EXERGY AND ENERGY ANALYSIS OF PHOTOVOLTAIC THERMAL (PVT)WITH AND WITHOUT FINS COLLECTOR

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ABSTRACT

Photovoltaic-thermal (PVT) is hybrid or a combination of photovoltaic panels (PV) and solar thermal collectors that can produce electricity and thermal energy simultaneously. In this study, the PVT based on air collector system with and without fins collector has been conducted with theoretical analysis. The mass flow rate varied in ranges of 0.01-0.05 kg/s, and the radiation intensity of 600 W/m^2 and 800 W/m^2. To develop predictive model, a mathematical model was constructed for PVT system with and without collectors. Energy balance equation has been solved by using the matrix inversion method. The PVT system with fins collector is higher efficiency then without fins collector. The increasing of PVT system efficiency with fins collector is 7% and efficiency exergy is 1%.

Keyword: mathematical model, exergy, energy, fins collector.

1. INTRODUCTION

Energy is a very important need in the life of modern society at this time. The rise and fall of the country's economic growth depends on its energy reserves. Renewable energy sources are critical because of the depletion of world oil reserves and the impact of environmental damage on fuel oil. Renewable energy has characteristic that are clean, safe and sustainable. Solar energy is a very promising energy among other renewable energies because its existence can be found everywhere and free as long as there is sun [1,2].

The country of Indonesia is a country with new and renewable energy has great potential. In Indonesia, Solar energy assets are about 112 GWp [3]. Zohri *et al.* [4] have conducted theoretical approach of PVT system with v-groove collector. The discussion results show that in the PV/T system with the v-groove collector is higher temperature, thermal and electrical efficiency than other collectors. The experimental and theoretical assessments of photovoltaic thermal with ∇-groove have been conducted by Fudholi *et al.* [5]. The theoretical yields were very close with the experimental investigation with accuracy of approximately 94%. Zohri *et al.* [6] have analyzed electrical and thermal efficiency of photovoltaic thermal with and without fins collector. Using fins collector was more effective than without fins collector. Zohri *et al.* [7] have done experimental analysis of photovoltaic thermal with ∇-groove by energy assessment.

The fins collector to absorb heat from solar energy has been conducted widely in solar collector. Solar collector with double-channel fins have been conducted by Naphon [8] with thermal efficiency is about 30-60%. Fudholi *et al.*[9] have compared solar collector double-channel with and without fins collector and price welfares analysis. The energy efficiency and cost-effective of two-channel with fins are higher than without fins collector. Fudholi *et al.* [10] has conducted exergy and improvement potential analysis for the fins double-channel solar collector. The result analysis for optimal energy efficiency is about 77%. The exergy efficiency is around 15-28% and the improvement potential of 740-1070 Watt for a solar radiation of 425-790 W/m^2.

The system that generates electricity and heat are called photovoltaic thermal system (PVT). In the last few years, an amount of experimental and theoretical studies have been up-to-date on PVT systems. In the case of heat absorption and lower production costs, a new design developed for PVT system collector and compared it with other designs [7]. The applications and different forms of Flat-plat PVT collector have been conducted by Zondag*et al.*[11]. The experimental analysis has been done on PVT system withferro-fluids as a coolant to increase the whole productivity system by Kamthania *et al.*[12]. Using thermal modeling for space heating has been developed by energy balance calculation of PVT system with semitransparent double pass module [13]. The different types of collectors like; with glazed and without glazed PVT tiles and conventional hybrid PVT collector have been compared by Agrawal *et al.* [14]. A new design of a dynamic model of air based PVT system has been offered by sohel*et al.*[15] The performance analysis of and new design of PVT system for low attentiveness PV panel has been conducted [16].

The purpose of the study is to calculate energy and exergy analysis of PVT system with and without fins collector by theoretical approach for different solar radiation and mass flow rate.

2. THEORETICAL APPROACH

This study use of fins and without fins collector. Based on energy balance, Figure-1 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 0.2 m of length and 0.03 m of width. The number of fins is 50.
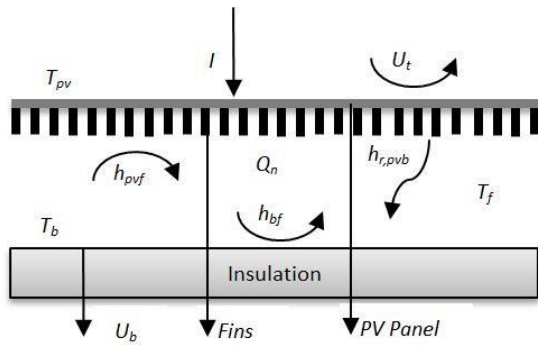
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Figure-1. The fins collector design to fit behind photovoltaic panel.

