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Photovoltaic-Thermal (PVT) System with and Without Fins Collector: Theoretical Approach

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ABSTRACT

The fins collector design for solar thermal has widely been used and it has a higher thermal efficiency than without Fins. Photovoltaic thermal (PV/T) system produced Electrical and thermal energy instantaneously. Mathematical modeling based on steady-state thermal analysis of PV/T system with and without fins was conducted with matrix inversion method. The value results show that the PV/T system with fins collector is higher thermal and electrical efficiency than without fins.

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1. INTRODUCTION

The collector design is greatest vital units of solar collector system or PV/T system to collect heat from solar energy. The use of fins absorber has been conducted widely in the solar collector. Solar collector with two-pass fins have been conducted by Naphon[1] with thermal efficiency is about 30-60%. Fudholi et al. [2] have compared solar collector two-channel with and without fins performance and price welfares analysis. The energy efficiency and cost-effective of two-channel with fins are higher than without fins collector.

Taghi et al. [3] have conducted the analysis of heat reaction for point covered topology in the photovoltaic thermal system. The basic idea is the exploit electrical energy through a new point covered topology. The experimental investigation shows that the performance of electrical analysis increases about 10 degrees. Kumari and Babu **[**4**]**have compared between theoretical and simulation approach of the photovoltaic cell by Matlab-Simulink Situation. The main of purpose is to catch factor of the nonlinear *I-V* calculation by modifying the curve at three ideas: open circuit, extreme power, and short circuit. Sharma et al. **[**5**]**haveanalyzed the demonstrating and simulation approach of off-grid power generation system by photovoltaic. The objective this research is to confirm steady process during responsibility and numerous network instabilities in network and islanding connected mode. Zohri et al. **[**6**]** have analyzed by mathematical modeling of photovoltaic thermal (PVT) with and without a v-groove collector. the energy analysis result displays that performance energy with v-groove is higher than without v-groove collector.

The PV/T system has well in the future because of generating both thermal and electrical energy which it’s higher dependability and lower ecological impact [7].Thermal application and different types of PV/T system solar collector on basis of physical assortment, scheme condition, and different heat removal improvement technologies have been reported by Tian et al. [8]. Two modes PV/T air heating and PV/T water heating of tri-functional PV/T collector has been designed by Guo et al. [9].The comparative results between the simple photovoltaic cell and unit model have been conducted by Zaoui et al. [10] on the elementary of connection temperature and isolation. The greater exergy performance with different types of PV/T system has been compared to another system[11]. The special effects of involuntary convection on solar cell temperature have been presented by experimental investigation. The solar cell temperature is powerfully prejudiced by the competence of drying [12].

The electrical and thermal performances of PV/T system based on air collector have been projected by Sarhaddi et al. [13]. In evolving the hybrid PV/T fleeting model, the experimental data and theoretical modeling have a good arrangement by typical steady-state current-voltage specific curve [14]. The effects of dissimilar factors like; length, channel penetration, fluid flow rate and packing factor on electrical and thermal performance have been developed by Elsafi et al. [15]. The Combination of thermal collector and photovoltaic panel are called PV/T system. A review work has been reported by Good et al. [16]. Using glazed PV/T system has been conducted for improving the whole exergy performance by Genetic Algorithm-Fuzzy system method [17]. Mohammad et al. [18] have conducted improved the model of solar photovoltaic (PV) array along with the implementation of fuzzy logic as maximum power point tracking (MPPT). Surya and Sai [19] have done mathematical analysis and simulation of photovoltaic cell using Matlab-Simulink. The model analysis based on circuit equation of photovoltaic solar cells with solar radiation and temperature parameters.

Mathematical modeling is very urgent to predict parameters, outlet temperature, thermal and electrical efficiency before doing experimental investigation

2. MATHEMATICAL MODEL

Based on energy balance, Figure1 shows schematic heat transfer coefficient for PV/T system with fins collector. The structure of collector with and without fins is same principally. For PV panel size (1.2 m x 0.53 m), fins size 1.2 m of length and 0.03 m of width. The number of fins is 50.

