TELKOMNIKA, Vol.16, No.2, April 2018, pp. 550~557
ISSN: 1693-6930, accredited **A** by DIKTI, Decree No: 58/DIKTI/Kep/2013
DOI: 10.12928/TELKOMNIKA.v16i2.8433

Exergy Assessment of Photovoltaic Thermal with V-groove Collector Using Theoretical study

Muhammad Zohri*[1], Nurato[2], Lalu Darmawan Bakti[3], Ahmad Fudholi[4]
[1,4] Solar Energy Research Institute (SERI), The National University of Malaysia,
43600 Bangi, Selangor, Malaysia
[2] Department of Mechanical Engineering, Mercu Buana University, Indonesia
[1,3] College Computer Information Management (STMIK) Mataram, Indonesia
*Corresponding author, e-mail: zohri.ukm@gmail.com

Abstract

The solution of the environmental problems because of fuel fossil is to use new and renewable energy. There are many studies about energy analysis of solar collector with v-groove but exergy analysis of photovoltaic thermal system with v-groove is still less especially by theoretical study. Photovoltaic thermal with v-groove collector has been conducted the exergy analysis by theoretical assessment. The matrix inversion methods were used to analyze the energy balance equation. The theoretical assessment was conducted under the solar intensity of 385 W/m^2, 575 W/m^2, and 875 W/m^2 and mass flow rate between 0.01 and 0.05 kg/s. The maximum exergy efficiency and exergy of PVT system with v-groove collector were 17.80% and 86.32 Watt at the solar intensity of 875 W/m^2.

Keywords: *Theoretical, V-groove, Exergy, Collector*

1. Introduction

The burning of the fossil fuels to generate energy is still dominantly worn around the world. The burning of the fossil fuels produces some carbon dioxide into the air. The increased carbon emissions could increase the greenhouse effect, and the greenhouse effect is a major cause of climate change. Therefore, the developed and developing countries have thought of alternative energy to reduce the use of the fossil fuels by utilizing the new and renewable energy. The Indonesia country has an abundant source of the new and renewable energy. Solar energy is one of renewable energy that has great potential in Indonesia. The solar energy reserves in Indonesia are about 112 GWp [1].

The system that generates electrical and thermal energy simultaneously is called photovoltaic thermal (PVT) system. The electrical and thermal analysis of photovoltaic thermal collector with v-groove collector has been conducted by Zohri et al. [2]. The exergy and energy studies of photovoltaic thermal with ∇-groove by theoretical and experimental investigation have been analyzed by Fudholi et al [3]. The experimental results were reliable with the theoretical approach results. The thermal and electrical performance of photovoltaic thermal with and without fins collector by mathematical model have been designed by Zohri et al. [4]. The electrical and thermal performance of PVT system with fins collector is more efficiency than without fins collector. The experimental investigation of photovoltaic thermal with ∇-groove with thermal and electrical analysis has been conducted by Zohri et al. [5]. The theoretical and simulation study of photovoltaic cell by Matlab-Simulink situation have been conducted by Kumari and Babu [6]. The simulation and representing study of off-grid power generation system by the photovoltaic have been done by Sharma et al. [7]. To improve the model of the photovoltaic array along with the implementation of fuzzy logic has been analyzed by Mohammad et al. [8]. The purpose of this study was to analyze the influence of solar radiation and integration of photovoltaic generator has been done by Aminullah et al. [9].

The quality of energy or helpful energy (accessibility) is called exergy. The exergy method is able to assess thermodynamic system effectively [10]. To optimize the thermodynamic system usually used exergy analysis [11]. Faizal et al. [12] have conducted the study of a flat-plat solar collector with energy, exergy, economic and environmental analysis with SiO_2. It was establish that exergy and energy performances of nanofluids were higher than

Received December 25, 2017; Revised February 7, 2018; Accepted February 26, 2018

base fluids. Tiwari et al [13] have analyzed the energetic and exergetic performances of photovoltaic thermal with flat plate collector integrated solar cleansing system. It was accomplished that the solar collector system could get together the water and electrical control during sundown hours. Chamoli [14] have investigated the exergy analysis of flat-plat solar collector using MATLAB Simulink. For the maximum exergy inflow, the parameter such as inlet temperature, outlet temperature, the mass flow rate and absorber plat have been maximized.