For PV/T system without fin is used matrix 3 x 3 to calculate Temperature PV panel T_p, temperature fluid T_f and Temperature bottom plate T_b. by matrix invers following:

$$[A][T] = [C] \qquad (1)$$

For PV panel:

$$\tau\alpha(1 - \eta_c)I = U_t(T_p - T_a) + h_{pf}(T_p - T_f) + h_{rpb}(T_p - T_b) \qquad (2)$$

For air channel:

$$2\dot{m}C(T_f - T_i)/WL = h_{pf}(T_p - T_f) + h_{bf}(T_b - T_f) \qquad (3)$$

For bottom plate:

$$h_{rpb}(T_p - T_b) = U_b(T_b - T_a) + h_{bf}(T_b - T_f) \qquad (4)$$

$$\begin{bmatrix} (A_1) & -h_{pf} & -h_{rpb} \\ h_{pf} & -(A_2) & h_{c2} \\ h_{rpb} & h_{bf} & -(A_3) \end{bmatrix} \begin{bmatrix} T_p \\ T_f \\ T_b \end{bmatrix} = \begin{bmatrix} A_4 \\ -A_5 \\ -A_6 \end{bmatrix}$$

Where,
$A_1 = (U_t + h_{pf} + h_r)$
$A_2 = \left(h_{pf} + h_{bf} + 2\dot{m}C/WL\right)$
$A_3 = (h_{rpb} + h_{bf} + U_b)$
$A_4 = U_t T_a + \tau\alpha(1 - \eta_{cell})I$
$A_5 = (\frac{2\dot{m}C}{WL})T_i$
$A_6 = U_b T_a$

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

$$[A][T] = [C] \qquad (5)$$

For PV panel:

$$\tau\alpha(1 - \eta_{cell})I = U_t(T_p - T_a) + h_{pf}(T_p - T_f) + h_{rpb}(T_p - T_b) + Q_n \qquad (6)$$

For air channel:

$$2\dot{m}C(T_f - T_i)/WL = h_{pf}(T_p - T_f) + h_{bf}(T_b - T_f) + Q_n \qquad (7)$$

For bottom plate:

$$h_{rpb}(T_p - T_b) = U_b(T_b - T_a) + h_{bf}(T_b - T_f) \qquad (8)$$

$$\begin{bmatrix} A_1 & -h_{pf} + Q_n & -h_{r,pb} \\ h_{pf} + Q_n & -(A_2) & h_{bf} \\ h_{rpb} & h_{bf} & -(A_3) \end{bmatrix} \begin{bmatrix} T_p \\ T_f \\ T_b \end{bmatrix} = \begin{bmatrix} A_4 \\ -A_5 \\ -A_6 \end{bmatrix}$$

Where,
$A_1 = (U_t + h_{pf} + h_{rpb} + Q_n)$
$A_2 = \left(h_{pf} + h_{bf} + \frac{2\dot{m}C}{WL} + Q_n\right)$
$A_3 = (h_{rpb} + h_{bf} + U_b)$
$A_4 = U_t T_a + \tau\alpha(1 - \eta_{cell})I$
$A_5 = (\frac{2\dot{m}C}{WL})T_i$
$A_6 = U_b T_a$

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

$$M = (2h_c l/kw)^{0.5}$$

$$U_b = k_t/l_t$$

$$U_t = \left(\frac{1}{h_w + h_{rpa}}\right)^{-1}$$

Referring to Eq. (1 and 5), the temperature vector be calculated with Excel by matrix inversion form;

$$[T] = [A]^{-1}[C] \qquad (9)$$

A standard matrix inversion subroutine is then called to invert $[A]^{-1}$ to calculate a new set of temperature matrix [T']. Each new temperature value in the matrix [T'] is then compared with the corresponding initially guessed [T]. If the difference between any corresponding new and old values less than 0.001°C, the iteration is stopped and the old temperatures are then replaced with the newly calculated ones and taken to be the required temperatures at the section concerned. In this study, sufficient convergence for T_p, T_f, and T_b was achieved in three to four iterations.

For the heat transfer coefficients are calculated, such as [17]

$$h_{rpb} = \frac{\sigma(T_p + T_b)(T_p^2 + T_b^2)}{\left(\frac{1}{\varepsilon_p} + \frac{1}{\varepsilon_b} - 1\right)} \qquad (10)$$

$$h_{rpa} = \varepsilon_p \sigma(T_p^2 + T_s^2)(T_p - T_s) \qquad (11)$$

$$T_s = 0.0522 T_a^{1.5} \qquad (12)$$

Where $\varepsilon_p, \sigma, T_a$, T_s, and T_p are the emissivity ofpanel Photovoltaic, Stefan Boltzman constant, ambient temperature, sky temperature and panel photovoltaic temperature, respectively.

