Penerbit Akademia Baru

Journal of Advanced Research in Fluid Mechanics and Thermal Sciences

Journal homepage: www.akademiabaru.com/arfmts.html
ISSN: 2289-7879

Thermal Efficiency and Heat Removal Factor for Hybrid Photovoltaic Thermal PVT System

Open Access

Amira Lateef Abdullah [1,*], Suhaimi Misha[2], Noreffendy Tamaldin[2], Mohd Afzanizam Mohd Rosli[2], Fadhil Abdulameer Sachit[3]

[1] Fakulti Kejuruteraan Mekanikal, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal,Melaka, Malaysia
[2] Centre for Advanced Research on Energy, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia
[3] Ministry of Electricity, Baghdad, Republic of Iraq

ARTICLE INFO

Article history:
Received 31 March 2019
Received in revised form 23 April 2019
Accepted 30 May 2019
Available online 6 June 2019

Keywords:
Photovoltaic thermal collector PVT; absorber design; heat removal factor FR; thermal efficiency

ABSTRACT

Heat removal factor (F_R) is vital in determining the photovoltaic thermal (PVT) system thermal efficiency. (F_R) represents the ratio of the actual (useful) heat gain via the heat transfer fluid that flows through a collector to the entire collector surface. In this study, simulations were conducted on three configurations using the PVT new design (dual oscillating absorber) to determine (F_R) and thermal efficiency. Using different tube gaps and tube diameters D, the designs were compared using validated model, which was presented using the MATLAB programme theoretical data. The findings indicate that the shape, gap, and diameter of the absorber tubes are crucial to the PVT performance. The study was done under solar radiation level of 300-1000 W/m^2 and mass flow rate of 0.01 kg/s at each solar radiation level. The results show that the best thermal efficiency of the new PVT designs reached η_{th} 31, 58%, and The heat removal factor can reach (F_R) 0.47 for dimension tube diameters 0.015m and tube gap 0.03m The continuous operation of the flowing water through absorber result reduces the temperature of the PV cells and simultaneously increasing it efficiency.

1. Introduction

In a PVT collector study by Kroiß *et al.,* [1] a polycrystalline module was installed to an absorber-exchanger to transform solar radiation to heat. The ‘‘absorber-exchanger” has back and side insulations (expanded polyurethane), as shown in Figure 1.

Kumar and Mullick [2] used analytical equation to estimate the top heat loss coefficient, Ut. The variables covered in the present analysis are absorber plate temperature (20-150) °C, absorber coating emittance (0.1-0.95), air gap spacing (20-50) mm, collector tilt (60°-90°), wind heat transfer coefficient 5-30 W/m^{2}K and ambient temperature (10-40) °C. The temperature of the PVT module

* *Corresponding author.*
E-mail address: amiraaljboury@gmail.com(Amira Lateef Abdullah)

back surface was calculated by Afzanizam *et al.,* [3] based on the thermal energy balance. Each layer was modelled according to the effect of heat transfer modes such as conduction, radiation, and convection. The heat transfer mode in the PV module is depicted in Figure 2.