The mainstream of the theoretical approach obtainable in references mainly focuses on solar collector using v-groove. The use of theoretical approach for photovoltaic thermal with v-groove collector was still few as specially for exergy analysis. The use of v-groove solar collector was widely used for maximum thermal efficiency to decide the necessary heat for the drying procedure. The process heat transfer with v-groove is higher thermal performance than without v-groove because of the expanded collector surface [15-19]. The purpose of this study is to predict the exergy performance of photovoltaic thermal with v-groove collector before doing experimental investigation.

2. Theoretical Analysis

Figure 1 shows the design of photovoltaic thermal with v-groove collector. The schematic design of v-groove collector was explained in Figure 2 with the coefficients of heat transfer. The length and height of v-groove collector were 1.2 m and 0.05 m. The triangle for each side was the 60^o angle.

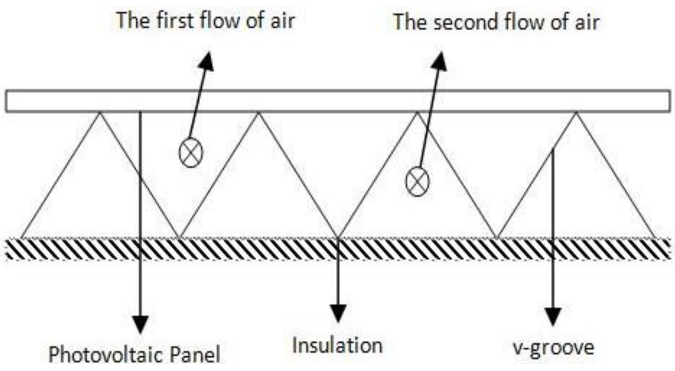

Figure 1. Design of Photovoltaic Thermal with v-groove Collector

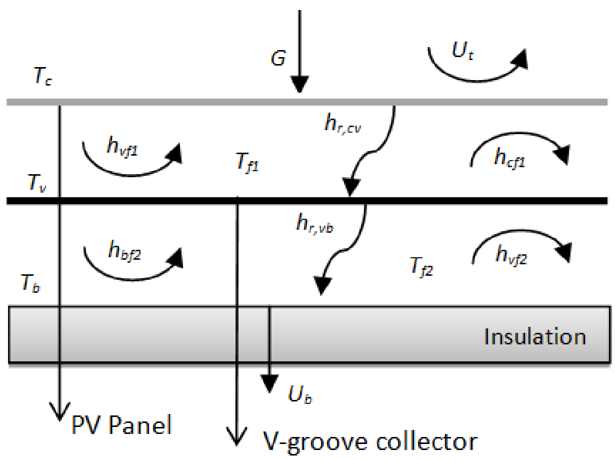

Figure 2. The Heat Transfer Coefficients of PVT System with v-groove Collector

For module PV

$$\alpha_c G(1-\eta_c) + h_{r,vc}(T_v - T_c) = h_{c,f1}(T_c - T_{f1}) + U_t(T_c - T_a) \quad (1)$$

For the below channel

$$2\dot{m}C(T_{f1,o} - T_{f1,i})/WL = h_{cf1}(T_c - T_{f1}) - h_{vf1}(T_v - T_{f1}) \quad (2)$$

For the v-groove

$$\alpha_v \tau_c G(1-\eta_c) = h_{r,vc}(T_v - T_c) + h_{vf1}(T_v - T_{f1}) + h_{r,vb}(h_v - h_b) + h_{vf2}(T_v - T_{f2}) \quad (3)$$