The convective heat transfer coefficients are given as[18]

$$h = \frac{k}{D_h} Nu \tag{13}$$

which,

$$D_h = \frac{4Wd}{2(W+d)} \tag{14}$$

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

$$Nu = 5.4 + \frac{0.00190\left[RePr\left(\frac{D_h}{L}\right)\right]^{1.71}}{1+0.00190\left[RePr\left(\frac{D_h}{L}\right)\right]^{1.71}} \tag{15}$$

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

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

For Re>6000 (turbulent flow region):

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

where, Re and Pr are the Reynolds and Prandtl number given as:

$$Re = \frac{\dot{m}D_h}{A_{ch}\mu} \tag{18}$$

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

The theoretical model assumes that for a short collector or less of 10 m. Then, the mean air temperature is then equal to the arithmetic mean, where:

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

2.1. Exergy analysis

Exergy analysis is based on the second of law of thermodynamics, which if the effects due to the kinetic and potential energy changes are neglected, the general exergy balance is expressed as [19]:

$$\sum Ex_i - \sum Ex_o = \sum Ex_d \tag{21}$$

Or the equation for exergy is

$$\sum Ex_i - \sum (Ex_{th} - Ex_p) = \sum Ex_d \tag{22}$$

Which,

$$Ex_i = ANI\left[1 - \frac{4}{3}\left(\frac{T_a}{T_a}\right) + \frac{1}{3}\left(\frac{T_a}{T_s}\right)^4\right] \tag{23}$$

$$Ex_{th} = \dot{m}C(T_o - T_i)\left[1 - \frac{T_a + 273}{T_o + 273}\right] \tag{24}$$

$$Ex_p = \eta_p AI \tag{25}$$

The electrical efficiency of PVT air collector can be calculated as,

$$\eta_p = \eta_{ref}\left[1 - 0.0045(T_p - 25)\right] \tag{26}$$

$$Ex_{pvt} = Ex_{th} + Ex_p \tag{27}$$

The PVT exergy efficiency is expressed as

$$\eta_{ex,pvt} = \frac{Ex_o}{Ex_i} \tag{28}$$

Where, Ex_{th} is thermal exergy, Ex_d is destruction exergy, Ex_p is photovoltaic exergy, Ex_{pvt} is photovoltaic thermal exergy, Ex_o is output exergy, Ex_i is input exergy (radiation exergy), $\eta_{ex,pvt}$ is photovoltaic thermal (PVT) exergy efficiency, A is PV area, N is PV number, I is solar radiation, T_s is sun temperature (T_s =5777K), T_a is ambient temperature, T_o, T_i and T_p are outlet, inlet and PV temperature respectively, ^{o}C

3. RESULT AND DISCUSSIONS

Figures 2-3 shows the difference of mass flow rate versus PVT efficiency and outlet temperature of PVT system with and without fins collector. The mass flow rate is used of 0.01-0.05 kg/s. For solar radiation 600 W/m^2 and 800 W/m^2, the efficiency result of PVT system with fins collector is between 39% and 55% and outlet temperature is between 30.29^{o}C to 41.39^{o}C. The PVT efficiency without fins collector is between 36% and 47% and outlet temperature is between 29.77^{o}C to 39.93 ^{o}C. The maximum temperature outlet and PVT efficiency are 39.93^{o}C and 55% by using fins collector. The result shows that the PVT system with fins collector be able to increase efficiency of PVT system. The Figures 2-3 show that by lowering the outlet temperatures (T_o) simultaneously the increasing the PVT efficiency. Using fins collector can improve PVT system efficiency average approximately 7%.
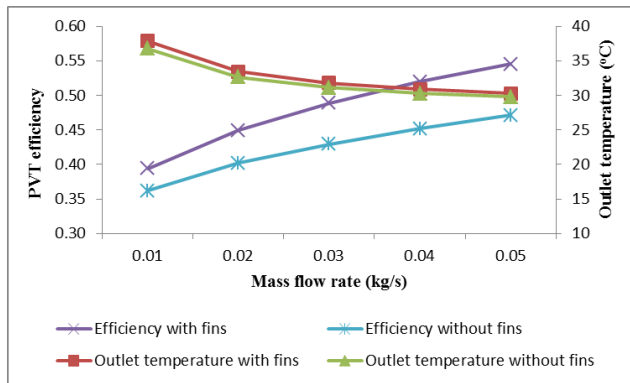
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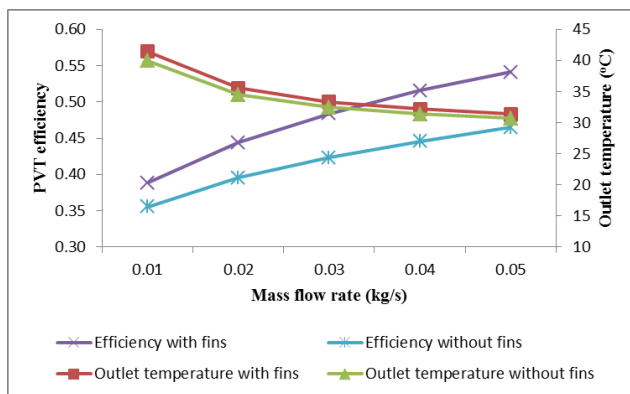**Figure-2.**Mass flow rate versus outlet temperature and PVT efficiency for S = 600 W/m^2.

