

## Effect analysis of the different channel length and depth of photovoltaic thermal system with $\nabla$ -groove collector

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### ABSTRACT

The converted Solar energy as electrical and thermal energy was named photovoltaic thermal (PVT). The aim of this study is to the analysis of different length and depth channel effect of photovoltaic thermal with  $\nabla$ -groove collector by a mathematical model. The matrix inversion was used to analyze the energy balance equation. Simulation results were conducted below the solar intensity of 800 W/m<sup>2</sup> and mass flow rate between 0.0069 kg/s and 0.0491 kg/s. Electrical and thermal efficiency was done to assess the effect of different length and channel depth of PVT system with  $\nabla$ -groove collector. The effect of different length and depth of  $\nabla$ -groove collector for electrical and thermal performance is caused by changed mass flow rate. The effect Increasing of the mass flow rate of collector increased the thermal and electrical performance of the  $\nabla$ -groove collector.

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## 1. INTRODUCTION

Solar energy is one of renewable energy which has characteristic sanitary and harmless and sustainable. The conversion of solar energy to thermal and electrical energy is called Photovoltaic thermal (PVT) system. The PVT system is a combination of photovoltaic and solar collector technology. The over heat from PV panel is removed by air as medium cooling [1]. The performance of PVT system is excessive total energy transformation efficiency. The enactment and financial effectiveness of PVT system be contingent of numerous scheme parameters for example collector design shape, collector dimension, collector penetration, amount of collectors, Photovoltaic module form , glazed and unglazed collector, focused solar intensity [2].

Many studies of the photovoltaic thermal system with collector have been done by The theoretical and experimental assessment in last decades. Zohri et al. [3] have developed mathematical modeling of photovoltaic thermal with v-groove. The electrical and thermal efficiency have been compared with other design collectors. The use of v-groove was the higher efficiency than other design collectors. Zohri et al. [4] have done energy and exergy analyses of photovoltaic thermal with fins collector with theoretical approach. The use of fins collector is higher energy and exergy efficiency than without fins collector. Zohri et al. [5] have done developed performances analysis of photovoltaic thermal with and without fins collector. The energy performance of fins collector was very good than without fins collector. The theoretical approach or mathematical model of photovoltaic thermal with and without v-groove collector have been conducted by Zohri et al. [6]. the exergy performance results showed that using of v-groove collector be able to increase the exergy efficiency.

Kumari and Babu [7] have analyzed the photovoltaic cell using the Matlab-Simulink situation with theoretical study. The objective of this study was to the discovery of nonlinear I-V equation. The best of I-V equation for the single-diode photovoltaic model counting the effect of the sequence and similar confrontations was found. Aminullah et al. [8] have conducted the influence analysis of solar intensity and combination of photovoltaic generator to power quality. The yield of dual adjusted passive sieve able to increase voltage and current THD grid. Sharma et al. [9] have done the modeling and representing analysis of off-grid control cohort system with photovoltaic. Mohammad et al. [10] have done theoretical approach of photovoltaic collection by application of fuzzy logic.

Many researchers just have conducted a thermal and electrical analysis of the PVT system with channel depth and length of collector constantly. The assessment with differences in length and a channel depth of collectors is still very rare in determining the achievement of the PVT system. In this simulation, a mathematical model for calculating the performance of the PVT system with  $\nabla$ -groove collector is calculated by variation of length and channel depth collector. Mathematical modeling is carried out to develop thermal and electrical efficiency using a steady-state condition. The  $\nabla$ -groove collector is a combination of V-groove and plat plate collector. The process heat removals improved thermal efficiency because of the extended surface of absorber collector. The purpose of this study is to determine the best of length and depth of collector before to do the experimental investigation.

## 2. THEORETICAL ANALYSIS

The cross sectional view of the PVT with  $\nabla$ -collector is shown in our paper [11]. It shows various heat transfer coefficients. In order to write the energy balance equation of PVT system with  $\nabla$ -collector, the following assumptions are made as showed our in paper [12]. The steady-state equation of photovoltaic thermal with  $\nabla$ -groove collector as following

For module PV:

$$\tau\alpha S - U_t(T_{pv} - T_a) - h_{c1}(T_{pv} - T_f) = h_r(T_{pv} - T_b) + S\eta_{pv} + Q_{\nabla} \quad (1)$$

The channel of air:

$$\dot{m}C(T_o - T_i) - h_{c1}(T_{pv} - T_f) = h_{c2}(T_b - T_f) + Q_{\nabla} \quad (2)$$

The bottom plate:

