Photovoltaic Thermal (PV/T) Water Collector Experiment Study

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Abstract: - PV/T collector can generate electric and heat energy simultaneously in a single solar collector had more advantage compare to conventional PV and thermal collector separately either in mass, space and energy collected. The thermal energy collected by PV/T can be in the form of air, water or any other fluids depend on the applications and fluid flow systems. A PV/T water based collector had been developed in this research to observe the electrical and thermal performance of the collector. A split flow design was fabricated using copper tubes placed below a PV panel working as an heat absorber. The collector was tested indoor under various solar irradiances and different fluid flow rates. The result of the PV/T collector had been shown under electrical efficiency and thermal efficiency. All comparison is based on fluid flow rate and solar irradiance determined in the experiments. 3 different solar irradiances 300 W/m^2, 600 W/m^2 and 800 W/m^2 and 3 fluid flow rates was choose to examine the performance of the PV/T collector.

Key-Words: -: PV/T, water based, split design, efficiency

1 Introduction

PV panel that expose under great sunlight will gain electric energy with photons and at the same time received excessive heat energy. This experiment was to remove the excessive heat energy and collect it. Photovoltaic thermal (PV/T) collector is a hybrid collector that generates electric and heat energy simultaneously. Heat energy produce by PV/T collector can be in the form of air or water. The reason of combining photovoltaic (PV) panel and thermal collector together is because of solar cell's efficiency drops with the increase of cell's temperature. The efficiency of PV drops about 0.3% for each 1^{o}C of temperature increase [1]. Another reason is that heat trap in PV panel has become waste heat and this heat energy can actually be used in various applications depending on the form of heat energy (water or air). Hot air collected can be used for drying purpose (normally crops drying) and hot water can be used for domestic application. So, by combining PV panel and thermal absorber can not only avoid electrical efficiency from decreasing but also gaining some thermal energy. PV/T collector can be classified as 5 different types as shown below [2], [3]:

- Liquid PV/T collector
- Air PV/T collector
- Ventilated PV with heat recovery
- Liquid and air PV/T collector
- PV/T concentrator

Single pass solar collector with open channel absorber has been studied by earlier researcher [4], [5]. The double pass solar collector with upper and lower channels has been fabricated by other researchers [6], [7]. Comparison of single pass and double pass collector has been done and double pass solar collector shows better performance [8].

There are several experiment done on PV/T water based collector but not many. An experiment testing the performance of different modules both using PV/T water based design [9]. The research on this experiment found that using cooling fluid could archive high PV/T collector performance both in electrical and thermal. Another researcher in China worked on hybrid of heat pipe PV/T collector and found that the collector get 8.45 % of electrical efficiency [10].

There are researches done on testing the performance of PV/T collector with glazing. The research shows that PV/T with glazing increased the thermal performance of PV/T while reduce the electrical performance. The research suggests adding more glazing to the PV/T collector if the application required more thermal energy [11].

Several researches conclude that some parameters other than solar irradiance can affect the total performance of a PV/T collector. The parameter such as mass flow rate of the fluid which runs inside an absorber either as air or water can effect greatly on electric and thermal performance of the PV/T collector. Selecting a correct mass flow rate can provide optimum performance of a PV/T collector [12]. A research suggests using minimum of fin and tube as absorber to the PV/T collector can minimize the production cost and increase the performance [13]. The research state that the optimize configuration PV/T collector archive higher performance, lower mass and cheaper cost compare to non-optimize PV/T collector. An experimental study and analytical model on PV/T collector using PPO polymer absorber plate to absorber heat from PV panel and transfer it to the water [14]. The collector was able to keep the operating cell temperature below 45^{o}C. Two Study case under Cyprus climate condition on an unglazed PV/T hybrid system has been done and was observe electrical efficiency of 7.7% and thermal efficiency of 49% while the other archive 6.7% and 33% of electrical and thermal efficiency respectively [15], [16].

Simulation on PV/T collector using TRNSYS to study the collector's optimizing performance. Simulation on electrical and hot water system performance shows the PV/T collectors have better energy and exergy advantage over the convention PV and thermal collector separately [17], [18].