For the second air flow channel

$$2\dot{m}C(T_{f2,o} - T_{f2,i})/WL = h_{vf2}(T_v - T_{f2}) + h_{bf2}(T_b - T_{f2}) \quad (4)$$

For the bottom plate

$$h_{r,vb}(T_v - T_b) = h_{bf2}(T_b - T_{f2}) + U_b(T_b - T_a) \quad (5)$$

where,

$$T_{f1} = (T_{f1,o} + T_{f1,i})/2 \quad (6)$$

$$T_{f2} = (T_{f2,o} + T_{f1,o})/2 \quad (7)$$

$$U_t = \left(\frac{1}{h_w + h_{rcs}}\right) \quad (8)$$

$$U_b = \frac{k_t}{l_t} \quad (9)$$

The Equation from 1 to 5 above is able to structure with 5 x 5 matrixes as follow;

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

$$\begin{bmatrix} A_1 & -h_{cf1} & -h_{rvc} & 0 & 0 \\ h_{cf1} & A_2 & h_{vf2} & 0 & 0 \\ -h_{rvc} & -h_{vf2} & A_3 & A_4 & -h_{rvb} \\ 0 & A_5 & A_6 & A_7 & h_{bf2} \\ 0 & 0 & h_{rvb} & h_{bf2} & A_8 \end{bmatrix} \begin{bmatrix} T_c \\ T_{f1} \\ T_v \\ T_{f2} \\ T_b \end{bmatrix} = \begin{bmatrix} C_1 \\ C_2 \\ C_3 \\ C_4 \\ C_5 \end{bmatrix}$$

where,

$$C_1 = U_t T_a + \alpha_c G(1-\eta_c) \quad (10)$$

$$C_2 = -\left(\frac{2\dot{m}C}{WL}\right)T_i \quad (11)$$

$$C_3 = \alpha_p \tau_c G(1-\eta_c) \quad (12)$$

$$C_4 = -B_4 \quad (13)$$

$$C_5 = -T_a U_b \quad (14)$$

$$A_1 = U_t + h_{rpc} + h_{cf1} \quad (15)$$

$$A_2 = -\left[h_{cf1} + h_{vf1} + (\frac{2\dot{m}C}{WL})\right] \quad (16)$$

$$A_3 = h_{vf1} + h_{vf2} + h_{rpc} + h_{rpb} \quad (17)$$

$$A_4 = -h_{vf2} \quad (18)$$

$$A_5 = 4\dot{m}C/WL \quad (19)$$

$$A_6 = -B_6 \quad (20)$$

$$A_7 = -\left[h_{vf2} + h_{bf2} + (\frac{2\dot{m}C}{WL})\right] \quad (21)$$

$$A_8 = -(h_{bf2} + h_{rpb} + U_b) \quad (22)$$

The heat transfer coefficient according to Ong [20] is

$$h_w = 2.8 + 3.3V \quad (23)$$

where h_w is heat transfer coefficient due to wind and *V* is the wind velocity [21]

$$h_{r,cs} = \frac{\sigma\varepsilon_c(T_c+T_s)(T_c^2+T_s^2)(T_c-T_s)}{T_c-T_a} \quad (24)$$

$$h_{r,pb} = \frac{\sigma(T_p+T_b)(T_p^2+T_b^2)}{\left(\frac{1}{\alpha_p}+\frac{1}{\alpha_p}-1\right)} \quad (25)$$

where, $T_s$is the sky temperature, T_c is the photovoltaic panel temperature.

$$T_s = 0.0552\,T_a^{1.5} \quad (26)$$

Resolve of heat transfer coefficient for symmetrical V-groove collector follows Equation in ref. [20].

$$h = 3kNu/4e \quad (27)$$

where, *Nu* is the Nusselt number, and *e* is the half-height of the V-groove (m).

