Predicting the Characteristics of a Special Designed Photovoltaic Thermal Collector Absorber (PVT)

ADNAN IBRAHIM[1], MOHD HAFIDZ RUSLAN[1], SOHIF MAT[1], MOHD YUSOF OTHMAN[1], AZAMI ZAHARIM[2] AND K. SOPIAN[3]
[1]Solar Energy Research Institute,
[2]Head for Renewable Energy Resources and Social Impact Research Group
Solar Energy Research Institute, and
Head Centre for Engineering Education Research
Faculty of Engineering and Built Environment,
[3]Director of Solar Energy Research Institute,
Universiti Kabangsaan Malaysia
43600, Bangi, Selangor
MALAYSIA
adnan@vlsi.eng.ukm.my, azaminelli@gmail.com , hafidz@ukm.my, sohif@ukm.my, myho@ukm.my and ksopian@vlsi.eng.ukm.my

Abstract: - The main motivation of combining the Photovoltaic (PV) and Thermal collector(T) to be Photovoltaic/Thermal collector systems (PV/T) is to increase the efficiency of the collectors. It is known fact that the efficiency of the Photovoltaic decreases when the ambient temperature increased and vice verse. The system works by absorbing the heat gain from the sun using the Photovoltaic panel and convert it to electrical energy. Some of this energy is then transfered to the absorber collector underneath the Photovoltaic panel as a waste energy. Special conFigureurations of absorber collector has been designed, investigated and compared before it is inserted underneath the Photovoltaic panel which is represented as flat plate polycrystalline silicon with single glazing sheet. Simulation has been performed to determine the absorption of the heat that influences the total efficiency of the system under certain range of conditions. . The simulation results shows that it can generates the total efficiency of 63.55% with electrical efficiency of 11.39% at ambient temperature set between 21 to 36°C, fluid flow rate at 0.02kg/s and solar radiation between 700 to 800 W/m^2.

Keywords: - Photovoltaic/Thermal (PVT), thermal and electrical efficiency, absorber collectors

1 Introduction

Many researches towards the solar energy occur all over the world due to the concern of global crisis on oil and gas prices. According to some experts, oil has already started to peak [1; 2]. Gas and coal reserves are bigger than oil, so the latter 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 [3].

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. The technology of solar energy or synonym to be known as photovoltaic technology (PV) has many advantages comparing to others energy [4]. It works on noiseless environment; do not produce any unwanted waste such as radioactive materials etc, highly credibility system with life span expectation is between 20 to 30 years and very low maintenance system.

Hybrid photovoltaic thermal system in the other hand is the continuity of the photovoltaic system. As reported by Zondag [5], Prakash [6] and Othman [7] in their journal, cited that the usage of the solar energy in general can be divided into two divisions; the photovoltaic technology that converts the solar energy into electricity, (which derived from solar cell technology) and thermal solar technology that convert the solar energy into heat, (which derived from the absorber plate) . The heat can be either in the form of hot air or water.

This paper investigates the relationship between absorption of heat from the solar radiation with the total efficiency of the special designed photovoltaic thermal absorber collector design configurations using the simulation method based on several design configurations [8; 9; 10].

2 Previous Research

There are many methods to produce the photovoltaic thermal collectors cite from the previous and prestige researchers all over the world. The most common design types can be either a flat-plate collectors or concentrating types have been designed depending on the types of working medium used such as water, air or combination between water and air.

The inspiration of combining photovoltaic and solar thermal collectors (PVT collectors) to provide electrical and heat energy is not new, however it is an area that has received only little interest [11]. With concern growing over energy sources and their usage, PVTs have become an area which is receiving much more attention. Research in this field was carried out in the middle of 1970s to early 1980s. The first inventor of flat-plate PVT liquid system, Wolf [12] analyzed the performance of the combination of heating and photovoltaic power systems for residences. He concluded that the system was technically feasible and cost effective. In his experiment, the Hottel-Whillier model [13] is used to analyze the combination of photovoltaic and thermal flat plate collectors with the traditional hot water system and PV panel to minimize the usage of the installation area. It is proven that by combining the system, the installation area produce more energy per unit surface area than one PV panel and one thermal system [14]. Zondag et al. [5] reviewed various concepts of combined PV-thermal collector technologies by introducing and evaluating nine different designs, ranging from the complicated to the simpler one, in order to investigate the maximum yield. They concluded that the design of the channel below the transparent PV, with PV-on-sheet and tubes design gives the best efficiency overall.