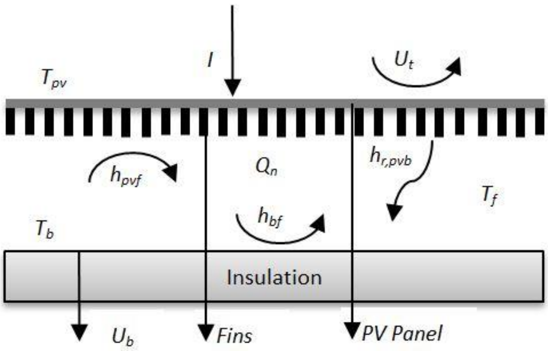

Figure 1. Heat Transfer Coefficient for PV/T System with Fins Collector

For PV/T system without fins is used matrix 3 x 3 to calculate Temperature PV panel T_{pv}, temperature fluid T_f and Temperature bottom plate T_b. by matrix inverse following:

$$[A][T] = [C]$$

For PV panel:

$$\tau\alpha(1-\eta_c)I = U_t(T_{pv}-T_a) + h_{c1}(T_{pv}-T_f) + h_r(T_{pv}-T_b) \tag{1}$$

For air channel:

$$2\dot{m}C(T_f-T_i)/WL = h_{c1}(T_{pv}-T_f) + h_{c2}(T_b-T_f) \tag{2}$$

For bottom plate:

$$h_r(T_{pv}-T_b) = U_b(T_b-T_a) + h_{c2}(T_b-T_f) \tag{3}$$

$$\begin{bmatrix} (U_t + h_{c1} + h_r) & -h_{c1} & -h_r \\ h_{c1} & -(h_{c1} + h_{c2}) & h_{c2} \\ h_r & h_{c2} & -(h_r + h_{c2} + U_b) \end{bmatrix} \begin{bmatrix} T_{pv} \\ T_f \\ T_b \end{bmatrix} = \begin{bmatrix} U_t T_a + \tau\alpha(1 - \eta_{cell})I \\ -(\frac{2\dot{m}C}{WL})T_i \\ -U_b T_a \end{bmatrix}$$

The PV/T system with fins collector is used matrix 3 x 3 to calculate Temperature PV panel T_{pv}, temperature fluid T_f and Temperature bottom plate T_b. by matrix inverse following:

$$[A][T] = [C]$$

For PV panel:

$$\tau\alpha(1 - \eta_{cell})I = U_t(T_{pv} - T_a) + h_{c1}(T_{pv} - T_f) + h_r(T_{pv} - T_b) + Q_n \tag{4}$$

For air channel:

$$2\dot{m}C(T_f - T_i)/WL = h_{c1}(T_{pv} - T_f) + h_{c2}(T_b - T_f) + Q_n \tag{5}$$

For bottom plate:

$$h_{r,}(T_{pv} - T_b) = U_b(T_b - T_a) + h_{c2}(T_b - T_f) \tag{6}$$

$$\begin{bmatrix} (U_t + h_{c1} + h_r + Q_n) & -h_{c1} + Q_n & -h_r \\ h_{c1} + Q_n & -(h_{c1} + h_{c2} + Q_n) & h_{c2} \\ h_r & h_{c2} & -(h_r + h_{c2} + U_b) \end{bmatrix} \begin{bmatrix} T_{pv} \\ T_f \\ T_b \end{bmatrix} = \begin{bmatrix} U_t T_a + \tau\alpha(1 - \eta_{cell})I \\ -(\frac{2\dot{m}C}{WL})T_i \\ -U_b T_a \end{bmatrix}$$

Where,
For Efficiency of fins, collector is

$$Q_n = \frac{N}{A_{fin}}(2kA_n l h_c)^{0.5} tanMH(T_f - T_i) \tag{7}$$

For Electrical efficiency [14]

$$\eta_{pv} = \eta_{ref}\left[1 - \beta_{ref}(T_{pv} - T_{ref})\right] \tag{8}$$

For the temperature coefficient β_{ref} can be written as [20]

$$\beta_{ref} = \frac{1}{(T_o - T_{ref})} \tag{9}$$

For Thermal efficiency by following [21].

$$\eta_{th} = \dot{m}C(T_o - T_i)/IA \tag{10}$$

For The convective heat transfer coefficients are given as[22]:

$$h = \frac{k}{D_h} Nu \tag{11}$$

which,

$$D_h = \frac{4Wd}{2(W + d)} \tag{12}$$

Where, W , d , D_h are the width, high, equivalence diameter of the channel, k is air thermal conductivity and Nu is a Nusselt number. Nusselt numbers are given as, for Re<2300 (laminar flow region):

$$Nu = 5.4 + \frac{0.00190\left[\mathrm{RePr}\left(\frac{D_h}{L}\right)\right]^{1.71}}{1 + 0.00563\left[\mathrm{RePr}\left(\frac{D_h}{L}\right)\right]^{1.17}}$$