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

The photovoltaic thermal with  $\nabla$ -groove collector uses the matrix 3 x 3 for calculating the module PV temperature  $T_{pv}$ , the air temperature  $T_f$ , and bottom plate  $T_b$  using inverse matrix as following. The completion of PVT system with  $\nabla$ -groove as following,

$$\begin{bmatrix} (U_t + h_{c1} + Q_{\nabla} + h_r) & -h_{c1} + Q_{\nabla} & -h_r \\ h_{c1} + Q_{\nabla} & -(h_{c1} + h_{c2} + Q_{\nabla} + \dot{m}C) & h_{c2} \\ h_r & h_{c2} & -(h_r + h_{c2} + U_b) \end{bmatrix} \begin{bmatrix} T_{pv} \\ T_f \\ T_b \end{bmatrix} = \begin{bmatrix} U_t T_a + \tau\alpha(1 - \eta_{pv})S \\ -2\dot{m}CT_i \\ -U_b T_a \end{bmatrix}$$

Where,

$$Q_{\nabla} = NAn h_c \eta_{\nabla}(T_{pv} - T_f)$$

$$\eta_{\nabla} = \tanh MH / MH$$

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

$$h_{c1} = h_{c2} = h_c$$

$$U_b = \frac{kt}{l_t}$$

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

The settlement procedure uses the iteration process. The excel program is used to calculate all the heat transfer coefficients required in the mathematical model. The heat transfer characteristics are calculated according to the initial estimation of temperature values. In this study, inlet air temperature, ambient temperature, PV panel temperature and bottom plate temperature are predicted first. For PV panel temperature is set at 30 °C above ambient temperature. For the bottom plate temperature and the air

temperature is set at 20 °C and 10 °C above the ambient temperature. The design parameters are  $L = 2.4$  m,  $W = 0.53$ ,  $\alpha = 0.9$ ,  $\tau = 0.92$ ,  $\varepsilon_{pv} = 0.7$ ,  $\varepsilon_b = 0.9$ ,  $T_a = 27$ ,  $T_i = 27$  °C.

The thermal energy efficiency of PVT system is given as [13-17]

$$\eta_{thermal} = \frac{\dot{m}C(T_o - T_i)}{AS} \quad (4)$$

Where, the area of collector is  $A$ , the specific heat of air is  $C$ , mass flow rate is  $\dot{m}$ , solar intensity is  $S$ , and the inlet and outlet temperature of air are  $T_i$ ,  $T_o$  respectively.

The electrical efficiency is calculated as [18]

$$\eta_{pv} = \eta_0 [1 - 0.0045(T_{pv})] \quad (5)$$

The heat transfer coefficient according to Ong [19] is

$$h_w = 2.8 + 3.3V \quad (6)$$

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

$$h_{r,pvs} = \varepsilon_{pv} \sigma (T_{pv}^2 + T_{sky}^2) (T_{pv} - T_{sky}) \quad (7)$$

$$h_{r,pvb} = \frac{\sigma(T_{pv} + T_b)(T_{pv}^2 + T_b^2)}{\left(\frac{1}{\varepsilon_{pv}} + \frac{1}{\varepsilon_b} - 1\right)} \quad (8)$$

Where  $T_s$  is the sky temperature,  $T_{pv}$  is the photovoltaic panel temperature.

$$T_{sky} = 0.0552T_a^{1.5} \quad (9)$$

Where,  $\varepsilon_p, \sigma, T_a, T_{sky}$ , and  $T_{pv}$  are the emissivity of panel Photovoltaic, Stefan Boltzman constant, ambient temperature, sky temperature and panel photovoltaic temperature, respectively

The convective heat transfer coefficients are calculated as follow [20]:

$$h = \frac{k}{D_h} Nu \quad (10)$$

where,

$$D_h = \frac{4Wd}{2(W+d)} \quad (11)$$

Where,  $W, D_h$  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):

$$Nu = 5.4 + \frac{0.00190 \left[ Re Pr \left( \frac{D_h}{L} \right) \right]^{1.71}}{1 + 0.00190 \left[ Re Pr \left( \frac{D_h}{L} \right) \right]^{1.71}} \quad (12)$$

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

$$Nu = 0.116(Re^{2/3} - 125)Pr^{1/3} \left[ 1 + \left( \frac{D_h}{L} \right)^{2/3} \right] \left( \frac{\mu}{\mu_w} \right)^{0.14} \quad (13)$$