In this paper will be focus on design of the PV/T collector and performance of split flow design of PV/T water collector. The performance will be determined from electrical and thermal efficiency by adding copper absorber underneath a polycrystalline PV panel. The benefits of hybrid PV/T collector are space saving and more energy can be generated by a single collector at the same time compare to convention PV panel and thermal collector. Application of hot air produce by PV/T collector can be of space heating and drying. There are various designs of PV/T air collector which shows different performance in either heat or electric energy efficiency.

2 Experiment Design

2.1 PV/T absorber Design and fabrication

A PV/T water collector was design, fabricated and tested under this experiment. This PV/T water collector is a simple split flow design using copper tube as heat absorber which was attach to the back surface of PV panel. The function of using copper tube was to extract the heat energy that trapped in PV panel more efficiently. Fig. 1 shows the design of PV/T absorber that attach under PV panel by simulation drawing.

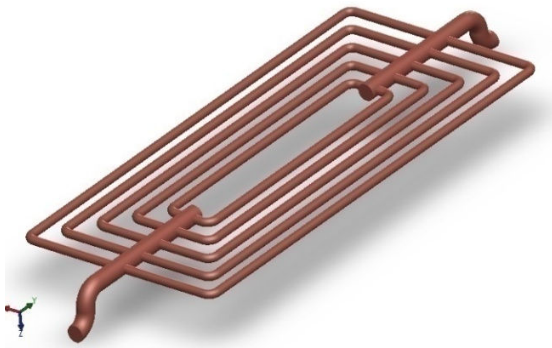

Fig. 1: Simulation drawing of split flow absorber.

The size and dimension of the absorber was measure and calculated according to the size of PV panel used in this experiment. The shape and size of absorber had to be measure carefully due to limited space under the PV panel to be fit in and there is a black box for circuit connection located at the middle of one end. The design of Split flow absorber was 10 copper tubes in parallel and both left and right side have equal length to the opposite side. The design was meant to cover the back surface of the solar panel. The specification of the PV panel used in this experiment was shown in Fig. 2 below.

Fig. 2: Specification of PV panel.

The PV panel was a poly-crystalline PV module with 110W Maximum power tested under STC: 1000 W/m^2, cell temperature 25^{o}C. The PV panel was produce by a Malaysia company SolarTIF. Dimension of the PV panel was 1468mm X 660mm X 47mm as measured. The dimension is the maximum size of an absorber can fit under a photovoltaic panel. The size of the absorber was sketch and measured as shown in Fig. 3.

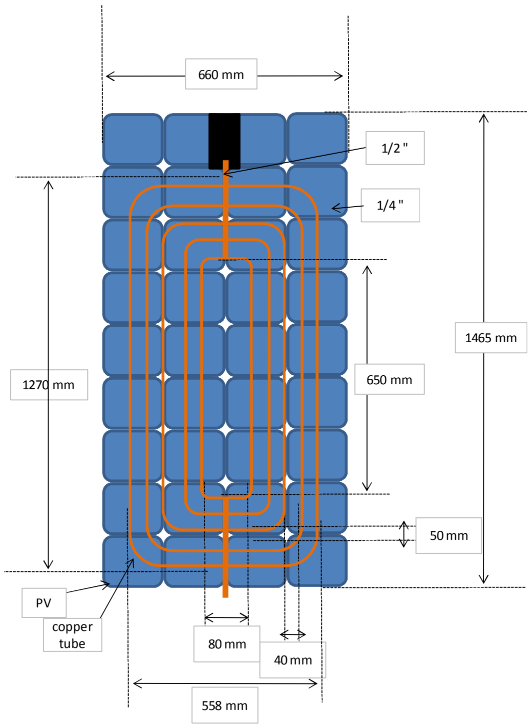

Fig. 3: Dimension of absorber (copper pipe) place under the PV panel.

