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Hybrid Photovoltaic Thermal PVT Solar Systems Simulation via Simulink/Matlab

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ABSTRACT

Photovoltaic–thermal PVT solar system is an emerging solar technology that enables simultaneous conversion of solar energy into electricity and heat. The PV performance was reduced as the temperature increased, PVT systems aim to improve the electrical efficiency by the cooling system by reducing the cell temperature. and the absorber collector took in excess heat underneath the PV. The heat was then transferred through working fluids such as water. The harvested heat was used in low-temperature applications, including domestic hot water supply, water preheating and space heating.In this study, thermodynamic modelling of the thermal and electrical performance of a hybrid PVT water collector was conducted as basis for the design of a new absorber (dual oscillating absorber). The hybrid PVT was compared with normal PV technology (without cooling system) through analysis simulation of the model that was based on theoretical data using MATLAB. A test was performed under solar radiation levels of 300–1000 W/m^2 and mass flow rate range of 0.01–0.049 kg/s at each solar radiation level. The results showed that the values of cell efficiency increases with decreasing solar radiation and cell temperature. The cell temperature increases with increasing solar radiation and decreases with the increasing mass flow rate. The outlet water temperature increases with rising solar radiation and decreases as mass flow rate rises.In addition, when the mass flow rate increased, thermal efficiency decreased and increased when solar radiation increased. Analysis was based on design parameters and basic energy balance equations.

Keywords: Photovoltaic–thermal collector PVT, new absorber design, Electrical efficiency, Thermal efficiency,Temperature of the PV module

1. Introduction

Hybrid photovoltaic–thermal PVT devices are manufactured to transform sunlight into electricity and heat by combining photovoltaic and thermal technology [1].

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The PV module transforms part of the solar event radiation into electricity, whilst the remaining part is stored via heat absorption in the rolling fluid used in thermal applications (e.g. hot water and heating spaces) (Figure 1).

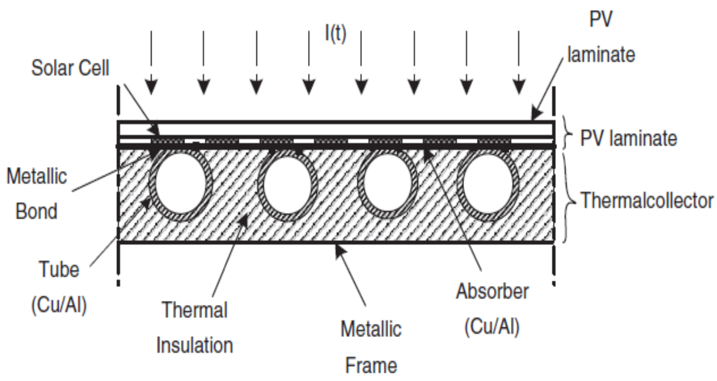

Fig. 1. The cross-sectional view of a PVT water collector

Engineering and May conducted 3D numerical analysis of a PVT module with flow channel design in varying environmental and operating conditions to forecast thermal and electrical performance. The results of the numerical analysis show that an increase in inlet velocity leads to a 37% reduction in cell temperature, whereas electrical efficiency and output power increase by 2% and 26%, respectively, for aluminum and copper. The overall efficiency of the PVT collector increases by 14.6% for aluminum and 16.3% for copper, with the increase of inlet velocity from 0.0009 m/s to 0.05 m/s. The efficiency rate decreases by 13% for aluminum and 12.7% for copper with the increases of inlet temperature from 20 °C to 40 °C.

Kim *et al.,* [2] analysed the experimental performance of two liquid-type PVT collectors: glazed and unglazed. The electrical and thermal performance of the PVT collectors was measured in outdoor conditions, and the results were compared. The results showed that the thermal efficiency of the glazed PVT collector was higher than that of the unglazed PVT collector. However, the unglazed collector had higher electrical efficiency than the glazed collector.

Silva *et al.,* [3] used a modular strategy approach based on Simulink/MATLAB environment to perform thermodynamic modelling on hybrid PVT solar systems. Lämmle *et al.,* [4] systematically compared the performance of unglazed and glazed PVT collectors with low-emissivity coatings. The yields of these PVT technologies were assessed using four types of solar thermal systems, including domestic hot water systems. The systems were then combined in single and multifamily homes in four European locations. An empirical PVT performance model was presented, validated and implemented into TRNSYS.

Kusakana [5] developed a mathematical model that dealt with the optimal switching of flow in PVT systems with forced circulation. The model aimed to control the surface operating temperature whilst increasing conversion efficiency. Proper cooling improves the thermal, electrical and overall efficiency of PV systems, which in turn also reduces the rate of cell degradation and maximizes the life span of the PV module. Aboghrara *et al.,* [6] critically reviewed the parameters of climatic, design

And operational factors to evaluate their effect on the thermal, electrical and overall efficiency of the PVT systems. Results showed that thermal efficiency decreased as the following parameters increased: inlet temperature, packing factor, duct length, channel depth, thermal resistance, ambient temperature, mass flow rate upon exceeding optimum value, inlet mass flow rate velocity and wind speed. Zhang *et al.,* [7] theoretically investigated the thermal–electric conversion performance of hybrid system by calculating its overall thermal, electrical and exergy efficiencies. The results show that the overall thermal, electrical and exergy efficiencies of heat-pipe PVT hybrid system could reach as much as 63.65%, 8.45% and 10.26%, respectively.