For  $Re > 6000$  (turbulent flow region):

$$Nu = 0.018Re^{0.8}Pr^{0.4} \quad (14)$$

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

$$Re = \frac{\dot{m}D_h}{A_{ch}\mu} \quad (15)$$

$$Pr = \frac{\mu C}{k} \quad (16)$$

The physical properties of air are hypothetical vary linearly with temperature by Fudholi [21]:  
Specific heat

$$C = 1.0057 + 0.000066 (T - 27) \quad (17)$$

Density,

$$\rho = 1.1774 - 0.00359 (T - 27) \quad (18)$$

Thermal conductivity

$$k = 0.02624 + 0.0000758 (T - 27) \quad (19)$$

Viscosity

$$\mu = [1.983 + 0.00184 (T - 27)]10^{-5} \quad (20)$$

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:

$$T_f = \frac{(T_i + T_o)}{2} \quad (21)$$

### 3. RESULTS AND DISCUSS

In this simulation, the thermal and electrical performance of PVT with  $\nabla$ -groove has been predicted by the mathematical model. The yield of the mathematical model is assumed steady-state condition. The different solar radiation and mass flow rate caused different thermal and electrical performances. The simulation studies have been done with the influence of the different collector length  $L$  and channel depth  $d$  with mass flow rate from 0.0069 kg/s to 0.0491 kg/s and the solar intensity of 800 W/m<sup>2</sup>. The collector length  $L$  determined with the distance of the air channel through the collector channel during the transfer process. Figure 1 shows the thermal efficiency versus mass flow rate with the different collector length  $L$ . The optimum thermal efficiency is 39.05% at the mass flow rate of 0.0491 kg/s with the length collector of 2.4 m. The minimum thermal efficiency is 30.71% with the length collector of 6 m. Generally, the thermal efficiency increases nonlinearly to the maximum and then decrease as the collector length increases.

Figure 2 shows the electrical efficiency versus the mass flow rate at the solar intensity of 800 W/m<sup>2</sup> with different collector length  $L$ . The electrical efficiency results were a non-linear reduction when the collector length  $L$  increased. The optimum electrical efficiency is 10.43% with the collector length of 2.4 m. and the minimum electrical efficiency is 10.22% with collector length of 6 m. The decrease of electrical efficiency is due to the higher rise of photovoltaic panel temperature for lower mass flow rate when the collector length increases.

Figure 3 shows the mass flow rate versus thermal efficiency with different channel depth  $d$  at the solar intensity of 800 W/m<sup>2</sup>. The collector channel depth affects the heat transfer rate from collector to the airflow through it and consequently affects the performance of the PVT system. In this study, the collector depth is used from 0.04 m to 0.07 m. The thermal efficiency in the collector channel depth of 0.04 m reaches about 41.89%. When the collector channel depth is 0.05 m, thermal efficiency decreases about 38.20%. And subsequently decreased by about 32.70% when the collector channels depth is 0.07 m.

Figure 4 shows electrical efficiency versus the mass flow rate with different channel depth  $d$  at the solar intensity of 800 W/m<sup>2</sup>. The electrical efficiency of the PVT system changes when the channel depth  $d$  is also changed. Electrical efficiency with mass flow rate from 0.0069 kg/s to 0.0491 kg/s about is 10.50% at channel depth of 0.04 m. When the channel depth is 0.05 m, the electrical efficiency decrease about 10.40%. and declining electrical efficiency is until 10.27% when the depth of the collector is 0.07 m. The reduction in electrical efficiency of the collector is due to the temperature increase of photovoltaic panel because the channel depth  $d$  is improved

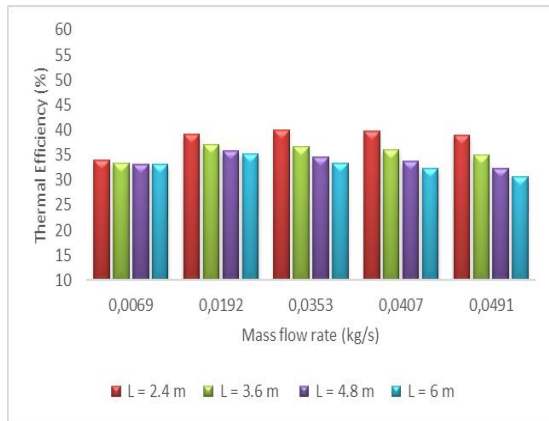


Figure 1. Thermal efficiency versus mass flow rate with different collector length  $L$  ( $d = 0.04$  m)

