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EFFECTS OF THE FLOW CHANNEL MATERIALS ON THE PERFORMANCE OF THE PHOTOVOLTAIC THERMAL SYSTEM

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ABSTRACT

Photovoltaic thermal (PV/T) system is a well-engineered extension of photovoltaic (PV) technology to get both heat and electricity. Heat exchanger (flow channel) extract heat from the PV cells by heat transfer fluid for thermal applications. Material used to fabricate the flow channel has a vital impact on effective heat removal. In the present research, effect of flow channel material on heat transfer rate and PV/T performance has been investigated experimentally for copper and aluminum based PV/T system under the same ambient condition. Maximum PV/T thermal efficiency attained are 71% and 70% for copper and aluminum channel respectively where the aluminum based PV/T is about 2.5 times cheaper than copper based PV/T. It can be concluded that aluminum based PV/T is more cost-effective.

Keywords: Solar energy, photovoltaic thermal system, flow channel materials, thermal applications.

NONMENCLATURE

Abbreviations	
PV	Photovoltaics
PV/T	Photovoltaic thermal
STC	Solar thermal collector

1. INTRODUCTION

Photovoltaic thermal (PV/T) system is a well-engineered merger of conventional photovoltaic (PV) with solar thermal collector (STC) that not only improves electrical efficiency of the system but also provides heat for thermal applications [1,2]. The PV/T system opens a new horizon in efficient utilization of solar energy. Many technological and economical aspects are still to be solved and/or improved to make this technology commercially viable. Hence, research works are under way both in academia and industry to ameliorate as well as upgrade this technology. In course of carrying out investigation into different aspects of PV/T, researchers have adopted both numerical and experimental methods. Shadi et al. [3] investigated the effect of weather conditions on PV cell ratio to maximize the overall thermal efficiency of PV/T systems. Huide et al. [4] carried a comparative performance analysis of PV/T systems coupled with PV pump, traditional pump and natural circulation. Nahar et al. [5] conducted a numerical investigation on the effect of different parameters in enhancing heat transfer performance of PV/T systems. Hossain et al. [6] carried out an experimental investigation of parallel serpentine flow PV/T system under Malaysian climatic conditions. Nahar et al. [7] numerically and experimentally investigated the performance of a PV/T system with parallel-plate collector. Authors also proposed a novel pancake flow channel configuration for thermal collector and investigated its performance features through numerical investigation [8].

The above literatures show that most of the researches focused on the performance analysis of PV/T systems with different thermal collector designs and optimization of geometrical configuration. However, investigation regarding the effect of channel material has not yet been addressed so far. In this article, effect of using different channel material, viz., copper and aluminum, on PV/T performance has been investigated experimentally in the outdoor conditions.

2. METHODOLOGY

Experimental investigation of the comparative performance of PV/T modules of the same design but different channel materials of copper and aluminum has been carried out in the Solar Garden of UM Power Energy Dedicated Advanced Centre (UMPEDAC), University of Malaya, Kuala Lumpur. Experiments were carried out in the tropical outdoor conditions where the average daytime temperature ranged from 27^o to 36^{o}C with an irradiation of 150 to 1100 W/m^2.

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2.1 *Experimental Set up and Instrumentations*

The experimental setup (Fig 1) includes two PV/T modules both with parallel-plate flow channel, the channels being made of different materials: copper and aluminum. The meteorological data have been taken on site; the irradiation is measured by a LI-COR PY82186 model silicon pyranometer. An I-V tracer is used for measuring module output in terms of short-circuit current (I_{sc}), open-circuit voltage (VoC), maximum current (I_m), maximum voltage (V_m) and maximum power (P_{max}). A variable-area meter of model LZB-10B is used to measure the flow rate and different temperatures were taken by using PTFE exposed welded tip K-type thermocouples. All the data were acquisitioned by using Data Taker DT80 model data logger in one-minute interval.