Aste *et al.,* [8] Leonforte presented the design of an experimental PVT collector and a new dynamic model for the simulation of flat-plate PVT water collectors. They also discussed the differences between the PVT collector and the standard PV module. The PVT technology exhibits higher overall efficiency than the simple PV module in terms of primary energy.

Liang *et al.,* [9] applied pan-theoretical modelling to analyses the characteristic equations of the PVT collector via MATLAB 2016. The researchers also conducted experiments to evaluate the performance of PVT collectors using basic energy balance equations and computer-based thermal models. The outlet temperature of the working fluid, PV module temperature and absorber plate temperature of PVT collectors were also analysed. Anderson *et al.,* [10] performed theoretical analysis using a modified Hottel–Whillier model; they validated the results using experimental data collected from a prototype PVT collector, as shown in Figure 2.

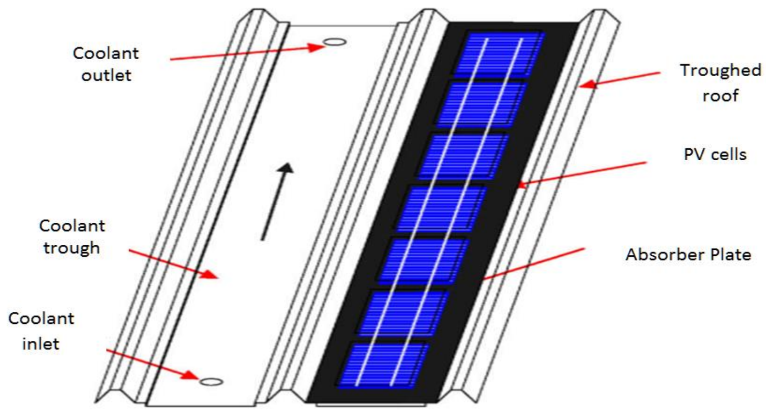

Fig. 2. Concept of BIPVT system

Dupeyrat *et al.,* [11] determined the development and test results of an experimental flat-plate PVT collector as shown by the performance of this hybrid collector, which was part of a solar thermal system in a building. The results were compared with those of systems operating on standard solar devices (i.e. solar thermal collector and PV panel) through simulations using TRNSYS. The findings showed that, in the configuration of limited available space for the solar collector area, using efficient PVT collectors in the building envelope can be more advantageous than using normal standard PV. Kumar *et al.,* [12] determined the thermal performance of a PVT flat-plate panel under 500–1000W/m^2 solar radiation levels. They performed fluid flow analysis and temperature distribution on the solar panel via experiment and computational fluid dynamic CFD.

Technique.They also compared the experimentally measured temperatures to the temperatures determined by the CFD model. The results showed that both temperatures were consistent. This paper presents alternative designs of PVT solar collectors. A prototype of this new absorber has been developed. Up to today, there has only been a few investigations on water-based PVT collectors. Thus, there should be more studies and analytical research to enhance the thermal and electrical performance of water-based PVT solar collectors via utilization of novel absorber collector designs. A new design of PVT (dual oscillating absorber) is shown in Figure 3. Modeling, analaysis and simulation of the model are presented in this paper using theoretical data by utilizing program MATLAB and comparative study with normal PV (without cooling) are shown in Figure 4.

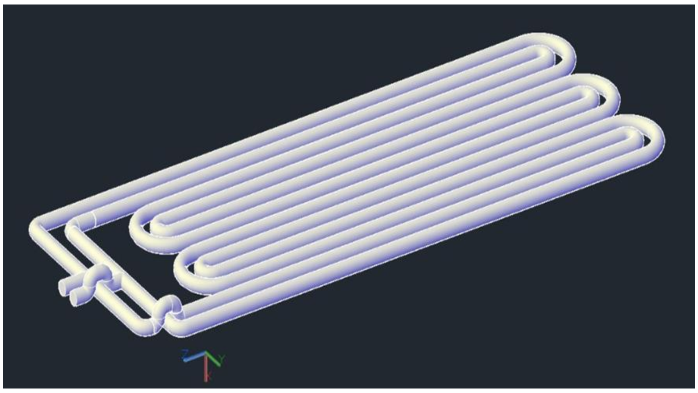

Fig. 3. A new design of PVT (dual oscillating absorber)

Fig. 4. Normal Standard PV panel semi flexible type

2. Methodology

Firstly the main characteristics and features of the PVT technology were analysed and implemented in a hybrid collector prototype. Secondly a simulation model of the PVT collector was developed through several mathematical equations.The model can calculate the electrical and thermal performance of the PVT collector connected to a storage tank as a function of inputs related to climatic and real operating conditions.The analysis simulation of the two models are then presented using theoretical data by utilizing program MATLAB and comparative results of the new design of PVT (dual oscillating absorber) as shown in Figure 3, with normal PV (without cooling system) as shown in Figure 4.The value variation include electrical efficiency, thermal efficiency, overall efficiency, temperature of the PV module and temperature of outlet water, with solar radiation rate of 300–1000 W/m^2 and mass flow rate of 0.01–0.049 kg/s. The evaluation of the PVT module performance was based on PV and thermal efficiencies, whereas the analysis was based on design parameters and basic energy balance equations.