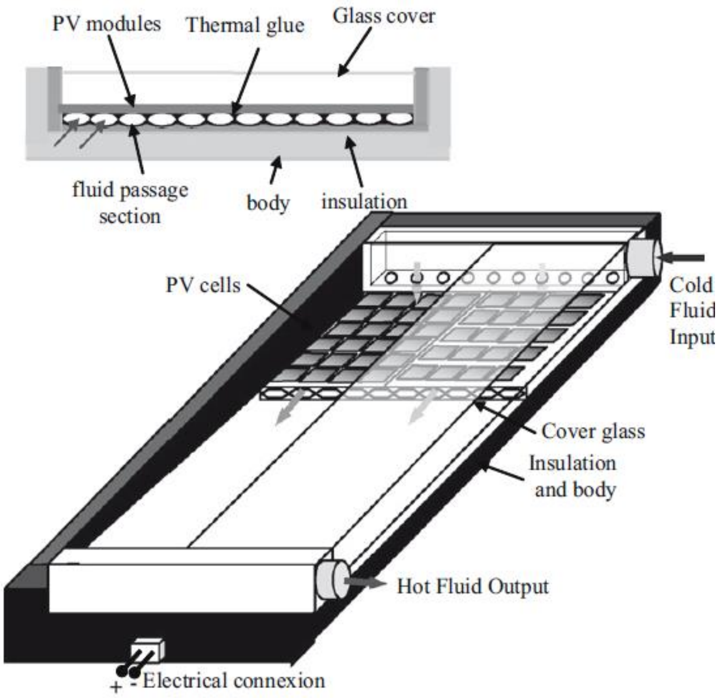

Fig. 1. The photovoltaic/thermal solar collector

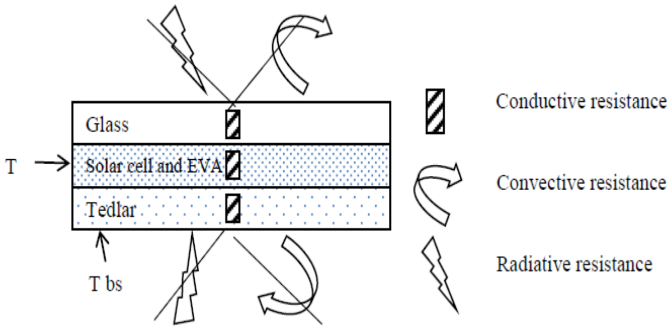

Fig. 2. Heat transfer for the PV module

The thermal efficiency of a polymer collector with unglazed PVT system was determined by Afzanizam *et al.,* [4] . Overall heat loss was estimated using the heat energy balance. Based on the analysis, the heat removal factor of the PVT system was found to be 0.55. The system thermal performance was 47% during the zero reduced temperature. Afzanizam *et al.,* [5] analysed the heat removal factor FR of four serpentine tubes with different dimensions and profiles. The rectangle tube shows the highest FR (0.93). The heat removal factor FR is in fact one of the key parameters to determine PVT thermal efficiency. A high FR means larger thermal efficiency and losses and vice versa.

The PVT water collector's thermal and electrical performances was investigated by Sachit *et al.,* [6] using two absorber designs. The first design (serpentine) and the new design (serpin-Direct) were compared under solar radiation levels of (300-1100) W/m^2. The mass flow rate was set from (0.011

to 0.1) kg/s at each solar radiation level. The PVT thermal model was developed to predict the system thermal efficiency.

Simulations were conducted by Rosli *et al.,* [7] on four serpentine tube configurations. Results showed that the best design can achieve 50% thermal efficiency at zero reduced temperature. The findings indicate that the shape, gap, and diameter of the absorber tubes are crucial to the PVT performance CATIA V5R20 was used by Afzanizam *et al.,* [8] to draw the PVT model with three designs of absorber tubes, they are serpentine, u-flow and spiral. The top of the PVT structure is glass cover, followed by the upper EVA encapsulant layer, photovoltaic panel, lower EVA encapsulant layer, Tedlar, thermal paste, absorber tube and water, as shown in Figure 3. The isometric view of serpentine is depicted in Figure 4.

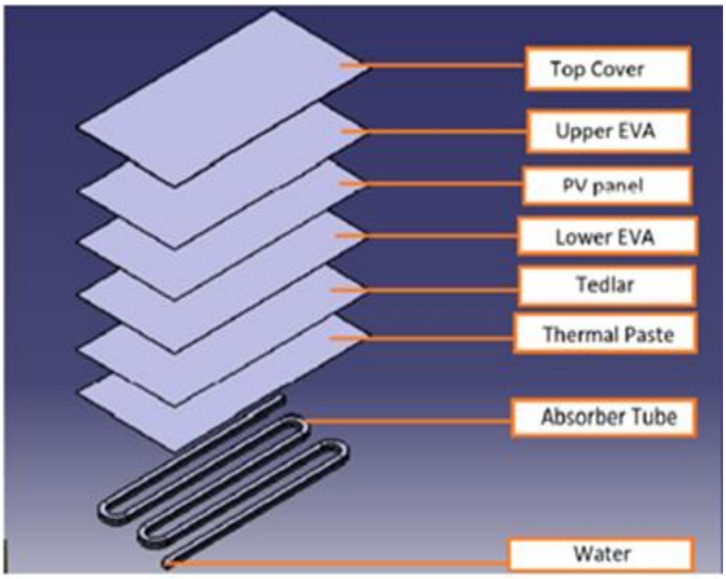

Fig. 3. Arrangement of PVT Water

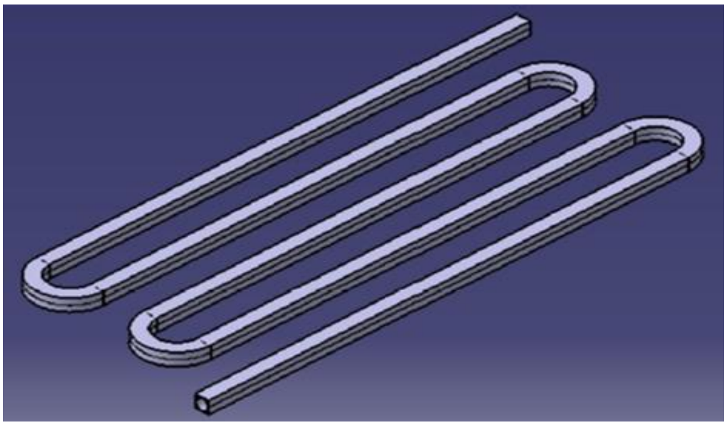

Fig. 4. Serpentine Absorber in CATIA Part Design

Sachit *et al.,* [6] studied the factors that affect the PVT system behavior, encompassing the design of solar collectors, solar cell materials in PV, working fluids inside the solar absorbers, the fluid heat-flow transfer (natural or forced) and panel covering (glazed or unglazed). The general structure of a PVT unit is depicted in Figure 5.