Split flow design was fabricated accordingly to the dimension as mention above as shown in Fig. 4. A split flow absorber was fabricated and then placed underneath a PV. The absorber had to contact with the back of the photovoltaic panel as conduction is the most efficient heat transfer process.

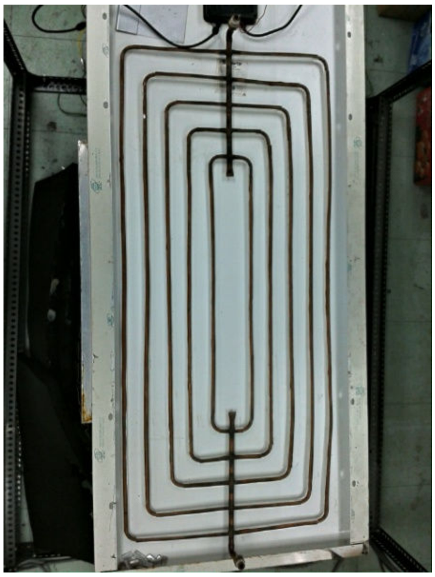
Fig. 4: Actual split flow absorber design.

Copper has a great thermal conductivity compare to other high heat conductivity material. Unfortunately, copper only comes in tube shape in most regions in the world. Most efficient way of heat transfer is by conduction and by that surface area of conducting among materials is important. As for copper which come in tube shape, conduction between materials is very limited as only a small region of the copper tube conduct with the back of flat surface material. In order to improve the conduction surface area between copper tube and the back of PV surface, a thin aluminium plate was band like a drain and fit among all copper tubes as shown in Fig. 5 below.

ISBN: 978-1-61804-175-3

Fig. 5: Thin aluminums are placed to all copper tubes.

Thin aluminium thickness was around 0.1mm to avoid heat loss and for better heat transfer. Thin aluminium is for copper tube to absorb heat from PV back surface easier. The thicker a material is a better heat insulation. The effectiveness of an insulator was depending on thickness, d and conduction coefficient, k as shown in R-value below.

$$R = \frac{d}{k} \tag{1}$$

The absorber was place nicely under the back of PV panel and covered by polyurethane insulation sheet of 1 inch thickness. Insulation under the absorber was to prevent heat loss to the surround and allowed better heat absorb by the copper. The more heat absorb by copper will provide higher water temperature output to be store.

2.2 Experiment indoor test

Experiment to determine the efficiency of the PV/T water based collector is done in the lab. Indoor experiment can provide standard solar irradiance and stable room temperature. Ambient temperature is important as it will affect the temperature on PV panel and change the electric and thermal efficiency of the PV/T collector. Outdoor environment unable to determine electrical efficiency as measuring Power Maximum (P_m) required standard ambient temperature and solar irradiance.

PV/T water based collector was tested under 23 unit of halogen light with various solar irradiance and mass flow rate. Efficiency was determined under 3 different solar irradiances which is 300 Wm^{-2}, 600 Wm^{-2} and 800 Wm^{-2} adjust using regulators. While a flow meter used in the experiment to set 3 different mass flow rates includes 0.5 LPM, 2 LPM and 4 LPM to determine optimum performance condition. Most electrical data such as current (A), voltage (V), short circuit current (I_{sc}) and open circuit voltage (V_{oc}) data was taken manually using multimeters. Electrical data was taken every 15 minutes along the experiment. Temperature data and solar irradiance was taken every second using ADAM DATA ACQUISITION MODULE. EPPLEY RADIOMETER was used as pyranometer with high sensitivity to indicate solar irradiance changes. The pyranometer used has a reference derived value constant of 9.13 x 10^{-6} V/Wm^{-2}. The experiment runs on each solar irradiance together with different mass flow rates. The electrical data was important to determine electrical efficiency as to collect the P_m data. P_m can be obtained from equation (2) below:

$$P_m = I_m \times V_m \tag{2}$$

Collecting a set of A and V data can provide an I-V Curve which is a most common graph used to determine P_m. Then P_m can be used in equation (3) below to determine electrical efficiency, πel correctly. While thermal efficiency can be determined from equation (4).

$$\pi_{el} = \frac{Im \times Vm}{A_{pv} \times S} X100\% \tag{3}$$

$$\pi_{th} = \frac{\dot{m} \times Cp \times \Delta T}{A_c \times S} X100\% \tag{4}$$

3 Result and Discussions

The purpose of hybrid PV panel to solar thermal collector was to improve both electrical and thermal efficiency. The way of improving the overall efficiency of PV/T collector was by design at better cooling system to the PV panel and also better heat collector and absorber that collaborate with PV panel. The better heat extract from PV panel, the higher performance of PV/T collector will be.