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For 2300 < Re < 6000 (transition flow region):

$$Nu = 0.116\left(\mathrm{Re}^{2/3} - 125\right)\mathrm{Pr}^{1/3}\left[1 + \left(\frac{D_h}{L}\right)^{2/3}\right]\left(\frac{\mu}{\mu_w}\right)^{0.14} \tag{14}$$

For Re >6000 (turbulent flow region):

$$Nu = 0.018\,\mathrm{Re}^{0.8}\,\mathrm{Pr}^{0.4} \tag{15}$$

Where *Re* and *Pr* are the *Reynolds* and *Prandtl* number given as:

For 2300 < Re < 6000 (transition flow region):

$$Nu = 0.116\left(\mathrm{Re}^{2/3} - 125\right)\mathrm{Pr}^{1/3}\left[1 + \left(\frac{D_h}{L}\right)^{2/3}\right]\left(\frac{\mu}{\mu_w}\right)^{0.14} \tag{16}$$

For Re > 6000 (turbulent flow region):

$$Nu = 0.018\,\mathrm{Re}^{0.8}\,\mathrm{Pr}^{0.4} \tag{17}$$

Where*Re* and *Pr* are the Reynolds and Prandtl number given as:

$$\mathrm{Re} = \frac{mD_h}{A_{ch}\mu} \tag{18}$$

$$\mathrm{Pr} = \frac{\mu C}{k} \tag{19}$$

The theoretical model simulated that for a short collector or less of 1 m. Then, the mean air temperature is then equal to the arithmetic mean, where:

$$T_f = \frac{\left(T_i + T_o\right)}{2} \tag{20}$$

The physical properties of air are hypothetical vary linearly with temperature (^{o}C) by Fudholi [23]:
Specific heat

$$C = 1.0057 + 0.000066(T - 27) \tag{21}$$

Density,

$$\rho = 1.1774 - 0.00359(T - 27) \tag{22}$$

Thermal conductivity

$$k = 0.02624 + 0.0000758(T - 27) \tag{23}$$

Viscosity

$$\mu = [1.983 + 0.00184(T - 27)]10^{-5} \tag{24}$$

The heat transfer coefficient to wind according to Ong [24] is

$$h_w = 2.8 + 3.3V \tag{25}$$

Where, h_w heat transfer coefficient due to wind and *V* is the wind velocity. The heat transfer coefficient from panel cell to sky

$$h_{r,pvs} = \frac{\sigma\varepsilon_{pv}(T_{pv}+T_s)(T_{pv}^2+T_s^2)(T_{pv}-T_s)}{T_{pv}-T_a} \tag{26}$$

$$h_{r,pvb} = \frac{\sigma(T_{vp}+T_b)(T_{pv}^2+T_b^2)}{\left(\frac{1}{\alpha_{pv}}+\frac{1}{\alpha_{pv}}-1\right)} \tag{27}$$

Where T_s is the sky temperature, T_c is the photovoltaic panel temperature.

$$T_s = 0.0552T_a^{1.5} \tag{28}$$

3. RESULTS AND ANALYSIS

Figure 2 shows mass flow rate versus outlet temperature of air at PV/T system with and without fins collector with solar intensity of 600 W/m^2 and 800 W/m^2. The result indicates that by growing the mass flow rate simultaneously fallen the temperature outlet of air. The mass flow rate from 0.01 kg/s to 0.02 kg/s is laminar flow state with (Re <2300) and mass flow rate from 0.03 kg/s to 0.05 kg/s is transition flow state with (2300 < Re < 6000). The maximum temperature outlet at intensity of 800 W/m^2 with fins collector is 41.39 ^{o}C and the minimum temperature outlet at intensity of 600 W/m^2 is 29.77^{o}C.