$$Nu = Nu_o + \beta\frac{b}{L}n \quad (28)$$

The following relationships for different flow conditions is suggested by Hollands [22]. For laminar flow (Re <2800):

$$Nu_o = 2.281 \quad (29)$$

$$\beta = 0.126Re$$

For transition flow ($2800 \le Re \le 10^4$):

$$Nu_o = 1.9\,x\,10^{-6}Re^{1.79} \quad (30)$$

$$\beta = 225 \quad (31)$$

For turbulent flow ($10^4 < Re < 10^5$):

$$Nu_o = 0.0302Re^{0.74} \quad (32)$$

$$\beta = 0.242Re^{0.74} \quad (33)$$

The second law of thermodynamics is called Exergy analysis, the exergy rate balance is expressed as [21]

$$\sum \dot{E}x_{input} - \sum \dot{E}x_{output} = \sum \dot{E}x_{destruction} \quad (34)$$

$$\sum \dot{E}x_{input} - \sum(\dot{E}x_{thermal} + \dot{E}x_{photovoltaic}) = \sum \dot{E}x_{destruction} \quad (35)$$

where,

$$\dot{E}x_{output} = \dot{E}x_{thermal} + \dot{E}x_{photovoltaic} \quad (36)$$

$$\dot{E}x_{photovoltaic} = \eta_c A_c G \quad (37)$$

$$\dot{E}x_{thermal} = \dot{m}C(T_o - T_i)\left(1 - \frac{T_a+273}{T_o+273}\right) \quad (38)$$

$$\dot{E}x_{input} = A_c N_c G\left[1 - \frac{4}{3}\left(\frac{T_a}{T_s}\right) + \frac{1}{3}\left(\frac{T_a}{T_s}\right)^4\right] \quad (39)$$

$$\eta_{exergy} = \frac{\dot{E}x_{output}}{\dot{E}x_{input}} \quad (40)$$

where, A_c is the area of collector, N_c is the number of collector, G is the intensity of solar, T_a is the temperature of ambient, and T_s is the temperature of sun (T_s = 5777 K).

3. Results and Discuss

Figure 3 shows the mass flow rate in opposition to exergy with different the solar intensity. The exergy maximum is 86.31 Watt at the solar intensity of 875 W/m^2 and the exergy minimum is 67.88 watt at the solar intensity of 385 W/m^2. The exergy in the mass flow rate of 0.05 kg/s is almost the same each solar intensity. Furthermore, the exergy increase from the mass flow rate 0.04 kg/s to 0.01 kg/s. Figure 3 indicates that the exergy value will increase if the mass flow rate is decreased.

Figure 4 shows the exergy efficiency versus the mass flow rate with the different solar intensity. The exergy efficiency results of PVT system with v-groove collector by Theoretical approach decrease from 17.80% to 13.86% in the solar intensity of 875 W/m^2. The exergy efficiency also decreases from 15.18% to 13.54% and from 14.00% to 13.59% in the solar intensity of 575 W/m^2 and 385 W/m^2, respectively. The Figure 4 indicates that the increase in the mass flow rate and solar intensity makes the exergy efficiency drop in the PVT system.