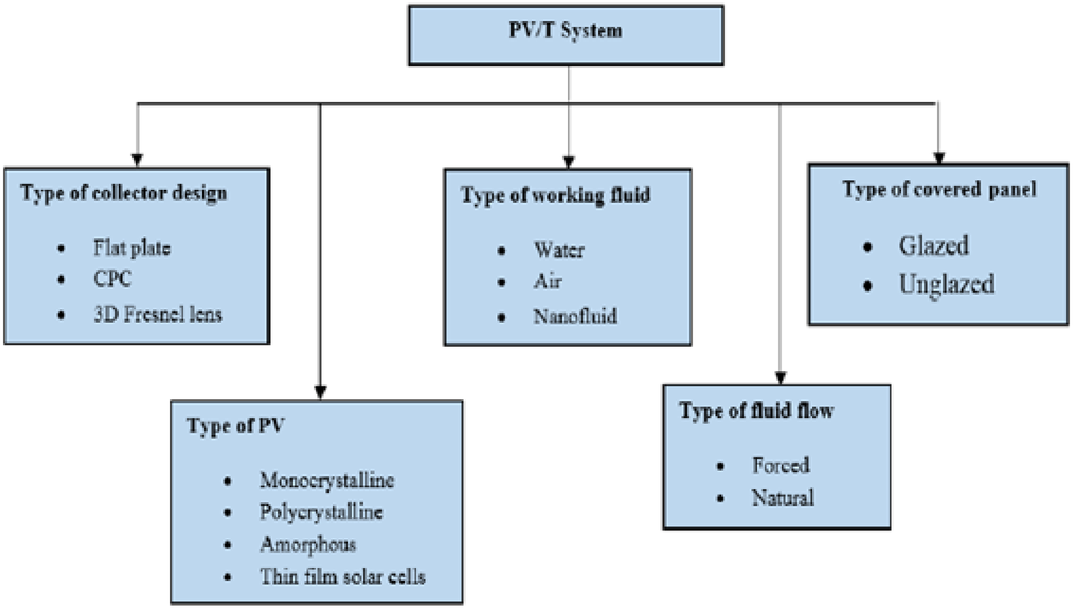

Fig. 5. Classification of PVT system

A two-dimensional numerical model was developed by Abdullah *et al.,* [9] using ANSYS Fluent and the results show that the increase in mass flow rate increases the overall efficiency while the increase in duct depth decreases the hybrid PVT air collector overall efficiency.

Study presents the effects of different metrological parameters on the performance of photovoltaic modules by Chatta *et al.,* [10] at three different inclination angles (0°, 33.74° and 90°) with horizontal.As solar radiation increases, the radiation losses from the surface of the module increases and resultant decrease the module efficiency and increase the module temperature at high solar irradiance.Simulated experimentation by ALI *et al.,* [11] was accomplished with small holes (about 0.4 mm in diameter) in 60 between the rectangular fins in longitudinal direction.

In this study, simulations were conducted on three PVT new designs with dual oscillating absorber, as shown in Figure 6, 7, and 8. Each design FR and thermal efficiency were determined using different tube gaps and tube diameters D. The comparison between these three designs were analysis via the model displayed in the MATLAB programme theoretical data. The conventional design may produce non-uniform temperature on the PV because the heat is accumulated along the flow of water. The new design will produce better temperature uniformity because the cold water come from both side.

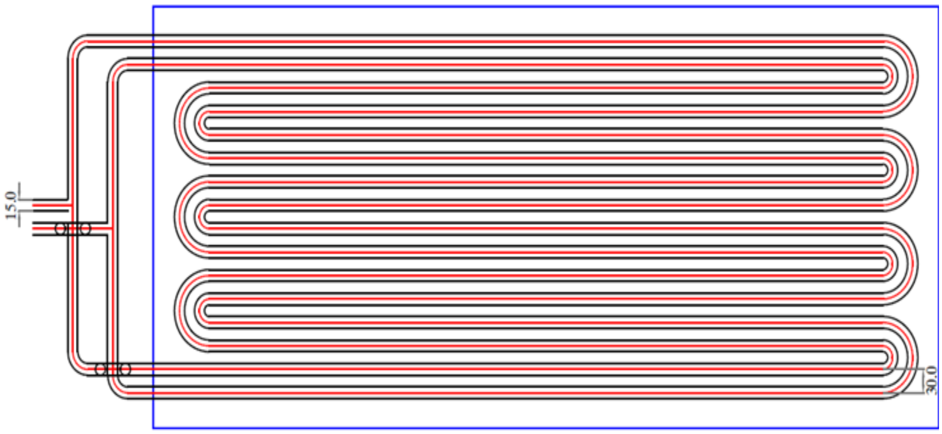

Fig. 6. First new design of PVT (dual oscillating absorber)