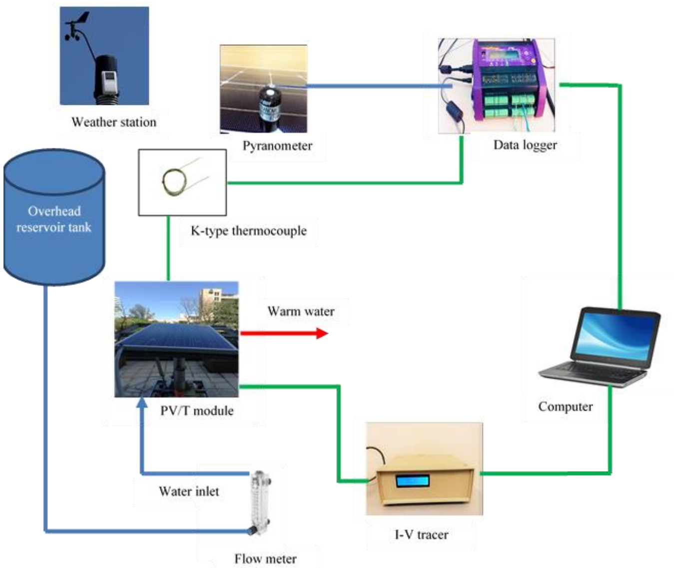

Fig 1 Schematic diagram of the experimental set up [7]

The dimensions of the parallel-plate channel are: 1350×920×30mm (L×W×D). Thermal conductivities channel material copper and aluminum are 401 and 237 W/m.K [9]. PV cell and glass properties are: transmissivity of cover glass is 0.9, absorptivity of PV cell 0.9, packing factor the cells 0.95, PV efficiency at STC 14% [10].

2.2 Mathematical Formulation

Total amount of energy (solar irradiance) into the PV module can be calculated as follows [11-13]:

$$E_c = p_c \tau_g \alpha_c R A_c \tag{1}$$

The thermal energy extracted by coolant water:

$$E_{th} = \dot{m} C_{pw} \left(T_{out} - T_{in} \right) \tag{2}$$

Where, $\dot{m} = \rho U_0 A_i$ mass flow rate. The electrical efficiency (η_{el}) is calculated by the following equation as

$$\eta_{el} = \eta_{ref} \left[1 - \beta_{ref} \left(T_c - T_{ref} \right) \right] \tag{3}$$

where η_{ref} is the reference efficiency at standard conditions (R = 1000 W/m^2 and T_{ref}= 25°C), β_{ref} is the thermal coefficient, 0.00045/K for silicon cell.

The thermal efficiency is calculated by

$$\eta_{th} = \frac{E_{th}}{E_c} \tag{4}$$

The total efficiency of PV/T collector is calculated by

$$\eta_{tol} = \frac{E_{th} + E_{el}}{E_c} \tag{5}$$

3. RESULTS AND DISCUSSION

3.1 Effect of Inlet Velocity on PV/T

The effect of the inlet velocity on the performance of the PV/T system is shown in Fig2 (a) to (d) under the condition inlet and ambient temperature 34°C at irradiation level 1000 W/m^2 with inlet velocities varying from 0.0003 to 0.0007m/s. Fig2 (a) shows that the average cell temperature decreases with increasing inlet velocity for both aluminum (by 5.5°C) and copper (by 5.4°C). It also shows that cell temperature achieved with copper channel is about 1.5°C lower than that with aluminum channel. As the thermal conductivity of copper is almost double the aluminum, so heat removal with copper channel is more effective. Therefore, copper is better choice as thermal collector material from the viewpoint of cell temperature reduction. Fig2 (b) and (c) show both output power and electrical efficiency are upraised with increasing water inlet velocity. The average cell temperature is reduced with increasing water velocity; as a result, PV current drops marginally with noticeable increase in PV voltage which in turn, increases the output power and electrical efficiency of the module. For aluminum channel, the maximum PV output power obtained is 106W and the electrical efficiency achieved is around 10%, while for copper channel the maximum PV output power and the electrical efficiency attained is 108W and 10.2% respectively. In Fig 2 (d), it is seen that thermal efficiency is increasing due to increasing the inlet velocity. The maximum thermal efficiency of copper channel is 71% and of aluminum is 70%.