2.1 Systems Description

The design system consisted of the PV panel and new absorber collectors made of copper plate at the underneath. The copper water tube was attached to the bottom of the absorber plate, which was 1.14 m long, 0.50 m wide and 0.003 m thick. The thermal insulator was fixed at the bottom and the edge of the absorber collector to reduce the heat loss from the bottom. The edge of the hybrid PVT water collector was made by placing a polystyrene board at the bottom of the standard PV module, as shown in Figure 5, The absorber collector assists in ensuring a uniform temperature within the system and reducing the temperature of the solar panel.

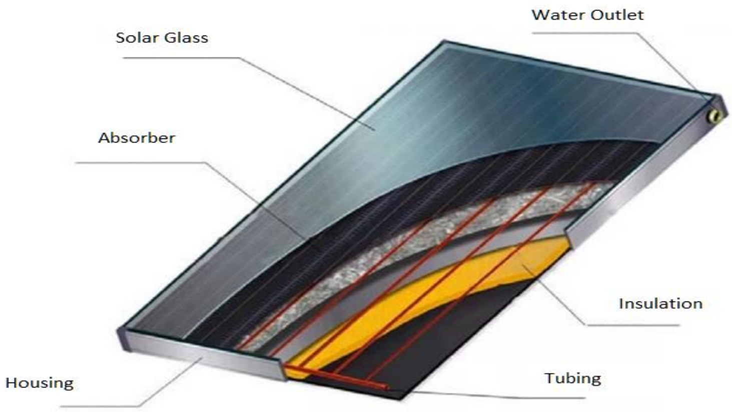

Fig. 5. Concept of PVT system

The normal PV module is a flat-plate single sheet of monocrystalline silicone, a semi-flexible type Figure 4. Composed of 36 monocrystalline cells connected in series/parallel. This PV generator can produce power of 100 W and consists of five layers (transparent PET, Ethylene Vinyl Acetate (EVA) film, solar cell, EVA and TPT) as shown in Figure 6, The electrical parameters of the PV module are shown in Table 1.

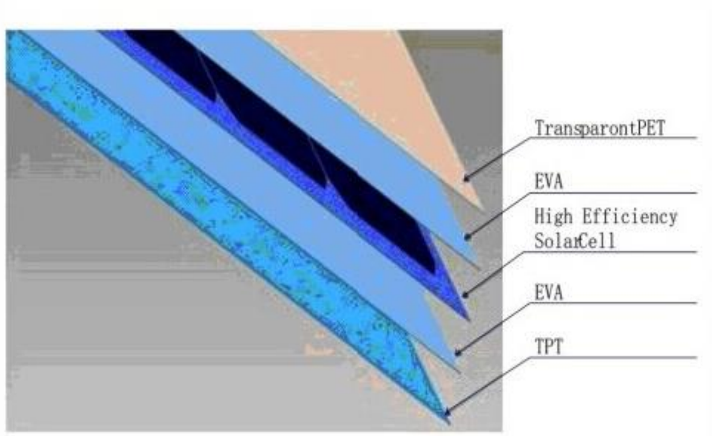

Fig. 6. Different components of the layers classical PV generator

Table 1
The electrical parameters of the PV module Semi flexible at SHINE

PV Module	Value
The Cell number in series, N	36
The short-circuit current, I_{SC}	6.11 A
The open-circuit voltage, V_{OC}	21.6 V
The maximum power, P_{max}	100 W
The maximum power voltage, V_{max}	21.6 V
The maximum power current, I_{max}	5.55 A
Cell efficiency,	21.5 %
Dimension	1180 x 540 x 3 mm
Cell dimension	125x125 mm

In addition, the classical PV generator is laminated and bonded with high-temperature silicone adhesive and sealant. The absorber collector is in the shape of a configured tube and made up of two outlets and inlets. The water flows in and out via the outlet and inlet tube arrangements and also covers the entire PV module. Low- to medium-temperature water penetrates the coil and exits the absorber collector as hot water, which may be used or stored for later use. In this way, sol ar energy may be completely used. Typically, the hot-water storage tank in a PVT system is situated in close proximity to the ground level, whereas the solar module is located above the roof. Heat loss could be prevented by ensuring proper insulation of the pipes. Only the collector unit absorbs the energy, and water is heated using the energy absorbed by the collector.