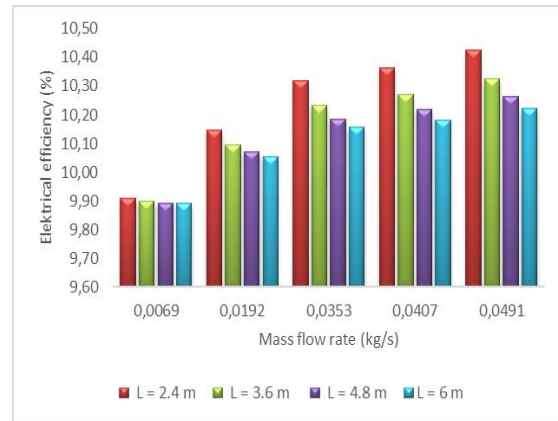


Figure 2. Electrical efficiency versus mass flow rate with different collector length  $L$  ( $d = 0.04$  m)

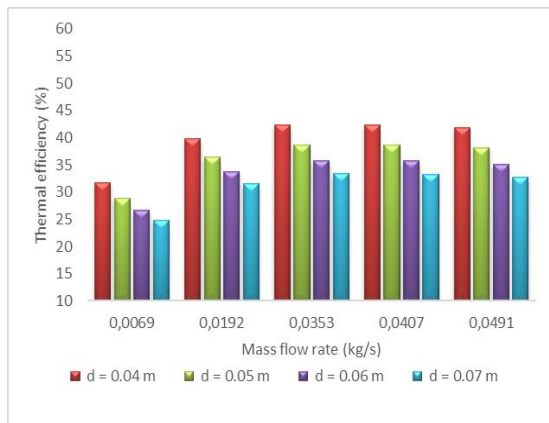


Figure 3. Mass flow rate versus thermal efficiency with different channel depth  $d$  ( $L=2.4$  m)

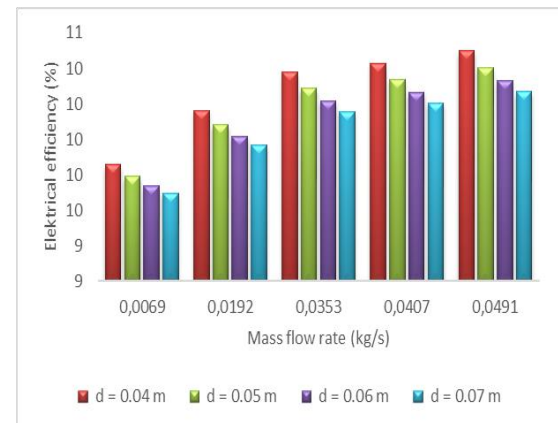


Figure 4. Electrical efficiency versus the mass flow rate with different channel depth  $d$  ( $L = 2.4$  m)

In this study, the comparison of the results with preceding theoretical or experimental studies is valuable. Table 1 shows that the use of channel depth of 0.04 m or 0.05 m and length of 2.4 m produced higher thermal and electrical efficiency than increase channel depth and length of the collector. The yield of this simulation shows that this result very closed to the results by Abd-AlRaheem and Amori [22]. The change in the channel depth and length of collector have an important effect on the electrical and thermal efficiency. The Increasing of the mass flow rate of collector increased the thermal and electrical performance of the collector.

Table 1. The comparison with previous studies

References	Parameters	Efficiencies	
		Thermal (%)	Electrical (%)
Kasaiean et al. [23]	$d = 0.01 - 0.05$ m $\dot{m} = 0.018 - 0.06$ kg/s	15 - 31	12 - 12.4
Joshi et al. [24]	$d = 0.05$ m $\dot{m} = 0.05$ kg/s	13.4 - 16.5	9.5 - 11
Sarhaddi et al. [25]	$d = 0.05$ m $\dot{m} = 0.06$ kg/s	25	10
Kim et al. [26]	$d = 0.06$ m	22	15
Tonui and Tripanagnostopoulos [27]	$d = 0.15$ m $\dot{m} = 0.05$ kg/s	18	12
Abd-AlRaheem and Amori [22]	$d = 0.24$ m	50	10
Present study	$d = 0.04 - 0.07$ m $\dot{m} = 0.0069-0.0491$ kg/s	32.70 - 41.89	10.50 - 10.27

#### 4. CONCLUSION

The performances of electrical and thermal efficiency with  $\nabla$ -groove collector have been conducted by a mathematical model with the difference channel depth  $d$  and length  $L$ . Optimum thermal and electrical efficiency are 39.05 %, 10.43% respectively with the collector length  $L$  of 2.4 m. The optimum thermal and electrical efficiency are 41.89 %, 10.50% respectively with the collector depth  $d$  of 0.04 m. The variation of the length and depth of the collector is effected by changed mass flow rate and solar intensity. The effect increasing of the mass flow rate of collector increased the thermal and electrical performance of the collector. The best of mass flow rate, length, and depth of collector is 0.0491 kg/s, 2.4 m and 0.04 m, respectively.

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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.