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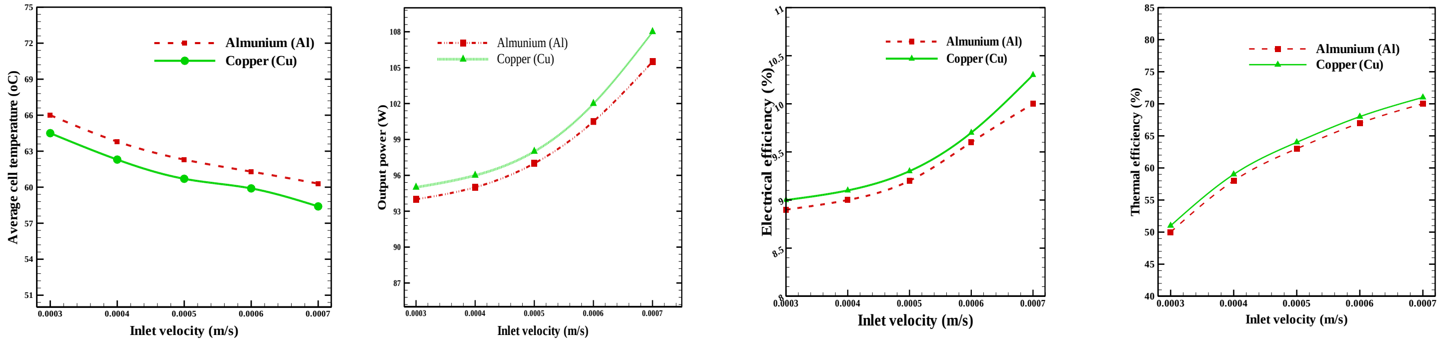


(a) (b) (c) (d)

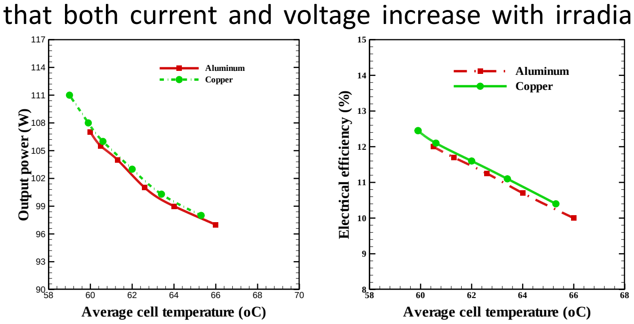
Fig 2 Effect of inlet velocity on the performance of PV/T at irradiation 1000 W/m

3.2 Effect of Cell Temperature on PV

In Fig 3 (a) and (b) is shown that both of output power and electrical efficiency decrease with increasing cell temperature. With decrease in cell temperature, output power increases by 9 W for aluminum and 10 W for copper and electrical efficiency increases by 0.8% for aluminum and 0.9% for copper. The reason behind the above trend is that a decrease in cell temperature causes significant increase in PV voltage with a slight decrease in PV current, which eventually increase the output power and electrical efficiency.

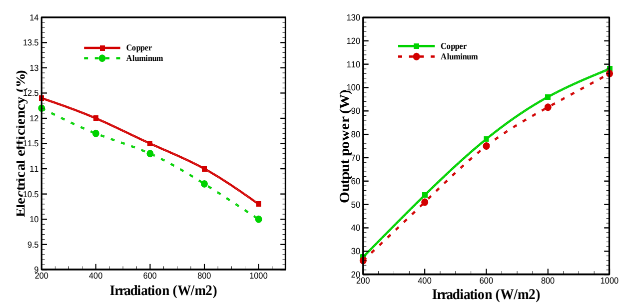
3.3 Effect of Irradiation on PV

It can be noticed from Fig 4(a) for both aluminum and copper channel that output power increases with increasing irradiation. It is due to the fact that both current and voltage increase with irradiance where the increment rate of current is linear and much greater than the logarithmic increasing rate of voltage; as a result, the output power increases almost linearly with irradiation. Fig4(b) shows that electrical efficiency decreases with increasing irradiation level for both aluminum and copper channel. As the irradiation level increases from 200 W/m^2 to 1000 W/m^2, electrical efficiency drops from 12.2% to 10% for aluminum and from 12.4% to 10.3% for copper channel. The effect of increase in irradiation and decrease in temperature on electrical performance of PV/T system is given in Table 1. It is apparent from the table that although output power increases with increasing irradiation and decreasing temperature level, but the electrical efficiency drops for both channel for the same increment level.