2.2 Systems Thermal Modeling

The basic energy balance equation discussed by Duffle [13] was used in the present study. To simplify the mathematical models of the classical PV generator and water hybrid PVT collector, the thermal energy balances have been performed according to the following assumptions:

I. Heat losses occur, for the top and loss equal be zero on the back and edge (the device is well insulated) during the same environmental conditions.
II. The water flow is uniform under force mode operation.
III. Wind speed surrounding the systems is uniform.
IV. The thermo-physical properties of each layer are supposed to be constant.
V. The system is in a quasi-steady state.

The mathematical equations under the conservation energy principle and the analytical characteristics of the PVT collector are presented in Table 2. The total efficiencies, known as PVT efficiency (η_{PVT}), are used to evaluate the overall system performance follows [14, 15].

$$\eta_{PVT} = \eta_{th} + \eta_{el} \tag{1}$$

The thermal efficiency of a conventional flat-plate solar collector is the ratio of the useful thermal energy Q_u In the overall incident solar radiation I_t And can be expressed as follows [16, 17]:

$$\eta_{thermal} = \frac{\int Q_u \, dt}{A_m \int I_t \, dt} \tag{2}$$

The useful collected heat absorbed by the flat-plate solar collector can be given as the combined results of the average mass flow rate ṁ, heat capacity of flowing medium Cp and temperature difference at the collector inlet *Ti* and outlet *To*. The collected heat can be as [18 – 20]

$$Q_u = \dot{m} \, C_p (\text{To-Ti}) \tag{3}$$

In addition, the useful heat gain can be written as the difference between the absorber solar radiation and thermal heat losses, which are determined using Equation follows [13, 19].

$$Q_u = A_c F_R \left[I_t \, (\tau\alpha)_{pv} - U_L (T_i - T_a) \right] \tag{4}$$

Where Ac is the collector area, Ta is the ambient temperature, Ti is the inlet temperature, U_L is the overall collector heat loss, $(\tau\alpha)_{pv}$ is the PV thermal efficiency, I_t is the solar radiation. F_R is the heat removal efficiency factor introduced by other studies [13, 17], this factor is expressed as follows [21]:

$$F_R = \frac{\dot{m}C_P}{A_C U_L}[1 - exp(-\frac{Ac\,U_L F'}{\dot{m}C_P})] \tag{5}$$

Where F' is the collector efficiency factor, this factor is expressed as follows:

$$F' = \frac{1/U_L}{W\left[\frac{1}{U_L\,[D+(W-D)F]}+\frac{1}{C_b}+\frac{1}{\pi h_{fi} D_i}\right]} \tag{6}$$

C_b Is the conductance of the bond between the fin and circular tubes, h_{fi} Is the heat-transfer coefficient of the fluid, W is the tube spacing, D is the diameter and F is the fin efficiency factor given by Zondag *et al.,* [22]. this factor is expressed as follows:

$$F = \frac{\tanh \mathrm{M(W-D)/2}}{\mathrm{M(W-D)/2}} \tag{7}$$

The coefficient M in Eq. (7) Considers the thermal conductivity of the absorber and the PV cell, is calculated as follows [23]

$$\mathrm{M} = \sqrt{\frac{U_L}{k_{abs}\, l_{abs} + k_{pv}\, l_{pv}}} \tag{8}$$

Where k_{abs} Is the absorber thermal conductivity, l_{abs} Is the absorber thickness, k_{pv} Is the PV thermal conductivity, and l_{pv} Is the PV panel thickness. U_LThe overall loss coefficient [13, 19] this overall loss coefficient are expressed as follows:

$$U_L = U_t + U_b + U_e \tag{9}$$

U_b Loss coefficient of the bottom, U_t Top loss coefficients and U_e The edge loss coefficient. The bottom loss coefficient is calculated as follows:

$$U_b = \frac{K_b}{l_b} \tag{10}$$

The edge loss coefficient is calculated as follows:

$$U_e = \frac{(U_A)_{edge}}{A_C} \tag{11}$$

The building overall heat loss coefficient is calculated as follows:

$$(U_A)_{edge} = \frac{K_b}{L_b}\;.P.L \tag{12}$$

The top loss coefficient U_t Is calculated as follows:

$$U_t = \frac{1}{\frac{N}{\frac{c}{T_{Pm}\left(\frac{T_{Pm}-T_a}{N+f}\right)^{e}}+\frac{1}{h_w}}}+\frac{\sigma\,(T_{Pm}+T_a).\left(T_{Pm}{}^{2}+T_a{}^{2}\right)}{\frac{1}{\varepsilon_p+0.00591.N.h_w.}+\frac{2.N+f+0.133\,\varepsilon_p}{\varepsilon_{PET}}-N} \tag{13}$$

where

$$c=520(1\text{-}0.000051\beta^2) \tag{14}$$

$$f=(1+0.089h_w-0.1166h_w\varepsilon_p)(1+0.07866N) \tag{15}$$

$$e=0.0430\left(1-\frac{100}{T_{Pm}}\right) \tag{16}$$

$$T_{Pm}=T_i+\frac{\frac{Q_u}{A_C}}{\mathrm{F_R}}(1\text{-}\mathrm{F_R}) \tag{17}$$