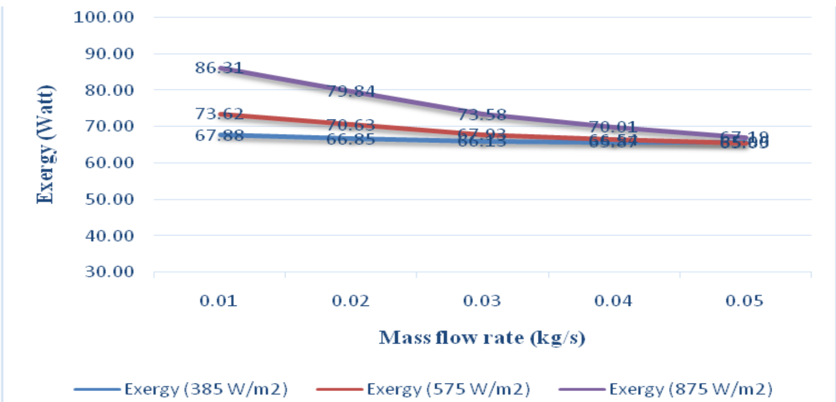

Figure 3. Exergy versus the Mass Flow Rate in Different Solar Intensity

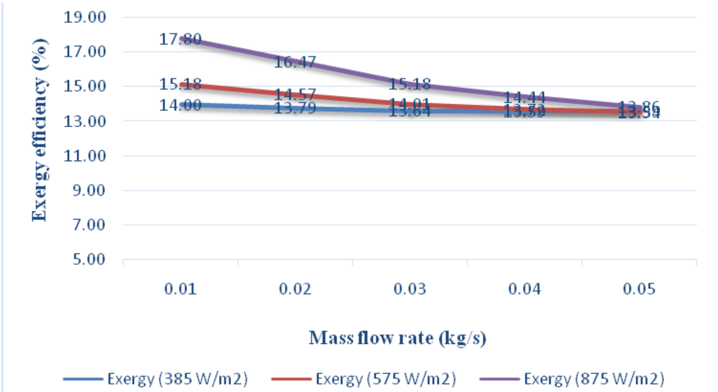

Figure 4. Exergy Efficiency Versus the Mass Flow Rate in Different Solar Intensity

Figure 5 explains the average exergy input, output, and destruction of the photovoltaic thermal system with v-groove collector at the solar intensity of 385 W/m^2. The average of exergy input, output and destruction is 484.81 W, 66.52 W, and 418.28 W. respectively. For solar intensity of 575 W/m^2, the exergy destruction and output were 415.94 Watt and 68.87 Watt, respectively as shown in Figure 6 and for solar intensity of 875 W/m^2, the exergy destruction and output are 409.42 Watt and 75.39 Watt, respectively as shown in Figure 7. Furthermore, the average input exergy was 484.81 Watt for all solar intensity. The exergy output or PVT exergy maximum between solar intensity was 75.39 Watt at solar intensity of 875W/m^2. The exergy output minimum was 66.52 Watt at solar intensity of 385W/m^2. The most of input exergy was exergy destruction because of the convection and radiation heat losses.

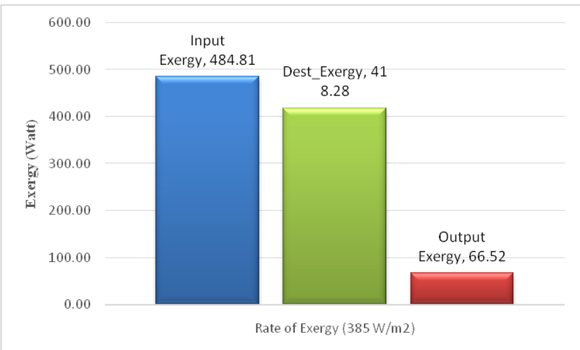

Figure 5. Exergy versus the Average of Exergy (385 W/m^2)

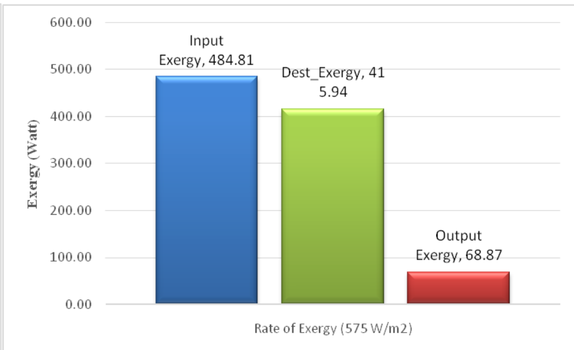

Figure 6. Exergy versus the Average of exergy (575 W/m^2)