3.1 Electrical Performance

Fig. 6, Fig.7 and Fig. 8 below shows the IV-Curve graph plot from the electrical data collected differently under 300 W/m^2, 600 W/m^2 and 800 W/m^2 for each graph. Each graph present current and voltage data for 0.5 LPM, 2 LPM and 4 LPM water flow rate. From this IV-Curve we can get the Pm for each line and determined the electrical efficiency for each condition. Fig. 6, Fig.7 and Fig. 8 indicate that increasing of the solar irradiance will increase the I_{sc}. Increasing of the fluid flow rate will also increase the P_m of the graph. The data collected also indicated that increase of fluid flow rate will improve the V_{oc} of the graph. Improve of the I_{sc} and V_{oc} will lead to higher P_m and better electrical efficiency performance. More accurate data of efficiency will be shown in tables below.

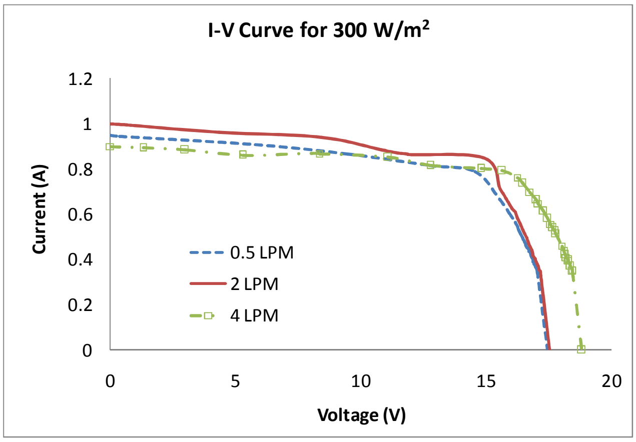

Fig. 6: IV-Curve for various mass flow rates tested under 300 W/m^2 solar irradiance.

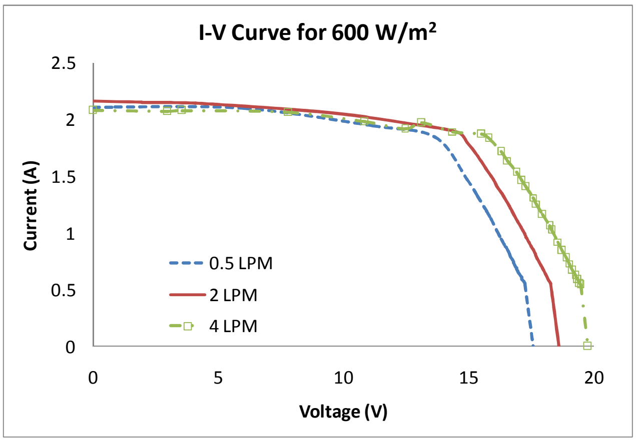

Fig. 7: IV-Curve for various mass flow rates tested under 600 W/m^2 solar irradiance.

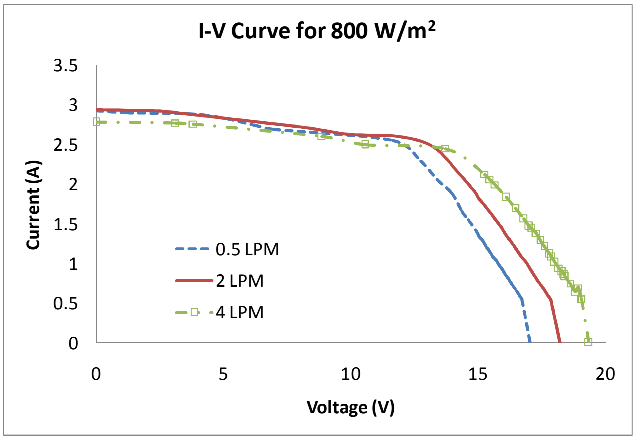

Fig. 8: IV-Curve for various mass flow rates tested under 800 W/m^2 solar irradiance.