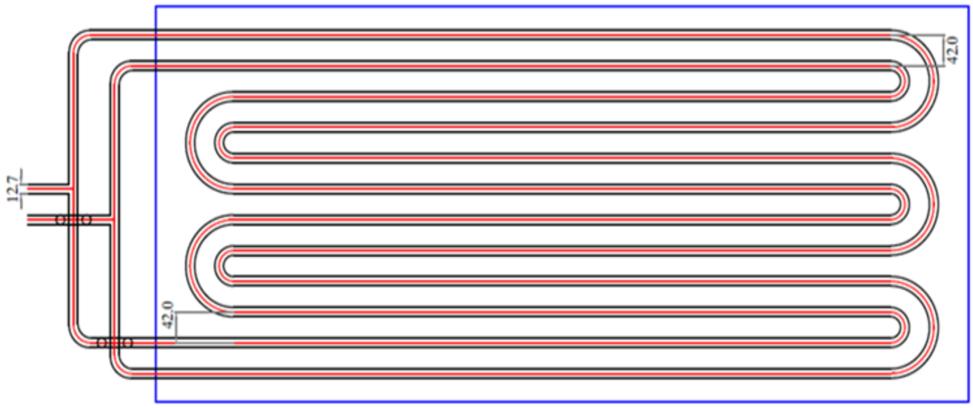

Fig. 7. Second design of PVT (dual oscillating absorber)

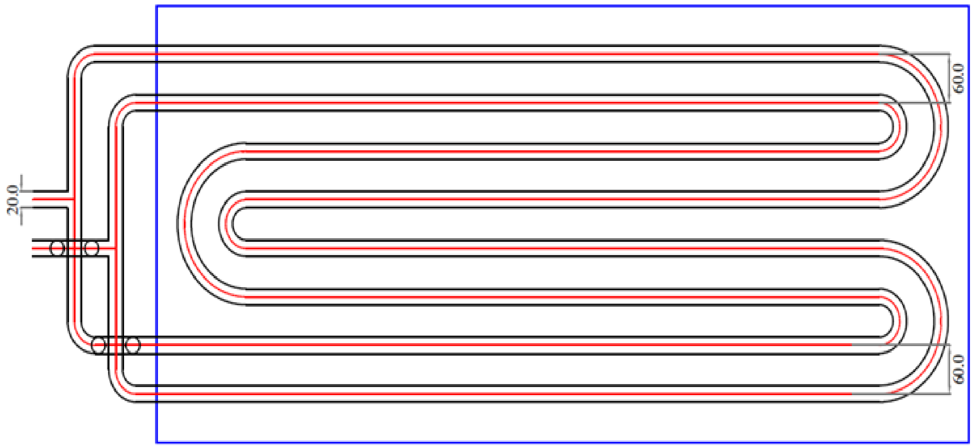

Fig. 8. Third new design of PVT (dual oscillating absorber)

2. Methodology

A simulation was conducted to evaluate the PVT thermal efficiency of domestic hot water system as shown in Figure 9. The energy balance was developed based on the thermal resistance circuit diagram, as shown in Figure 10. Meanwhile, the PVT collector cross section is depicted in Figure 11. The analysis was simplified based on the following assumptions.

i. No heat loss is observed under the absorber collector (the device is well-insulated).
ii. The mean temperature for each layer is assumed.
iii. Transmissivity of ethyl vinyl acetate (EVA) is approximately 100%.
iv. The water flow inside tubes is uniform under force mode operation.
v. One-dimensional conduction and convection is ensured for thermal analysis.
vi. The heat capacitance of the solar cells, tedlar, and insulation are negligible.
vii. The system is in a quasi-steady state.
viii. The bottom and edge losses are negligible.

Table 1 shows the configurations of the PVT with new design (dual oscillating) absorber features. The material for each design is copper.