The expression for cell temperature is as follows [24, 25]

$$T_c=\frac{(\alpha\tau)_{1,eff}I(t)+U_{tc,a}T_a+h_{c,p}T_p}{U_{tc,a}+h_{c,p}} \tag{18}$$

For blackened absorber plate temperature, the PV module should be [25, 26]

$$T_p=\frac{(\alpha\tau)_{2,eff}I(t)+PF_1(\alpha\tau)_{1,eff}I(t)+U_{L1}T_a+h_{pf}T_{fi}}{U_{L1}+h_{pf}} \tag{19}$$

The outlet water temperature can be obtained using The useful collected heat absorbed by the flat-plate solar collector in Eq. (3) and Eq. (4).

$$\mathrm{To}=\frac{Q_u}{\dot{\mathrm{m}}\,C_p}+\mathrm{Ti} \tag{20}$$

An expression for temperature-dependent electrical efficiency of a PV module is given as follows: [26 – 28]

$$\eta_{el}=\eta_c\left[1-0.0045\left(T_c-T_{ref}\right)\right] \tag{21}$$

The thermal efficiency of the collector is expressed as [17, 19]:

$$\eta_{th}=F_R\left[(\tau\alpha)_{pv}-U_L\left(\frac{T_i-T_a}{I(\mathrm{t})}\right)\right] \tag{22}$$

The total efficiency η_{PVT} is sum of the thermal efficiency and electrical efficiency [29]

$$\eta_{PVT}=\eta_{cell}+\eta_{thermal} \tag{23}$$

In modeling equations,we use the following relations for defining the design parameters, which is shown in [25]

$$(\alpha\tau)_{1,eff} = \tau_c(\alpha_c - \eta_c)\ \beta_c \tag{24}$$

$U_{tc,a}$ overall heat transfer coefficient from solar cell to ambient is expressed as:

$$U_{tc,a} = 2.8 + 3.0\ V \quad \text{, V= 1 m/s} \tag{25}$$

h_{cp} is the heat transfer coefficient between solar cell and plate is given as follows:

$$h_{cp} = 5.7 + 3.8\ V \text{ , V= 0 m/s} \tag{26}$$

$$(\alpha\tau)_{2,eff} = \alpha_p(1 - \beta_c)\tau_{PET}{}^2 \tag{27}$$

Overall heat-transfer coefficient from the absorber plate to the ambient air is expressed as:

$$U_{L1} = \frac{h_{c,p}U_{tc,a}}{h_{c,p}+U_{tc,a}} \tag{28}$$

The penalty factors of PV module

$$PF_1 = \frac{h_{c,p}}{U_{tc,a}+h_{c,p}} \tag{29}$$

Table 2
Photovoltaic–thermal collector characteristics

Parameter	Value	Unit
α_c	0.85	
τ_{PET}	0.88	
β_c	0.83	
η_c	15.5	%
T_a	26	K
T_{ref}	25	K
Ti	26	K
h_{pf}	100	W/m^2K
C_p	4190	J/kg k
I_t	(300-1000)	W/m^2
A_c	0.489	m^2
τ_c	0.95	
W	0.042	m
D	0.0127	m
D_i	0.01198	m
h_{fi}	333	W/m k
k_{abc}	401	W/m. k
I_{abc}	0.0015	m
k_{pv}	0.036	W/m. k
N	0	
ε_p	0.95	
α_p	0.8	
τ_{PET}	0.88	
σ	5.67*10^{-8}	W/m^2 k^4

3. Result and Discussion

3.1 Analysis Study

Analysis was based on design parameters and basic energy balance equations .A simulation model of the PVT collector was developed through several mathematical equations,The analysis simulation of the two models are then presented using theoretical data by utilizing program MATLAB and comparative results between them .The performance efficiency of the PVT collectors are segregated into three sections, namely, PV efficiency, thermal efficiency and a combination of both. Figure 7 to 12 show the analysis results of the PVT collectors after exposure to 300–1000 W/m^2 of solar radiation at 0.01–0.049 kg/s mass flow rates. The results show that the PV efficiencies, thermal efficiencies and total efficiencies of the collectors have considerably changed under various, mass flow and solar radiation rates.The evaluation of the PVT module performance was based on PV and thermal efficiencies, whereas the analysis was based on design parameters and basic energy balance equations.

3.2 Effect Of Mass Flow Rate On The PVT Collectors

The mass flow rate through the collectors and into the designated channels indirectly affect the PV module cooling. The effects of the mass flow rate on the absorber collectors are shown in Figure 7 to 11. The mass flow rates used in this analysis were 0.01–0.049 kg/s, which were applied under various solar radiation levels. 300 –1000 W/m^2. The results show that increasing the mass flow rate simultaneously decreased the cell temperature of the PVT collector's at all solar radiation levels. At the same mass flow rate, the cell temperatures increased alongside increase the solar radiation level, as shown in Figure 7.The temperature decreased from 338.34 K at mass flow rate of 0.01 kg/s to 332 K at mass flow rate of 0.049 kg/s under maximum solar radiation1000 W/m^2.