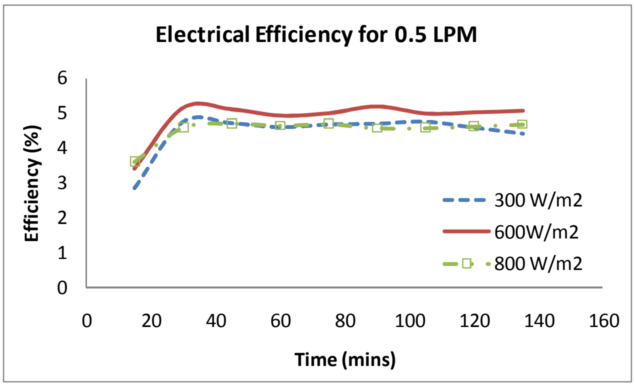

Fig. 9: Electrical efficiency for various solar irradiances under 0.5 LPM fluid flow rate.

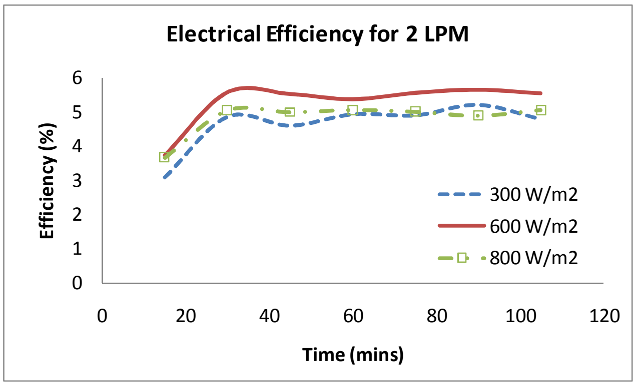

Fig. 10: Electrical efficiency for various solar irradiances under 2 LPM fluid flow rate.

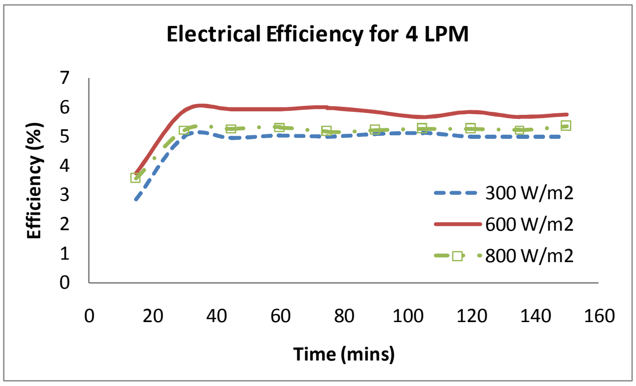

Fig. 11: Electrical efficiency for various solar irradiances under 4 LPM fluid flow rate.

Fig. 9, Fig. 10 and Fig 11 shows electrical efficiency for different fluid flow rate for each graph. Each one graph from Fig. 9 to Fig. 11 indicates electrical efficiency under same fluid flow rate but different solar irradiances. Surprisingly the electrical efficiency is the highest for 600 W/m^2 instead of 800 W/m^2.