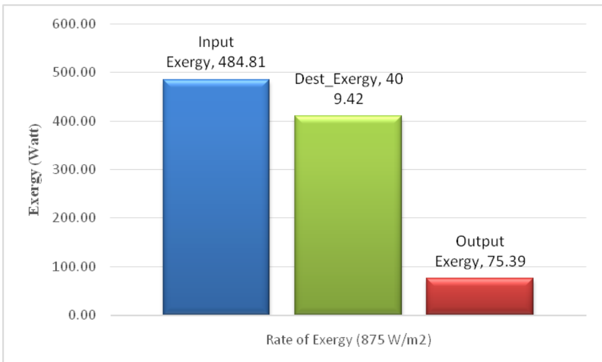

Figure 7. Exergy versus the average of exergy (875 W/m^2)

Table 1 shows the comparison between exergy efficiency present study and previous studies. In this present study, the exergy efficiency maximum is 17.80%. It is shown that this result very close to the results by Joshi and Tiwari [24]. The exergy efficiency is determined by the value of the output exergy. If the output exergy value increases then the exergy efficiency value also increases.

Table 1. The Comparison of Exergy Analysis with Previous Studies

Designs of PVT system	PVT exergy efficiency	References
PVT Based on air collector	T and E: 10.75%	[23]
PVT Parallel-plate air collector	T and E: 12.00% - 15.00%	[24]
PVT integrated greenhouse system	T and E: 4.00%	[25]
PVT solar collector	T and E: 13.50%	[26]
PVT with ∇-groove	T: 11.72 - 13.06% E: 12.44 - 13.26%	[3]
PVT with v-groove	T: 14.00% - 17.80%	Present study

*T= theoretical and E= experimental

4. Conclusion

The exergy analysis of photovoltaic thermal with v-groove collector has been conducted by the theoretical study. PVT system with v-groove collector has been calculated with a matrix inversion method to explain the temperature equation for each element. The average exergy efficiency at the solar intensity of 385 W/m^2, 575 W/m^2, and 875 W/m^2 was 66.52 Watt, 68.87 Watt, and 75.38 Watt, respectively. The maximum exergy efficiency of PVT system was 17.80% at a solar intensity of 875 W/m^2. The mass flow rate and the solar intensity make the exergy efficiency drop in the PVT system.

Nomenclature

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

Greek letters

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

Subscripts

i	inlet
o	outlet
f	air
s	sky
r	radiation
c	photovoltaic
b	bottom plate
a	ambient
v	v-groove

References

[1] M Zohri, A Fudholi. Keselamatan Tenaga dalam Pandangan Islam (Studi Kasus Negara Indonesia). *Fikiran Masyarakat*. 2016; 4(2).
[2] M Zohri, A Fudholi, MH Ruslan, K Sopian. *Mathematical modeling of photovoltaic thermal PV/T system with v-groove collector*. AIP Conference Proceedings. 2017; 1862: 030063.
[3] A Fudholi, M Zohri, GL Jin, A Ibrahim, CH Yen, MY Othman, MH Ruslan, K Sopian. Energy and exergy analyses of photovoltaic thermal collector with ∇-groove. *Solar Energy*. 2018; 159: 742-750.