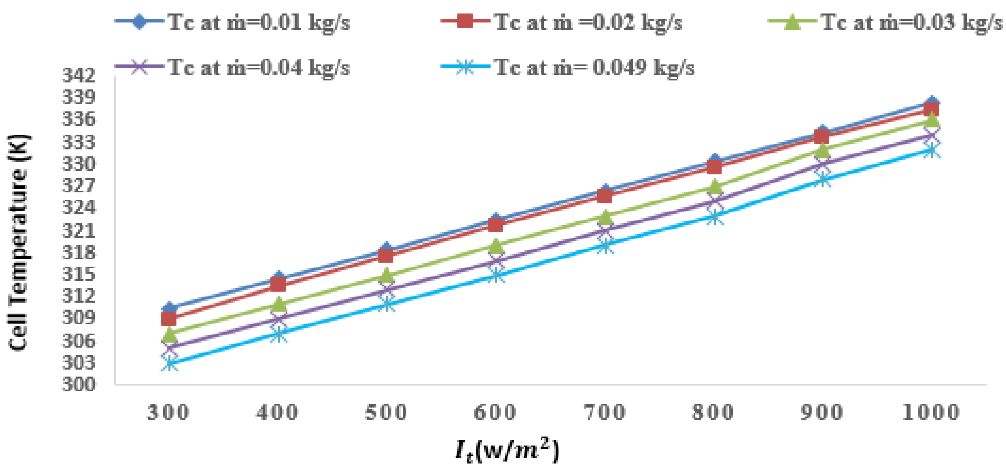

Fig. 7. Cell temperature of the PVT collector against solar radiation at different mass flow rate

The results show that increasing the mass flow rate decreased the outlet water temperature of the PVT collector's at all solar radiation levels and at the same mass flow rate. The outlet water temperatures increased alongside increase the solar radiation level, as shown in Figure 8. The temperature decreased from 307.98 K at mass flow rate of 0.01 kg/s to 301.02 K at mass flow rate of 0.049 kg/s under maximum solar radiation 1000 W/m^2.

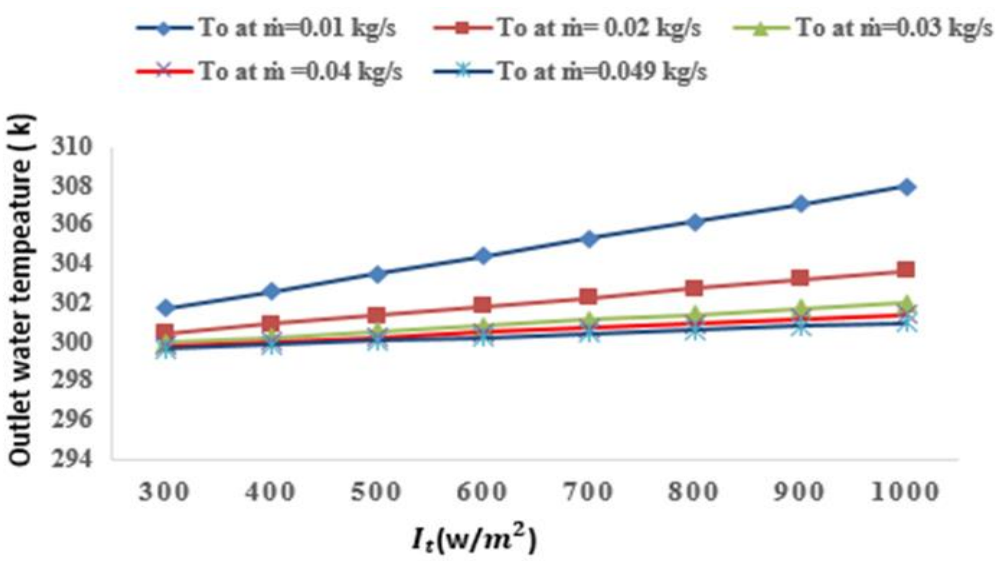

Fig. 8. Outlet Water temperature of the PVT collector against solar radiation at different mass flow rate

3.3 PVT Performance Of PVT Water Collectors

The performance of the PVT collectors can be represented by a combination of electrical efficiency and thermal efficiency. The sum of both efficiencies, known as PVT efficiency, is used to evaluate the overall performance of the system based on the testing performed on the collectors. Therefore, when the mass flow rate increased, electrical efficiency increased. Furthermore, electrical efficiency decreased when solar radiation increased from 12.7% at mass flow rate 0.01 kg/s to 13.13% at mass flow rate 0.049 kg/s under maximum solar radiation, 1000 W/ m^2. as shown in Figure 9.

