to compare the performance. System collecting data using computer called data logger can be used to collect data like for more precise data.

**Acknowledgment**
The researcher is grateful to have supports from Prof. Kamaruzzaman, Prof. Yusof, Dr. Hafidz and also financial support from SERI, UKM.

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