(a) (b)

Fig 3 Effect of cell temperature on PV performance at irradiation level 1000 W/m^2



(a) (b)

Fig 4 Effect of irradiation on PV performance at inlet velocity 0.0007 m/s

Table 1 Effect on PV performance by different parameters

Performance parameters	**Change in PV performance parameters per 1°C decrease in cell temperature**		**Change in PV performance parameters per 100 W/m^2 increase in radiation**	
	Al	**Cu**	**Al**	**Cu**
Output power (W)	increase by 1.6	increase by 1.8	increase by 10.0	increase by 10.1
Electrical efficiency (%)	increase by 0.12	increase by 0.14	decrease by 0.27	decrease by 0.26

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3.4 Cost Benefit Analysis

Cost benefit analysis of the two PV/T systems (copper and aluminum thermal collector has been carried out based on the local Malaysian market prices of the materials and equipment. Analysis shows that using aluminum as thermal collector material will save the total cost of PV/T by almost 2.5 times as compared to using copper. In addition, use of aluminum reduce the weight by about 3.3 times that makes it convenient for installation and operation. Hence, PV/T system with aluminum thermal collector is recommended for cost-effective application of PV/T.

4. CONCLUSIONS

The following inferences have been drawn from the present research works:

- Maximum electrical efficiency obtained are 10% for aluminum and 10.3% for copper
- Maximum PV/T thermal efficiency attained are 71% for copper and 70% for aluminum channel
- For every 1°C decrease in cell temperature, output power increases by 1.6 W for aluminum and 1.8 W for copper, while electrical efficiency increases by 0.12% for aluminum and 0.14% for copper.
- For every 100 W/m^2 increase in irradiation level, electrical efficiency drops by 0.27% for aluminum and 0.26% for copper, while output power increases by 10 W for aluminum and 10.1 W for copper.
- Aluminum based PV/T collector is about 2.5 times cheaper than copper based PV/T.

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REFERENCE

[1] Islam MM, Pandey AK, Hasanuzzaman M, Rahim, NA. Recent progresses and achievements in photovoltaic-phase change material technology: A review with special treatment on photovoltaic thermal-phase change material systems. Energy Convers Manage 2016; 126:177-204.

[2] Hasanuzzaman M, Malek ABMA, Islam MM, Pandey AK, Rahim NA. Global Advancement of Cooling Technologies for PV Systems: A Review, Sol Energy 2016; 137:25-45.

[3] Shehadeh SH, Aly HH, El-Hawary ME, Investigation of photovoltaic coverage ratio for maximum overall thermal energy of photovoltaic thermal system. Renew Energ 2019; 134:757-768.

[4] Fu H, Li G, Li F. Performance comparison of photovoltaic/thermal solar water heating systems with direct-coupled photovoltaic pump, traditional pump and natural circulation. Renew Energ 2019; 136:463-472.

[5] Nahar A, Hasanuzzaman M, Rahim NA, Parvin S. Numerical investigation on the effect of different parameters in enhancing heat transfer performance of photovoltaic thermal systems. Renew Energ 2019; 132:284-295.

[6] Hossain MS, Pandey AK, Selvaraj J, Rahim NA, Rivai A, Tyagi VV. Thermal performance analysis of parallel serpentine flow based photovoltaic/thermal (PV/T) system under composite climate of Malaysia. Appl Therm Eng 2019; 153:861-871.

[7] Nahar A, Hasanuzzaman M, Rahim NA. Numerical and experimental investigation on the performance of a photovoltaic thermal collector with parallel plate flow channel under different operating conditions in Malaysia. Sol Energy 2017; 144:517-528.

[8] Nahar A., Hasanuzzaman M, Rahim NA. A three-dimensional comprehensive numerical investigation of different operating parameters on the performance of a photovoltaic thermal system with pancake collector. J Sol Energ Eng 2017; 139(3): 031009.

[9] Engineering ToolBox. Thermal Conductivity of common Materials and Gases. 2003; https://www.engineeringtoolbox.com/thermal-conductivity-d_429.html, Retieved on 09/05/2019.

[10]Tiwari A, Sodha MS, Chandra A, Joshi JC. Performance Evaluation of Photovoltaic Thermal Solar Air Collector for Composite Climate of India,Sol Energy Mater Sol Cells2012; 90(2):175–189.

[11]Rahman MM, Hasanuzzaman M, Rahim NA. Effects of various parameters on PV-module power and efficiency, Energ Convers Manage 2017; 103:348-358.

[12] Dubey S, Tay AA. Testing of Two Different Types of Photovoltaic–Thermal (PVT) Modules With Heat Flow Pattern Under Tropical Climatic Conditions, Energy for Sustainable Development, 2013;17(1):1–12.

[13]Rahman MM, Hasanuzzaman M, Rahim NA. Effects of operational conditions on the energy efficiency of photovoltaic modules operating in Malaysia, J Clean Prod 2017; 143: 912-924.

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