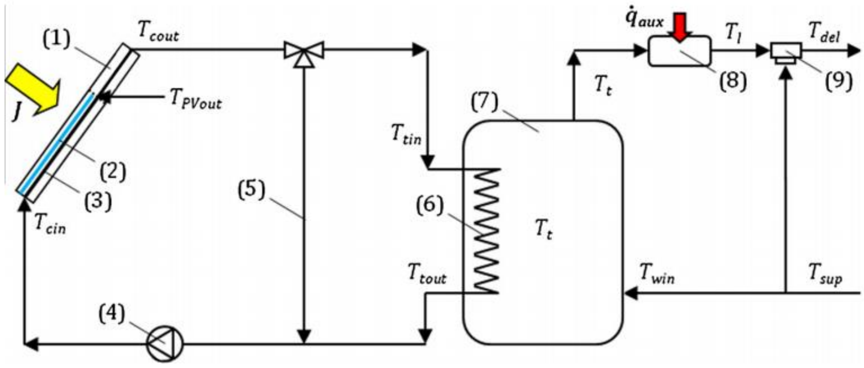

Fig. 9. Schematic diagram of the PVT domestic hot water system

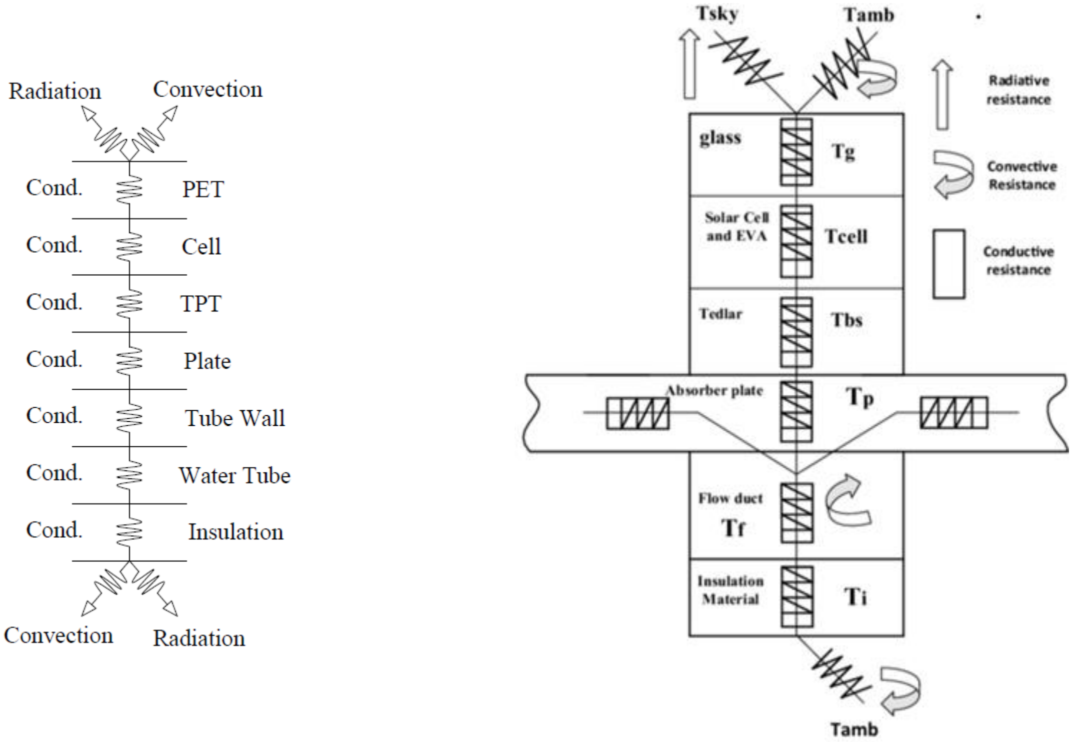

Fig. 10. Thermal resistance circuit diagram for PVT

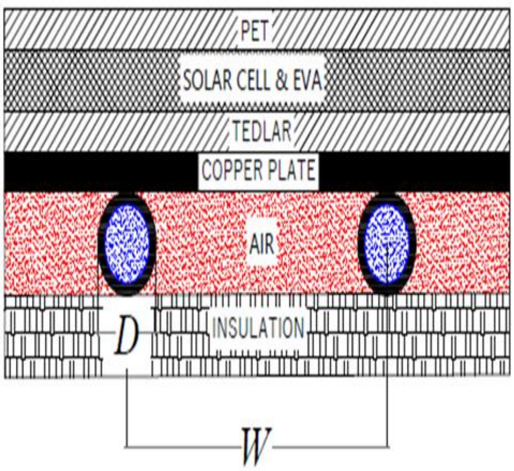

Fig. 11. Cross section of PVT collector

Table 1
Configurations of the PVT with new design (dual oscillating) absorber features

Number	Diameter D (m)	Width(m)	Volume (m^3)
1	0.015m	0.03m	0.0032
2	0.0127m	0.042m	0.0031
3	0.02m	0.06m	0.0029

4. Theoretical Analysis

The collector thermal efficiency is calculated based on the modified Hottel-Whillier equation [12-14] .The value of $(\alpha\tau)_{,eff}$, (U_L), and (F_R) depends on the geometry of the absorber.

$$\eta_{th} = F_R\left[(\tau\alpha)_{eff} - U_L\left(\frac{T_i - T_a}{It}\right)\right] \quad (1)$$

where

$$(\alpha\tau)_{,eff} = \tau_{PET}[\alpha_C\beta_c + \alpha_T(1-\beta_c) - \eta_c\,\beta_c] \quad (2)$$

Figure 12 describes the energy distribution direction and explains the energy analysis of the simple flat plate collector and integrated system according to Kaushik and Ranjan [15]. The thermal energy analysis includes the evaluation of thermal capacity, heat loss coefficient and heat removal factor, all these are estimated by assuming one-dimensional heat flow through tubes and the integrated system is according to Chabane *et al.,* [16] and Struckmann[17].