[4] M Zohri, Nurato, A Fudholi. Photovoltaic-Thermal (PVT) System with and Without Fins Collector: Theoretical Approach. *International Journal of Power Electronics and Drive System (IJPEDS).* 2017; 8(4): 1756-1763.
[5] M Zohri, A Fudholi, MH Ruslan, K Sopian. Performance Analysis of Photovoltaic Thermal (PVT) with and without ∇-groove Collector. *J. Eng. Appl. Sci.* 2017; 12(22): 6029–6032.
[6] JS Kumari, CS Babu. Mathematical Modeling and Simulation of Photovoltaic Cell using Matlab-Simulink Environment. *International Journal of Electrical and Computer Engineering (IJECE).* 2012; 2(1): 26-34.
[7] H Sharma, N Pal, PK Sadhu. Modeling and Simulation of Off-Grid Power Generation. *TELKOMNIKA Indonesian Journal of Electrical Engineering*. 2015; 13(3): 418- 424.
[8] N Mohammad, MA Islam, T Karim, QD Hossain. Improved solar photovoltaic array model with FLC based maximum power point tracking. *International Journal of Electrical and Computer Engineering (IJECE)*. 2012; 2: 717-730.
[9] O Amirullah, A Penangsang, Soeprijanto. Power Quality Analysis of Integration Photovoltaic Generator to Three Phase Grid under Variable Solar Irradiance Level. *TELKOMNIKA (Telecommunication Computing Electronics and Control)*. 2016; 14(1): 29~38.
[10] MJ Moran, HN Shapiro. Fundamentals of engineering thermodynamics, 3rd Edition. New York, USA. John Wiley & $2 Sons. 1998.
[11] Z Rant. Thermodynamische bewertung der verluste bei technischen energieumwandlungen. *Brennst Wärme-Kraft*. 1964; 16(9): 453–7.
[12] M Faizal, R Saidur, S Mekhilef, A Hepbasli, IM Mahbubul. Energy, economic, and environmental analysis of a flat-plate solar collector operated with SiO2 nanofluid. *Clean Technol Environ Policy.* 2014.
[13] GN Tiwari, JK Yadav, DB Singh, IM Al-Helal, AMA Ghany. Exergoeconomic and enviroeconomic analyses of partially covered photovoltaic flat plate collector active solar distillation system. *Desalination.* 2015; 367: 186–96.
[14] S Chamoli. Exergy analysis of a flat plate solar collector. *Journal of Energy in Southern Africa.* 2013; 24(3): 8–13.
[15] EAM Elshafei, MM Awad, EE Negiry, AG Ali. Heat transfer and pressure drop in corrugated channels. *Energy.* 2010; 35(1): 101–110.
[16] MA Karim, MNA Hawlader. Performance investigation of flat plate, v-corrugated and finned air collectors. *Energy.* 2006; 31(4): 452–470.
[17] MA Karim, MNA Hawlader. Performance evaluation of a v-groove solar air collector for drying applications. *Appl. Therm. Eng*. 2006; 26(1): 121–130.
[18] BF Parker. Derivation of efficiency and loss factors for solar air heaters. *Sol. Energy.* 1981; 26(1): 27–32.
[19] BF Parker, MR Lindley, DG Colliver, WE Murphy. Thermal performance of three solar air heaters. *Sol. Energy.* 1993; 51(6): 467–479.
[20] KS Ong. Thermal performance of solar air heaters: Mathematical model and solution procedure. *Solar Energy.* 1995; 55(2): 93-109.
[21] A Fudholi, K Sopian, MY Othman, MH Ruslan. Energy and exergy analyses of solar drying system of red seaweed. *Energy Build*. 2014; 68: 121–129.
[22] KGT Hollands, EC Shewen. Optimization of Flow Passage Geometry for Air-Heating, Plate-Type Solar Collectors. *J. Sol. Energy Eng.* 1981; 103(4): 323-330.
[23] F Sarhaddi, S Farahat, H Ajam, A Behzadmehr. Exergetic performance assessment of a solar photovoltaic thermal (PV/T) air collector. *Energy Build*. 2010; 42: 2184–2199.
[24] AS Joshi, A Tiwari. Energy and exergy efficiencies of a hybrid photovoltaic thermal (PV/T) air collector. *Renew. Energy*. 2007; 32: 2223–2241.
[25] S Nayak, GN Tiwari. Energy and exergy analysis of photovoltaic/thermal integrated with a solar greenhouse. *Energy Build*. 2008; 40(11): 2015–2021.
[26] M Bosanac, B Sorensen, I Katic, H Sorensen, B Nielsen, J Badran. Photovoltaic/Thermal Solar Solar Collectors and Their Potential in Denmark. Danish Technological Institute. *Solar Energy Centre*. 2003.