Table 1: Electrical performance and cell temperature

Solar Irradiance (W/m^2)	Fliud Flow Rate (LPM)	Electrical Efficiency (%)	PV Cell Temperature (°C)
300	0.5	4.73656	48.45117
300	2	5.215432	43.8185
300	4	5.100551	46.23478
600	0.5	5.174498	57.76924
600	2	5.659525	57.19538
600	4	5.96784	56.93749
800	0.5	4.689981	66.82916
800	2	5.062641	65.9006
800	4	5.331563	61.74425

3.2 Thermal Performance

Below are the thermal performances of PV/T water based collector fabricated in this experiment. Fig. 12, Fig. 14 and Fig. 16 shows the temperature at the back surface of the PV panel. From the graph Fig. 12, Fig. 14 and Fig. 16, lower temperature shows better electrical performance and vice versa. All the graphs for thermal performance below are constant in solar irradiance and various fluid flow rates.

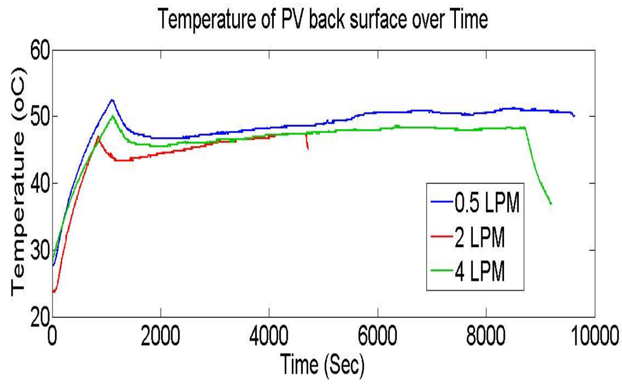

Fig. 12: Temperature for back surface of PV for various mass flow rates tested under 300 W/m^2 solar irradiance.

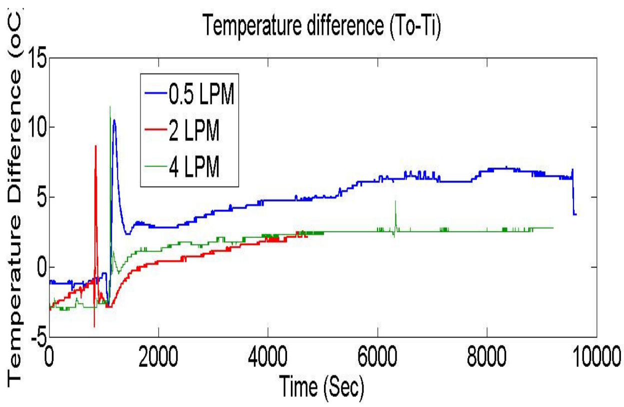

Fig. 13: Fluid Temperature Difference (To-Ti) for various mass flow rates tested under 300 W/m^2 solar irradiance.

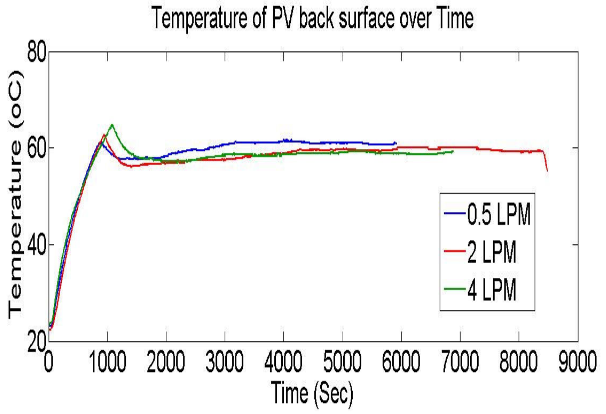

Fig. 14: Temperature for back surface of PV for various mass flow rates tested under 600 W/m^2 solar irradiance.

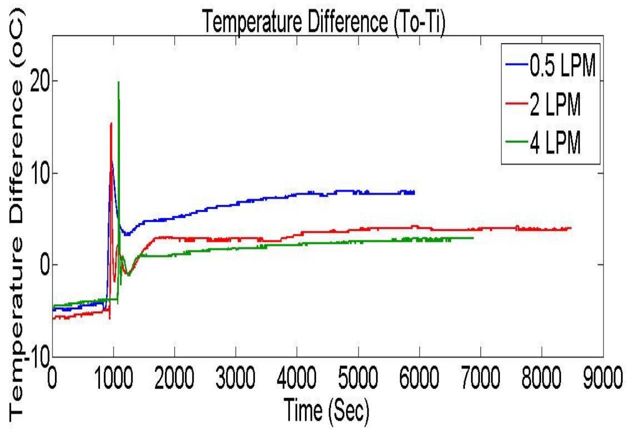

Fig. 15: Fluid Temperature Difference (To-Ti) for various mass flow rates tested under 600 W/m^2 solar irradiance.