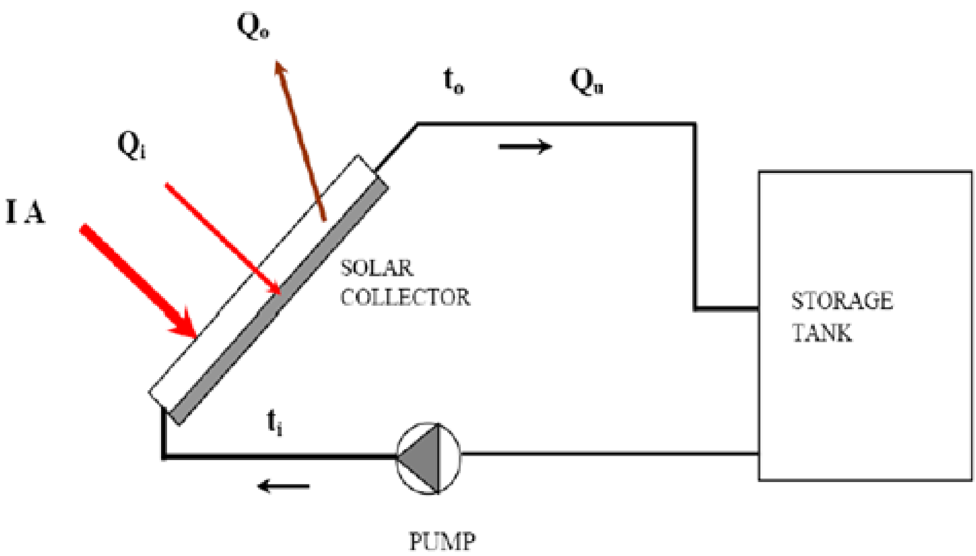

Fig. 12. Energy distribution diagram

Radiant energy received by the collector is defined as the product of the solar radiation intensity and area of the collector, which can be expressed according to Kumar [18].

$$Q_i = I_t\ A_C \quad (3)$$

Radiant energy absorbed by the collector is the absorber plate absorptiveness as all radiations hitting the surface may not go into collector and are reflectedd back to the environment, which is expressed as follows.

$$Q_{i1}= I_t \ A_C\tau \tag{4}$$

The heat loss rate via the collector is defined as the product of the overall heat transfer coefficient, collector area and temperature difference between the collector area surfaces, which can be expressed as follows.

$$Q_o = U_L A_C(T_C - T_a) \tag{5}$$

The useful heat gain is defined as the heat energy extraction rate from the working fluid flowing through the solar flat plate collector (Qu). The useful heat gain is also defined as the difference between radiant energy absorbed by the collector, considering the absorber plate absorptiveness and heat loss rate through the collector, which can be expressed as follows.

$$Q_{u,i} = Q_{i1} - Q_o = I_t A_C\tau - U_L A_C(T_C - T_a) \tag{6}$$

Overall heat transfer coefficient U_L. Higher (U_L)means indicates losses for the PVT. Following Eq. (1), the thermal efficiency linearly decreases with the increase in the overall heat loss. The overall loss are the combined loss of the top, bottom, and edge parts of the PVT. The major contributor to the loss is the top heat loss, which is resulted from optical loss, convection, and radiation. Overall heat transfer coefficient is expressed as follows, [19].

$$U_L=\frac{Q_i- Q_u}{U_L A_C(T_C- T_a)} \tag{7}$$

$$U_L=\frac{Q_o}{A_C(T_C- T_a)} \tag{8}$$

Heat removal factor, (FR) is defined as the ratio of useful energy calculated using (Tout ₋ Tin) using (Tc ₋ Ta), which indicated the ratio of the actual useful heat gain of the heat transfer fluid flowing through a collector to the useful heat gain of the entire collector surface. The useful energy gain (Q_u) is expressed as follows.

$$Q_u = \dot{m}c_p(T_o - T_i) \tag{9}$$

Heat Removal Factor (F_R) can be expressed as follows.

$$F_R=\frac{Q_u}{Q_{u,i}} = \frac{Q_u}{A_C[I_t \tau- U_L (T_i- T_a)]} \tag{10}$$

$$A_C = 2 \pi r L_{total} \tag{11}$$

The parameters to solve all the equations for the analysis are presented in Table 2.

Table 2
Parameters for the PVT collector

Parameters	Value	Unit
A_{C1}	0.8388	m^2
A_{C2}	0.489	m^2
A_{C3}	0.5658	m^2
$\dot{m}$	0.01	Kg/s
I_t	300-1000	W/m^2
c_p	4178	J/Kg.K
τ_{PET}	0.88	---
α_c	0.85	---
β_c	0.83	---
α_T	0.8	---
η_c	0.155	---
T_a	298.15	K
T_i	299.15	k

5. Results and Discussions

The parameter of the PVT thermal efficiency is calculated using Eq. (1) and parameters shown in Table 2. Figure 12 and Figure 13 show the results of the PVT collectors after being exposed to (300-1000) W/m^2 solar radiation at 0.01 kg/s mass flow rate. The results show that the thermal efficiency and heat removal factor (FR) of the collectors with differences in tube gaps, tube diameter (D) and solar radiation. And volume effect of water tube on performance PVT as show in Table 3. The highest thermal efficiency was obtained by Design 1, followed by Design 2 and then Design 3, due to the differences in tube gaps and tube diameters (D). As shown in Figure 13, the thermal efficiency of the new PVT were (31.58%, 30.35%, 29.13%) for design 1, 2, 3 respectively. Meanwhile, the heat removal factor (FR) of the newly designed PVT were (0.47, 0.44, 0.40) for design 1, 2,3 respectively, as shown in the Figure 14. The results show that the increase in solar radiation does increases both heat removal factor and thermal efficiency of the new PVT. Meanwhile, increase in the heat removal factor increases the new PVT thermal efficiency.