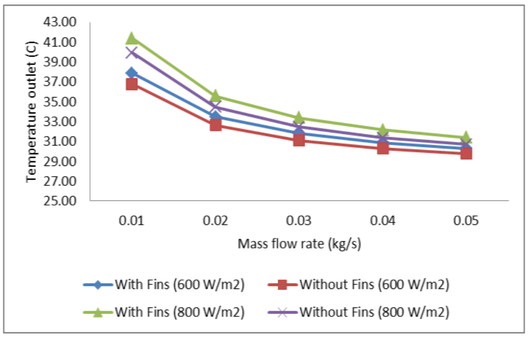

Figure 2. The Mass Flow Rate Versus Outlet Temperature of With and Without Fins Collector at Solar Intensity of 600 W/m^2 and 800 W/m^2

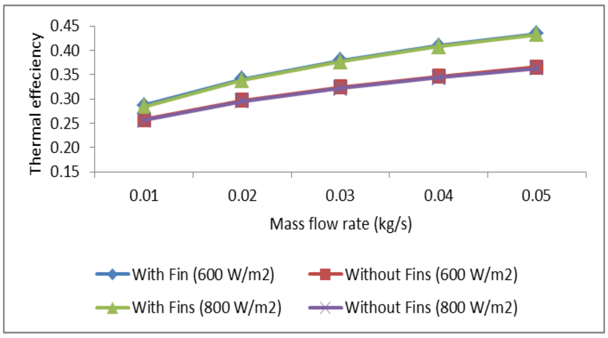

Figure 3. The Mass Flow Rate Versus Thermal Efficiency of With and Without Fins Collector at Solar Intensity of 800 W/m^2 and 600 W/m^2

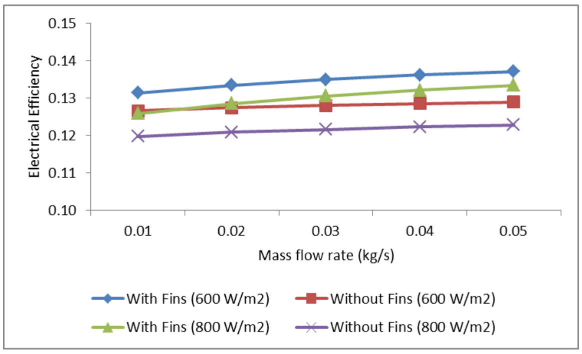

Figure 4. The Mass Flow Rate versus Cell Efficiency of Fins Collector for the Solar Intensity of 600 W/m^2 and 800 W/m^2

Figure 3 shows the mass flow rate versus thermal efficiency of with and without fins collector. For the mass flow rate from 0.01 to 0.05 kg/s, the thermal efficiency maximum at the solar intensity of 600 W/m^2 and 800 W/m^2 is 43 % with fins collector and thermal efficiency minimum at the intensity of 600 W/m^2 and the intensity of 800 W/m^2 is 26% without fins collector. When mass flow rate value decreases thermal efficiency follow it. This situation can be concluded that the higher the mass flow rate, the higher thermal efficiency. Figure 4 shows distribution mass flow rate versus electrical efficiency with and without fins collector. The conduct of electrical efficiency indicates that electrical performance increase with following increasing mass flow rate. The use of fins collector be able to upsurge the electrical efficiency. It show that the effect of fins collector make cooling photovoltaic panel.

Table 1. The Comparison with the Other Collector Designs in Reference [25,26]

Designs of collector	Predicted Results	
	Thermal efficiency	Electrical efficiency
glass	36%	-
metal sheet collector and glass	41%	-
fins and glass	51%	-
Two-absorber (no cover type)	65%	8.4%
Two-absorber (cover type)	66%	8.5%
Free channel	64%	8.6%
current study (fins collector)	43%	14%

Table 1 demonstrates the comparison designs of collector between using fins collector, metal sheet, with glass, two-absorber with and without cover type. The usage of fins is higher thermal efficiency than without fins and with metal sheet. The other way, PVT with fins collector combination with glass cover and two-absorber with and without cover type are higher thermal efficiency than just with fins collector without glass cover. It shows that the glass cover and two-absorber be able to rise drying up in PVT system.

4. CONCLUSION

Mathematical modeling for predicting thermal and electrical efficiency of photovoltaic thermal (PV/T) system with and without fins has been conducted. The maximum results of outlet temperature, thermal efficiency, and electrical efficiency are 41.39 ^oC, 43%, 14% respectively. Using fins collector to cooling PV panel has higher efficiency than without fins collector.