Figure-3. Mass flow rate versus outlet temperature and PVT efficiency for S = 800 W/m^2.

Figures 4-5 shows the mass flow rate versus exergy and exergy efficiency of the PVT system with and without fins collector. For solar radiation of 600 W/m^2, the exergy efficiency of PVT system without fins collector is between 11% and 12% with exergy of about 41.71-42.92W. The exergy efficiency of PVT system with fins collector is between 12% and 13% with exergy of about 44.30-44.88W.For solar radiation of 800 W/m^2, the exergy efficiency of PVT system without fins collector is between 11% and 12% with exergy of about 54.07-56.16 W. The exergy efficiency of PVT system with fins collector is between 12% and 13% with exergy of about 58.57-59.51

W. The exergy and exergy efficiency of the PVT system with and without fins collector falls as the mass flow rate upsurges. The maximum exergy efficiency is 13% with fins collector and the minimum exergy is 11% without fins collector.
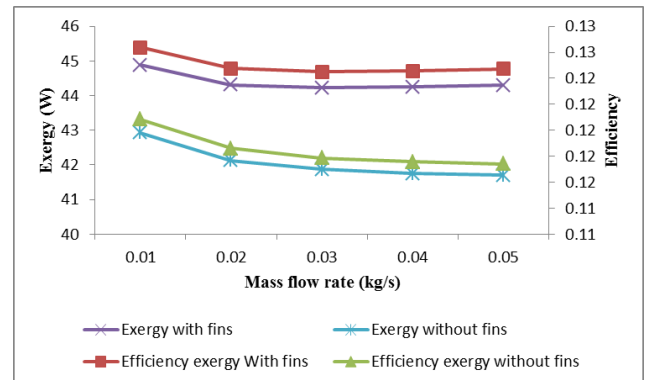

Figure-4. Mass flow rate versus exergy and exergy efficiency for 600 W/m^2.
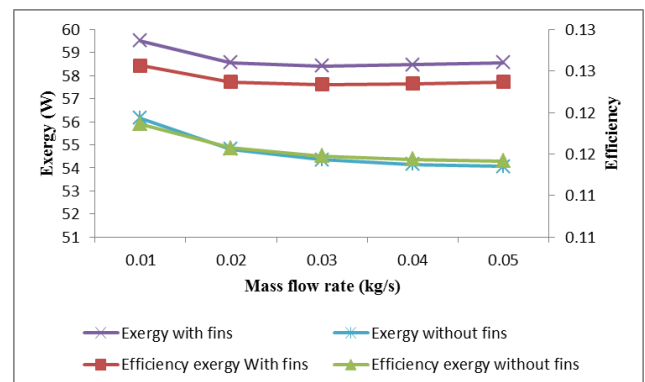

Figure-5. Mass flow rate versus exergy and exergy efficiency for 800 W/m^2.

The Table-1 shows the comparison of energy and exergy efficiency with other literature. The present study yield shows that energy and exergy efficiency with fins collector is very close with other references.

Table-1. The comparison present study of exergy efficiencies.

Energy efficiency (%)	PVT exergy efficiency (%)		References
	Theo.	**Exp.**	
Theo.: η_{pv}=10, η_{th} =17.2	10.75	-	[20]
Theo.: η_{pv}=14-15	12-15	-	[21]
	13.5	-	[22]
Theo.: η_{pvt}=39-55	11-13	-	Present study

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4. CONCLUSIONS

The theoretical study was conducted to calculate the energy and exergy analysis of PVT based on air with and without fins collector. On the basis of present study, the results of these studies may be decided as follow:

- The maximum temperature outlet and PVT efficiency are between 39.93 $^{\circ}$C and 55% by using fins collector.
- The maximum exergy efficiency is 13% with fins collector and the minimum exergy is 11% without fins collector. The increasing of PVT system efficiency with fins collector is 7% and efficiency exergy is 1%.

Nomenclature

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

Greek letters

ε	emissivity
τ	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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