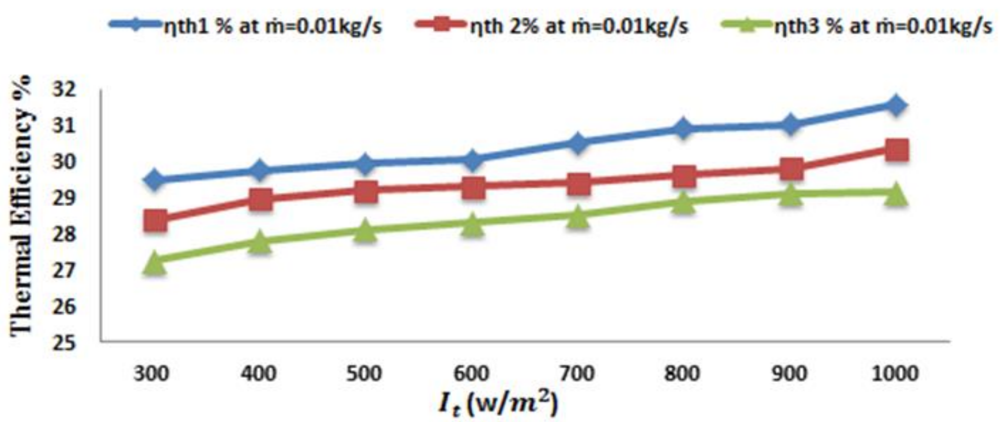

Fig. 13. Thermal efficiency the PVT collector against different solar radiation

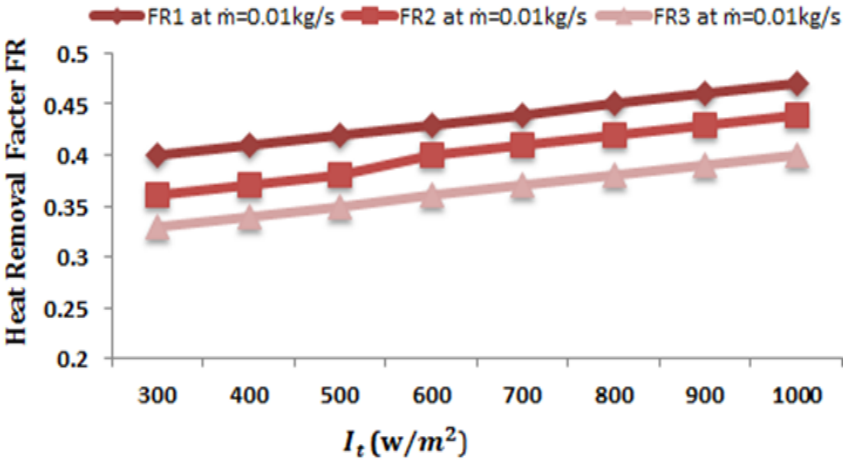

Fig. 14. Heat Removal Factor FR of the PVT collector against different solar radiation

Table 3
Variation of Thermal efficiency and (FR) with different volumes of PVT

Design	Volume, (m^3)	η_{th}%	F_R
1	0.0032	31.58	0.47
2	0.0031	30.35	0.44
3	0.0029	29.13	0.40

6. Conclusion

The energy balance analysis is effective to predict the PVT thermal performance because it saves cost, time, and energy from the beginning of the project. The tube shape, dimension, and gap significantly affect the thermal efficiency and heat removal factor performances. The overall loss should be minimized to obtain better thermal efficiency. In this study, three new PVT modules were analysis using theoretical results via MATLAB. The mass flow rate of 0.01 kg/s and solar radiation level in the range of (300-1000) W/m^2 were used in this analysis. The results show that the increase of solar radiation does increases both heat removal facter and thermal efficiency of the new PVT. Meanwhile, the increase in heat removal factor simultaneously increases the new PVT thermal efficiency.

Acknowledgement
The author would like to thank the Faculty of Mechanical engineering of the Universiti Teknikal Malaysia Melaka, Centre for Advanced Research on Energy in Universiti Teknikal Malaysia Melaka and Ministry of Electricity in Iraq for supporting this work.

References
[1] Kroiß, Alexander, Alexander Präbst, Stephan Hamberger, Markus Spinnler, Yiannis Tripanagnostopoulos, and Thomas Sattelmayer. "Development of a seawater-proof hybrid photovoltaic/thermal (PV/T) solar collector." *Energy Procedia* 52 (2014): 93-103.
[2] Kumar, Suresh, and S. C. Mullick. "Glass cover temperature and top heat loss coefficient of a single glazed flat plate collector with nearly vertical configuration." *Ain Shams Engineering Journal* 3, no. 3 (2012): 299-304.
[3] Rosli, Mohd Afzanizam Mohd, Sohif Mat, Kamaruzzaman Sopian, Mohd Khairul Anuar Sharif, Mohd Yusof Sulaiman, and Lim Chin Haw. "PREDICTING THE BACK SURFACE TEMPERATURE OF PHOTOVOLTAIC MODULES IN HOT AND

HUMID CLIMATES." *Jurnal Mekanikal* 37, no. 2 (2014).