5. APPENDIX

NOMENCLATURE

A	area	m^2
C	specific heat of air	$J/kg.^oC$
d	channel high	m
h	heat transfer coefficient	$W/m^2.^oC$
L	length collector	m
I	intensity	W/m^2
w	width collector	m
Pr	Prandtl number	
Re	Reynold number	
T	Temperature	^oC

Greek letters

ε	emissivity
t	transmission coefficient
α	absorption coefficient
μ	dynamic viscosity
η	efficiency

Subscripts

i	inlet
o	outlet
f	fluid
s	sky
r	radiation
c	convection
b	back plate
a	ambient
pv	photovoltaic panel
a	ambient

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BIOGRAPHIES OF AUTHORS

Muhammad Zohri obtained his S.Si (2009) in physics and received the Master of Science degree in Solar Energy Research Institute from The National University of Malaysia, Malaysia in 2017, with a thesis based on PVT system with and without ∇-groove collector. He was appointed a Graduate Research Assistant (GRA) under Dr. Ahmad Fudholi in Solar Energy Research Institute (SERI) in UKM Malaysia, during his master's degree. He worked at College Computer Information Management (STMIK) Mataram, Indonesia. He was a speaker at The 2nd International Symposium on Current Progress in Mathematics and Science (2nd ISCPMS) FMIPA UI in Depok and The 4th Solar Energy Research Institute (SERI) Colloquium 2016, in UKM Bangi, Malaysia. He has published 5 Paper, which 2 Paper in Scopus Index and 3 Paper has accepted for publication in Scopus Index.

Nurato Obtained ST (2000) in Mechanical Engineering, has a working experience of about 10 years (1998-2008) as a mechanical engineering laboratory of Krisnadwipayana University, Jakarta. Completed master degree in Mechanical Engineering (2009-2011) at Pancasila University Jakarta. Appointed as Secretary of Mechanical Engineering Study Program of Krisnadwipayana University (2013), then joined Mercu Buana University (2014-Now). Continuing PhD studies at the Institute of Fuel Cells Universiti Kebangsaan Malaysia (2016-present)

Dr. Ahmad Fudholi obtained his S.Si (2002) in physics. He has working experience about 4 years (2004-2008) as Head of Physics Department at Rab University Pekanbaru, Indonesia. A. Fudholi started his master course in Energy Technology (2005-2007) at UniversitiKebangsaan Malaysia (UKM). After his master he became Research Assistant at UKM up to 2012. After his Ph.D (2012) he became Postdoctoral in Solar Energy Research Institute (SERI) UKM up to 2013. He joined the SERI as a Lecture in 2014. More than USD 304,000 research grant in 2014–2017 obtained. More than 25 M.Sc project supervised and completed. Until now, he managed to supervise 5 Ph.D (4 main supervisor and 1 Co. supervisor), 2 Master's student by research mode, and 5 Master's student by coursework mode, he was also as examiner (3 Ph.D and 1 M.Sc). His current research focuses on renewable energy, especially energy technology. He has published more than 100 peer-reviewed papers, which 25 papers in ISI index (20 Q1, impact factor more than 3) and more than 48 papers in Scopus index, 10 more currently accepted manuscript, 20 more currently under review, and 2 book chapters. Addition, he has published more than 70 papers in international conferences. His total citations of 571 by 395 documents and h-index of 12 in Scopus (Author ID: 57195432490). His total citations of 1093 and h-index of 19 in google scholar. He is appointed as reviewer of high impact journal such as Renewable and Sustainable Energy Reviews, Energy Conversion and Management, Applied Energy, Energy and Buildings, Applied Thermal Engineering, Energy, Industrial Crops and Products, etc. He is appointed as reviewer of reputation journals such as Drying Technology, International Journal of Green Energy, Drying Technology, Bio system Engineering, Journal of Sustainability Science and Management, Journal of Energy Efficiency, Sains Malaysiana, Jurnal Teknologi etc. He is also appointed as editor journals. He has received several awards such as Gold Medal Award at the International Ibn Al-Haytham's Al-Manazir Innovation and Invention Exhibition 2011, Silver Medal Award at the International Technology EXPO (ITEX) 2012, Silver Medal Award at the Malaysia Technology Expo (MTE) 2013, Bronze Medal Award at International Exposition of Research and Invention (PECIPTA) 2011, also 2 Bronze Medal Award at PECIPTA 2017. He was also invited as speaker: Workshop of Scientific Journal Writing; Writing Scientific Papers Steps Towards Successful Publish in High Impact (Q1) Journals.