Bergene at al. [15] perform theoretical examination of a flat plate solar collector model that integrated with solar cells. They developed a series of algorithms for making quantitative predictions for both the electrical and thermal efficiency of a PVT system. They concluded that a system with combination of both components produced approximately about 60-80% efficiency. Huang et al. [16] have developed PV/T system using a polycrystalline solar PV panel, adopted to be combined with a collector plate. The collector plate is directly attached with the commercial PV panel using the thermal grease, for better contact. Underneath the collector, a PU thermal insulation layer is attached using a fixing frame. The collector was designed using the corrugated plate made of polycarbonate material. The water was flowed into the flow channel of the corrugated plate structure.

3 Research Method

The performance of PVT collectors can be depicted by the combination of efficiency expression [17]. It comprised of the thermal efficiency η_{th} and the electrical efficiency η_e. 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 analytical parameters of the PVT collector are presented in Table 1.

The total of the efficiencies, which is known as total efficiency η_o is used to evaluate the overall performance of the system:

$$\eta_o = \eta_{thermal} + \eta_{electrical}$$

The thermal performance of the PVT is affected by many system design parameters and operating conditions. In this simulation, the system is analyzed with various configurations of solar radiation, ambient temperature, and flow rate conditions. The collector is assumed to be represented as a flat plate thermal collector with single glazing sheet. Based on this assumption, the thermal performance η_{th} of the PVT unit is evaluated for its thermal and photovoltaic performance, as such, the derivation of the efficiency parameters based on the Hottel-Whillier equations [13] were used. The thermal efficiency (η_{th}) of the conventional flat plate solar collector is calculated using the formula below:

$$\eta_{th} = \frac{Qu}{G}$$

Where Q_u = actual useful collected heat gain (W/m^2) and G= measurement of incoming solar-irradiation on the collector surface (W/m^2). Under these conditions, the useful collected heat gain (Q_u) is given by:

$$Qu = \dot{m} C_p (T_o - T_i)$$

Where $\dot{m}$ = mass flow rate (Kg/s), C_p = specific heat of the collector cooling medium (J/kg K), T_o = fluid outlet temperature (K) and T_i = fluid inlet temperature (K)

The difference between the absorber solar radiation and thermal heat losses is identified by Hottel-Whillier equations [13]:

$Qu = A_c F_R \left[S - U_L (T_i - T_a)\right]$, S can be identified as $S = (\tau\alpha)_{PV}\, G_T$

Where A_c = function of the collector area (m^2), F_R = heat removal efficiency factor, S = absorbed solar energy (W/m^2), U_L = overall collector heat loss coefficient (W/m^2 K), T_i = fluid inlet temperature (K), T_a = ambient temperature (K), $\tau\alpha_{PV}$ = PV thermal efficiency and G_T = solar radiation at NOCT (irradiation level 800 W/m^2, wind velocity 1 m/s, ambient temperature at 26 ºC taken from 6:00 - 20:00)

Table 1: Photovoltaic-thermal collector simulation parameters.

Description	**Symbol**	**Value**	**Units**
Ambient temperature	Ta	293	K
Inlet fluid temperature	Ti	293	K
Tube length	L	1	m
Collector width	b	0.65	m
Tube diameter	D	0.0127	m
No. of tube	n	1	m
Tube spacing	W	0.0327	m
Collector parameter	P	3.3	m
Collector area	Ac	0.65	m²
Number of glass cover	N	1	
Emittance of glass	εg	0.88	
Emittance of plate	εp	0.95	
Tilt (slope)	º	14	
Fluid flow rate	mdot	0.02	kg/s
Fluid thermal conductivity	kfluid	0.613	
Specific heat	Cp	4180	
Back insulation conductivity	kb	0.045	W/mºK
Back insulation thickness	Lb	0.05	m
Insulation conductivity	ke	0.045	W/mºK
Edge insulation thickness	Le	0.025	m
Absorber conductivity	kabs	51	W/mºK
Absorber thickness	Labs	0.002	m
Fin conductivity	kf	84	W/mºK
Fin thickness	δ	0.0005	m
Heat transfer coefficient from cell to absorber	hca	45	W/mºK
Heat transfer inside tube	hfi	333	W/mºK
Transmittance	τ	0.88	
Absorptance	α	0.95	

The heat removal efficiency factor (F_R) can be calculated as below, where F' is the corrected fin efficiency.

$$F_R = \frac{\dot{m} C_p}{A_c U_L}\left[1 - \exp\left[-\frac{A_c U_L F'}{\dot{m} C_p}\right]\right]$$

The corrected fin efficiency (F') is calculated using:

$$F' = \left[\frac{\frac{1}{U_L}}{U_L (d_h + (W - d_h) F)}\right] + \frac{1}{Cb} + \frac{1}{2(a+b)_{h_{fi}}}$$