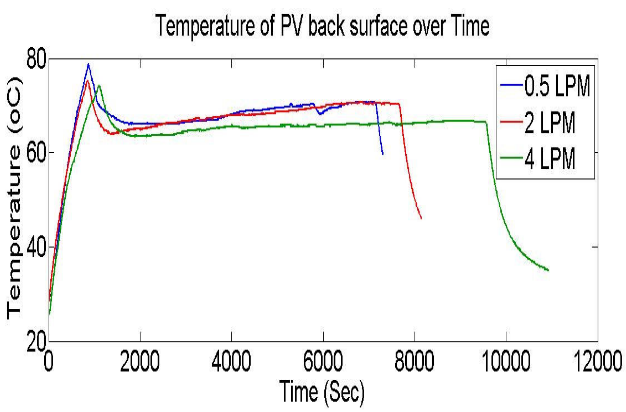

Fig. 16: Temperature for back surface of PV for various mass flow rates tested under 800 W/m^2 solar irradiance.

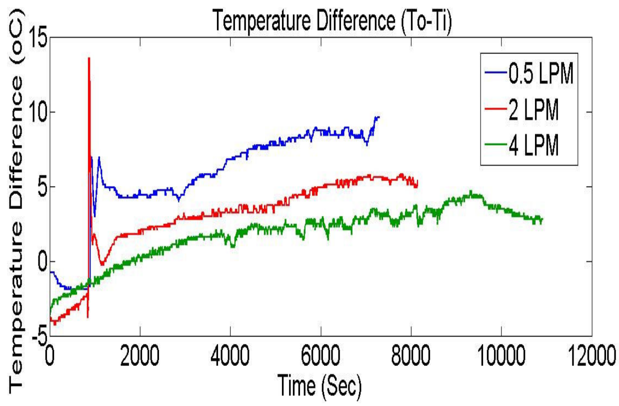

Fig. 17: Fluid Temperature Difference (To-Ti) for various mass flow rates tested under 800 W/m^2 solar irradiance.

Fig. 13, Fig. 15 and Fig. 17 shows the temperature difference of the working fluid flow inside the copper tubes. Temperature Difference is between fluid inlet to the absorber and the outlet of absorber. Higher fluid temperature difference indicates greater thermal efficiency or better capability to extract the heat out from PV panel.

S (W/m^2)	Fluid Flow Rate (LPM)	Average PV cell temperature (^oC)	Temperature Difference (T_o-T_i)	Thermal Efficiency (%)
300	0.5	48.45117	5.226835	55.37142
300	2	43.8185	0.18773	7.955025
300	4	46.23478	1.549316	131.3303
600	0.5	57.76924	4.90951	26.00489
600	2	57.19538	2.238415	47.42611
600	4	56.93749	1.004594	42.57801
800	0.5	66.82916	5.577729	22.15825
800	2	65.9006	2.885635	45.85424
800	4	61.74425	1.797308	57.1319

4 Conclusions

This paper shows some PV/T developed by different researcher and the result is shown and compared. The heat absorber and glazing added in the collector will affect the performance in PV/T collector. Below are some suggestions concluded from the results in this research:

- The electrical efficiency decreased with the increased in cell temperature.
- Adding heat absorber will definitely increase both the electrical and thermal efficiency.
- Increasing mass flow rate will improved thermal performance but electrical efficiency only shows high performance at certain mss flow rate.
- Good insulation is important to prevent heat loss from the PV/T and to improve thermal performance.
- Electrical efficiency varies among 4 to 6%.
- Thermal efficiency can reach more than 57% depend on the design of PV/T collector.

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ISBN: 978-1-61804-175-3