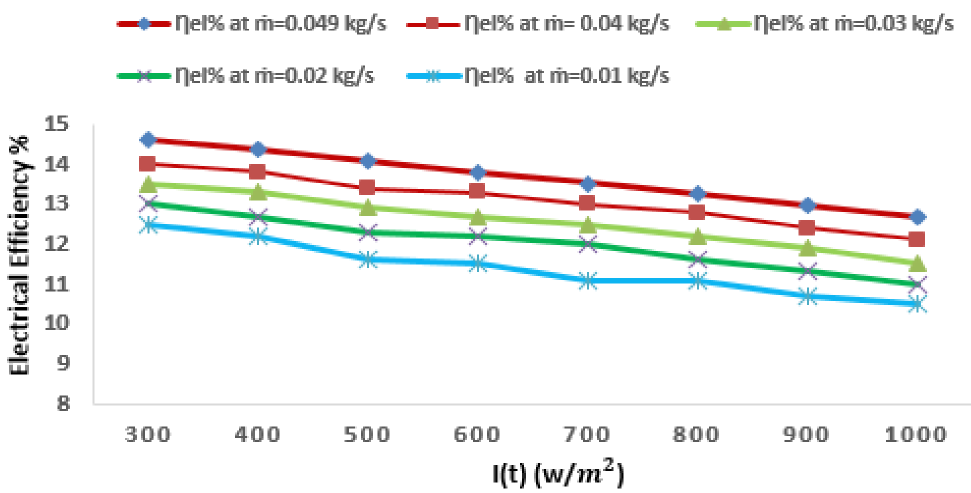

Fig. 9. Electrical Efficiency of the PVT collector against solar radiation at different mass flow rate

In addition, when the mass flow rate increased, thermal efficiency decreased and increased when solar radiation increased as shown in Figure 10, from 28.39% at mass flow rate 0.049 kg/s to 30.2535% at mass flow rate 0.01 kg/s under maximum solar radiation, 1000 W/m^2.

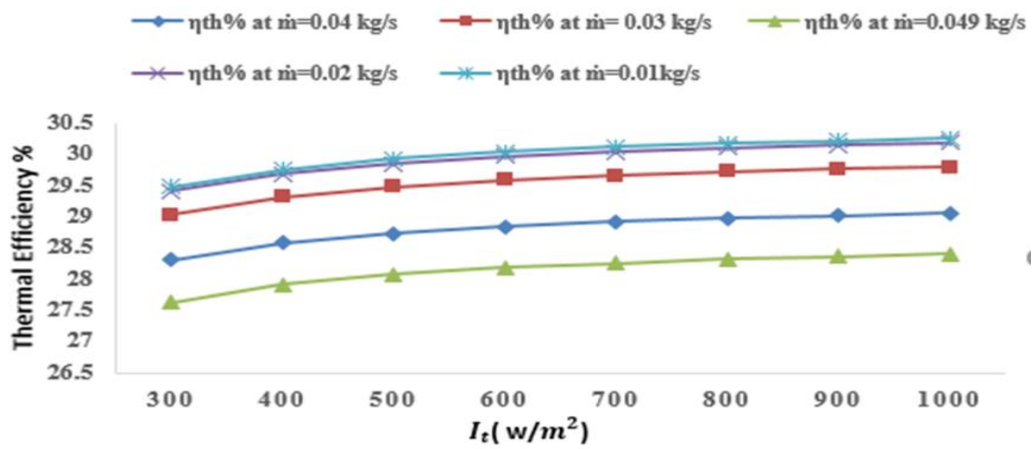

Fig. 10. Thermal Efficiency of the PVT collector against solar radiation at different mass flow rate

When the mass flow rate increased, the PVT efficiency decreased. Then, the PVT efficiency decreased when solar radiation rose from 41.50% at mass flow rate 0.049 kg/s to 42.96% at mass flow rate 0.01 kg/s under maximum solar radiation 1000 W/m^2, as shown in Figure 11.