Where d_h = hydraulic diameter of the tube (m), W = tube spacing (m), F = fin efficiency factor, C_b= conductance of the bond between the fin and square tube (W/m^2 K) and h_{fi} = heat transfer coefficient of fluid (W/m^2 K)

The fin efficiency factor F is then be calculated as:

$$F = \frac{\tanh\left(m\left(\frac{W-d_h}{2}\right)\right)}{\sqrt{m\left(\frac{W-d_h}{2}\right)}}$$, where $m = \sqrt{\frac{U_L}{K_{abs}.L_{abs} + K_{PV}.L_{PV}}}$

Where m = mass flow rate (Kg/s), K_{abs} = absorber thermal conductivity (W/m2 K), L_{abs} = absorber thickness (m), K_{PV} = photovoltaic thermal conductivity (W/m2 K) and L_{PV} = PV collector thickness.

From this equation, it is then possible to calculate the useful heat gain of the solar collector by rearranging the equation, the thermal efficiency of the collector can be expressed as [18]:

$$\eta_{th} = F_R(\tau\alpha)_{PV} - F_R U_L \frac{T_i - T_a}{G_T}$$

For temperature-dependent electrical efficiency of the PV panel, (η_e) the expression is given as below[19]:

$$\eta_e = \eta_r[1 - \beta(T_c - T_r)]$$

Where η_e = electrical efficiency, η_r = reference efficiency of PV panel (η_r = 0.12), β = temperature coefficient (ºC 0.0045ºC^{-1}), T_c = temperature of the solar cells (K), Tr = the reference temperature and T_r = the reference temperature.

3.1 Simulation consideration

In order to obtain the best results, proper design factors need to be considered. The dual requirement of good thermal conduction and good electrical insulation between the solar cells and absorber collector need to be considered [20]. The absorber collector conceptual design as shown in Figure 1 is drawn using Solidworks software is made of rectangular hollow tubes of stainless steel material with dimension of 12.7mm x 12.7mm. The tubes are connected together using a welding method. The absorber collector should have a single unilateral channel for the water to flow in it with the size of 815mm x 628mm before it is assembled underneath the PV panel.

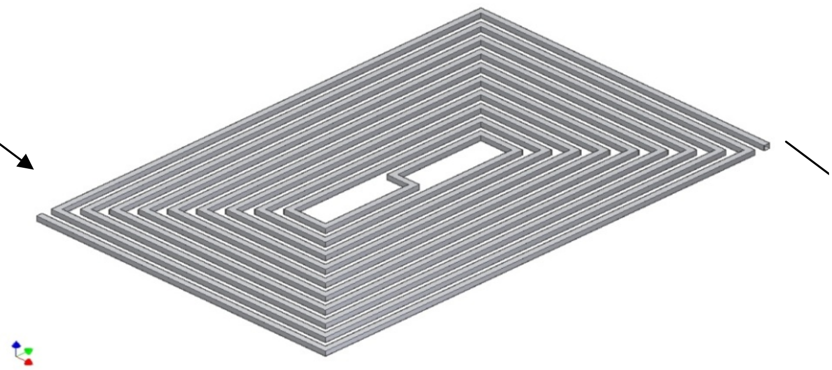

Fig. 1 Spiral Flow design simulation

Table 2: Results of the simulation tests

Time	Temperature (°C)				Fluid flow rate	Collector efficiency factor	Collector heat removal factor	Useful Heat Gain		Efficiencies		
t	T_a	T_i	T_o	G_T	mdot (kg/s)	F'	F_R	Qu	(Ti-Ta) /G	η_t	η_c	η_o
6	21.49	25.00	25.00	5.27	0.02	0.9869	0.9665	0.0	0.0	0.0	0.0	0.0
7	21.42	25.00	25.00	5.63	0.02	0.9869	0.9665	0.0	0.0	0.0	0.0	0.0
8	22.03	25.00	25.24	56.89	0.02	0.9869	0.9664	19.8486	0.0523	34.887	11.981	46.868
9	23.66	27.00	27.91	165.90	0.02	0.9868	0.9661	76.1889	0.0201	45.924	11.844	57.767
10	28.73	30.00	32.71	437.13	0.02	0.9865	0.9653	226.6088	0.0029	51.840	11.603	63.443
11	31.80	33.00	36.94	631.40	0.02	0.9862	0.9647	329.3261	0.0019	52.158	11.387	63.545
12	33.44	35.00	40.07	812.72	0.02	0.9861	0.9644	423.6781	0.0019	52.131	11.229	63.360
13	34.56	36.00	41.52	883.31	0.02	0.9860	0.9642	461.2735	0.0016	52.221	11.155	63.377
14	36.11	38.00	43.42	871.43	0.02	0.9859	0.9639	453.1458	0.0022	52.000	11.052	63.052
15	35.14	39.00	43.47	734.70	0.02	0.9860	0.9641	373.7999	0.0053	50.878	11.039	61.917
16	34.44	38.00	41.45	570.34	0.02	0.9861	0.9642	288.2044	0.0062	50.532	11.138	61.670
17	33.42	35.00	36.86	304.93	0.02	0.9861	0.9644	155.3181	0.0052	50.936	11.370	62.306
18	31.98	33.00	33.95	157.70	0.02	0.9862	0.9647	79.6294	0.0065	50.495	11.518	62.013
19	30.21	32.00	32.11	28.81	0.02	0.9864	0.9650	0.0	0.0	0.0	0.0	0.0
20	26.49	29.00	28.93	5.98	0.02	0.9866	0.9656	0.0	0.0	0.0	0.0	0.0