[4] Rosli, Mohd, Mohd Afzanizam, Sohif Mat, Kamaruzzaman Sopian, Mohd Yusof Sulaiman, Elias Ilias Salleh, and Mohd Khairul Anuar Sharif. "Thermal performance on unglazed photovoltaic thermal polymer collector." In *Advanced Materials Research*, vol. 911, pp. 238-242. Trans Tech Publications, 2014.

[5] Rosli, M. A. M., S. Misha, Kamaruzzaman Sopian, Sohif Mat, M. Yusof Sulaiman, and E. Salleh. "Parametric analysis on heat removal factor for a flat plate solar collector of serpentine tube." *World Appl. Sci. J* 29 (2014): 184-187.

[6] Fadhil Abdulameer Sachit, Mohd Afzanizam Mohd Rosli,Noreffendy Tamaldin, Suhaimi Misha, Amira Lateef Abdullah. "Modelling, Validation and Analyzing Performance of Serpentine-Direct PV/T Solar Collector Design." *CFD Letters* 11, no. 2 (2019): 50-65.

[7] Rosli, M. A. M., Suhaimi Misha, Kamaruzzaman Sopian, Sohif Mat, Mohd Yusof Sulaiman, and Elias Salleh. "Thermal Efficiency of the Photovoltaic Thermal System with Serpentine Tube Collector." In *Applied Mechanics and Materials*, vol. 699, pp. 455-461. Trans Tech Publications, 2015.

[8] Rosli, Mohd Afzanizam Mohd, Yap Joon Ping, Suhaimi Misha, Mohd Zaid Akop, Kamaruzzaman Sopian, Sohif Mat, Ali Najah Al-Shamani, and Muhammad Asraf Saruni. "Simulation Study of Computational Fluid Dynamics on Photovoltaic Thermal Water Collector with Different Designs of Absorber Tube." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 52, no. 1 (2018): 12-22.

[9] Abdullah, Amira Lateef, Suhaimi Misha, Noreffendy Tamaldin, and Mohd Afzanizam Mohd. "Numerical Analysis of Solar Hybrid Photovoltaic Thermal Air Collector Simulation by ANSYS." *interactions* 11, no. 2 (2019): 1-11.

[10] Chatta, Muhammad Bilal, Hafiz Muhammad Ali, Muzaffar Ali, and Muhammad Anser Bashir. "Experimental investigation of monocrystalline and polycrystalline solar modules at different inclination angles." *Journal of Thermal Engineering* 4, no. 4 (2018): 2137-2148.

[11] Darul, Perak, and Petroleum Engineering. n.d. “Retention Angle Was Aluminum Was Mounted On,” 1–7.

[12] Fudholi, Ahmad, Kamaruzzaman Sopian, Mohammad H. Yazdi, Mohd Hafidz Ruslan, Adnan Ibrahim, and Hussein A. Kazem. "Performance analysis of photovoltaic thermal (PVT) water collectors." *Energy conversion and management* 78 (2014): 641-651.

[13] Vokas, G., N. Christandonis, and F. Skittides. "Hybrid photovoltaic–thermal systems for domestic heating and cooling—a theoretical approach." *Solar energy* 80, no. 5 (2006): 607-615.

[14] Tiwari, Arvind, and M. S. Sodha. "Performance evaluation of hybrid PV/thermal water/air heating system: a parametric study." *Renewable energy* 31, no. 15 (2006): 2460-2474.

[15] Kaushik, S. C., and K. R. Ranjan. "Energetic and exergetic performance evaluation of natural circulation solar water heating systems." *Applied Solar Energy* 52, no. 1 (2016): 16-26.

[16] Chabane, Foued, Noureddine Moummi, Djamel Bensahal, and Abdelhafid Brima. "Heat transfer coefficient and thermal losses of solar collector and Nusselt number correlation for rectangular solar air heater duct with longitudinal fins hold under the absorber plate." *Applied Solar Energy* 50, no. 1 (2014): 19-26.

[17] Struckmann, Fabio. "Analysis of a flat-plate solar collector." *Heat and Mass Transport, Project Report, 2008MVK160*(2008).

[18] Kumar, G Vinod. 2017. “Heat Removal Factor of an Integrated Solar Flat Plate Collector with Packed Bed System” *International Journal of Engineering Technology, Management and Applied Sciences* 5, no.7 (2017.): 720–27.

[19] Balotaki, H. Kavoosi. "Experimental Investigation of Dual-Purpose Solar Collector using with Rectangular Channels." *Journal of Thermal Engineering* 3, no. 1 (2017): 1052-1059.