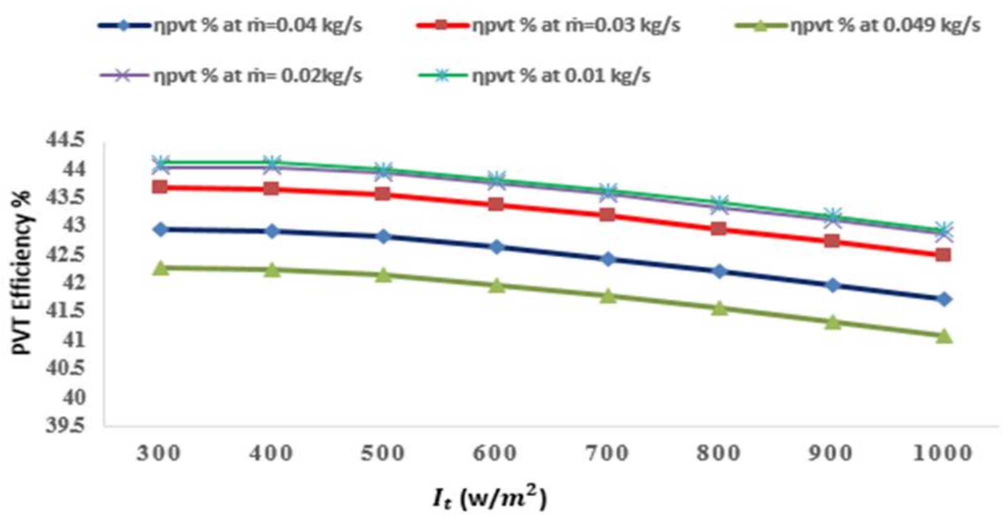

Fig. 11. PVT Efficiency of the PVT collector against solar radiation at different mass flow rate

3.4 Comparison PVT Collector New Design With Normal PV Stander

The results of the comparison between the new PVT collector and normal PV are shown in Figure 12. The electrical efficiency of the new design is higher than that of the normal PV (without cooling system). Electrical efficiency increased from 12.7% at mass flow rate 0.01 kg/s to 13.13% at mass flow rate 0.049 kg/s under maximum solar radiation 1000 W/m^2 for the new PVT design. Compared with the normal PV electrical efficiency is 12.2%, the new PVT design exhibits higher electrical efficiency. The enhancement of the electrical and thermal efficiency contributed to the efficiency improvement of the PVT water collectors with mass flow rates under distinct solar radiation levels. This result is due to the rise in the cooling factor of the PV module cells as the mass flow rate increases. Thus, the mass flow rate plays an important role in PVT water collector temperature.

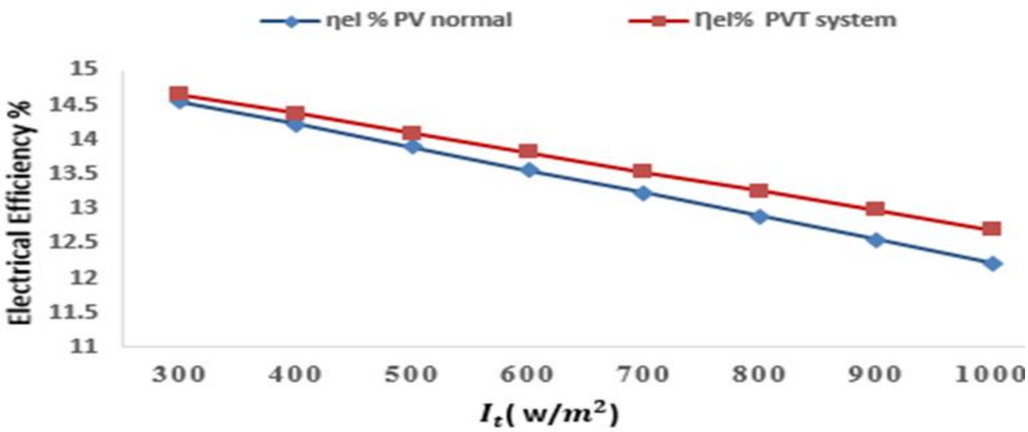

Fig. 12. Variations of electrical efficiency of the PVT collectors with normal standard PV

4. Conclusion

In this study, distinct versions of PVT modules were analysis by using theoretical results via MATLAB. A new PVT water collector consisting of a combined PV module and an absorber collector was investigated. The mass flow rates in the range of 0.01–0.049 kg/s under solar radiation levels in the range of 300–1000 W/m^2 were used for this analysis. The following results were observed:

I. Increasing the mass flow rate decreased the cell temperature of the PVT collectors at all solar radiation levels. At the same mass flow rate, the cell temperatures increased alongside increase the solar radiation level. The temperature decreased from 338.34 K at mass flow rate 0.01 kg/s to 332 K at mass flow rate 0.049 kg/s when the maximum solar radiation was 1000 W/m^2.
II. Increasing the mass flow rate decreased the outlet water temperature of the PVT collectors at all solar radiation level, at the same mass flow rate, the outlet water temperatures increased with increase the solar radiation level, the temperature decreased from 307.98 K at mass flow rate 0.01 kg/s to 301.02 K at mass flow rate 0.049 kg/s at maximum solar radiation 1000 W/ m^2.
III. Increasing the mass flow rate decreased the outlet water temperature of the PVT collectors at all solar radiation levels. At the same mass flow rate, the outlet water temperatures increased alongside increase the solar radiation level. The temperature decreased from 307.98 K at mass flow rate 0.01 kg/s to 301.02 K at mass flow rate 0.049 kg/s when the maximum solar radiation was 1000 W/m^2.
IV. When the mass flow rate increased, the PVT efficiency decreased when the solar radiation increased from 41.50% at mass flow rate 0.049 kg/s to 42.96% at mass flow rate 0.01 kg/s under maximum solar radiation of 1000 W/m^2.
V. The present study showed that the PVT technology exhibited a higher electrical efficiency than the normal PV module , by affected the mass flow rate.

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