4 Results of the Simulations

In this simulation, the specific operation condition is set from 06.00 hours till 20.00 hours. Data for the ambient temperature were collected from local weather station shows that at 06.00 hours, the ambient temperature is at 21.49ºC and 26.49 ºC at 20.00 with the peak at 36.11 ºC at 14.00 hours. The average solar radiation level during the simulation period was 883.11 W/m^2 respectively. In this simulation, the fluid flow rate is set to 0.02 kg/s as shown in Table 2. The result of this simulation as seen in Figure 3 shows that when Plate mean temperature (Tpm) is increases due to the increases of solar radiation (G_T) the cell efficiency is decreases.

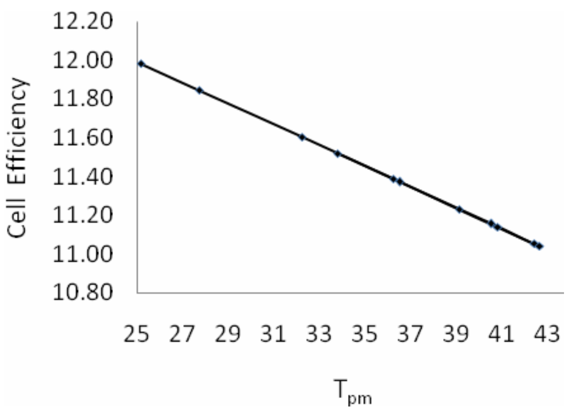

Fig. 3: The Cell efficiency versus Plate Mean Temperature of the PVT

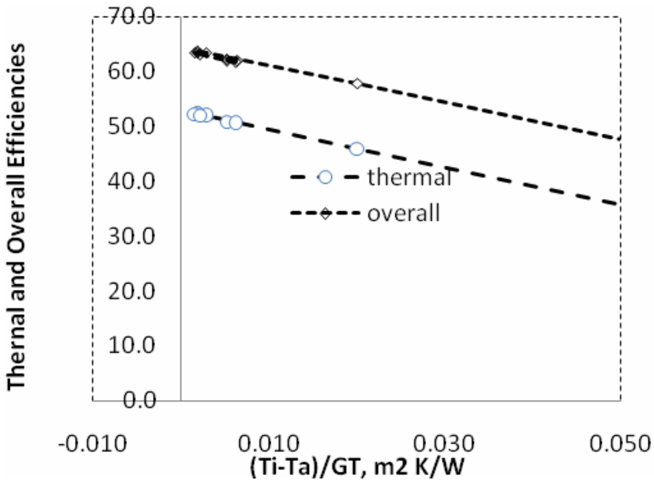

Fig. 4: Variation of thermal and overall efficiency of the PVT collector with reduced temperature.

Figure 4 shows the efficiency plot of thermal and overall against reduced temperature. The design concepts of water type PVT collectors can be group into four main types, namely, sheet and tube, channel, free flow and two absorber collectors [21].In this simulation, the collector has been identified as channel types. From the viewpoint of the author, the single glazing sheet and tube hybrid PVT collector as the best design for overall performance and structural simplicity. Because of that, this simulation was performed using the single glazing sheet and tube hybrid PVT collector.

5 Conclusion

The case study performed under the zero reduced temperature condition gives results of thermal efficiency of 52.16%, with a corresponding cell efficiency of 11.39%. It is very encouraging, due to the simplicity of this type of design.

It is recommended that the PVT collector can be further improved by using other types of cell such as the amorphous silicon cell that provided higher thermal absorption due to it black mat surfaces.

Besides that, by minimizing the gap between the absorber and cell, can improve the efficiency by direct contact between both, the absorber and the cell.

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