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Modelling, Validation and Analyzing Performance of Serpentine-Direct PV/T Solar Collector Design

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ABSTRACT

The photovoltaic thermal, PV/T water collector's thermal and electrical performance was investigated for two absorbers design. Comparison between them were done using validated simulation of the model which was presented using theoretical data with the help of program MATLAB. The first design serpentine and the second serpin-Direct (new design), were defined under solar radiation levels (300-1100)W/m^2. Mass flow rate range from (0.011 kg /s to 0.1 kg /s) at each level of solar radiation. The PV/T system was evaluated in terms of thermal efficiency, electrical efficiency and a combination of both PV/T efficiencies. 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. At optimum conditions of 900W/m^2 solar radiation and 0.06 kg/s mass flow rate, the results indicated that serpin-direct PV/T design achieved 53% thermal and 14.3% electrical efficiency respectively. Under same operating conditions the results showed the priority of serpen-direct PV/T collector design performance versus the serpentine PV/T collector in term of thermal and electrical efficiency.

1. Introduction

The combination of solar thermal collector and photovoltaic (PV) as a source of heat, water and electricity has raised interest in utilization of energy sources. This simultaneously raised interest in solar thermal (PV/T) collectors. Solar radiation is converted directly by the PV/T solar collectors into both

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thermal and electrical energies. Thus, it primarily fuses the roles of a photovoltaic panel and a solar collector. The mid-1970s saw the initiation of investigations into PV/T that were focused on PV/T collectors, with the main aim of raising PV efficiency. The main market was local application. The initial focus was on collectors of water glazes and air. PV/T system is unsustainable for residential owners and industries as it is costly. Currently, the highly developed BIPVT, is one of the most sought after application for water collectors and photovoltaic [1].

Nonetheless, there has been further development of the PV/T-based systems. PV/T system has the ability to generate both types of energy due to their higher reliability and impact on the lower environment. Generally, the water-based PV/T system is made up of a tube-shaped collector, an isolated container, a photovoltaic module and a transparent glass lid. There is expected increase in BIPVT publications and rapid growth of PV/T products [2-4].The development in PV/T system performance in many directions got more interesting in the researchers, depended on the type of working fluid in the PV/T system, manufacturing materials of the solar collector and the absorber design [5-7] .In theory, the analysis were made following a modified Hottel-Whillier model, while validation of the results were based on experimental data collected from a prototype PV/T collector [8, 9]. There was also identification of the impact of design parameters on the thermal and electrical efficiency of PV/T, which include thermal conductivity between PV cells and their supporting structure, lamination method and fin efficiency. In addition, lower cost material including pre-coated steel cooler, can be used to prepare the PV/T without drastically impairing efficiency. System cost can also be reduced by integrating PV/T into a building instead of a building.

In a study of water-based system PV/T system, a digital version of water-based PV/T systems was built via modification of the Hottel-Whillier model, which was originally utilized for heat analysis of flat-plate solar thermal collectors. Recently, performance analysis for PV/T energy analysis had been carried out. Distinct PV technology instead of a similar PV/T system was used to assess the cost of performance and life cycle of PV/T systems. Results indicate that there is a great benefit in using PV/T systems, in terms of economic and efficiency factors. The mono crystalline PV/T systems are better in terms of energy efficiency, and are appropriate for applications with greater external and power requirements, or have little installation spaces [10].

In theory, system performance was analyzed using a computer simulation. The common effects of solar cell filling factor was investigated. The mass flow rate of water has been tested for electrical and thermal efficiency. Results of simulation tests indicate that the rise of flow rate in the working fluid is beneficial for photovoltaic cooling. Nonetheless, the benefits of raising flow rate drop as the critical flow rate is superseded, thus lowering thermal efficiency. In addition to enhancing the system's thermal performance, the operating system at the optimum mass flow rate can also meet the requirements of PV cooling in order to obtain greater electrical performance [11]. There were experimental study done on centralized PV and hot-water collector wall system that is mounted onto vertical facades [12]. Results indicate that during late summer, electrical efficiency was at 8.56% while thermal efficiency was at 38.9% at reduced (zero) temperature. A water heating system and a dynamic simulation model of a PV/T had been developed. Validation of this modeling approach was done via comparison with experimental data [13].

In the same direction of studies, results indicate that on-site shading influences the electrical performance. In addition, there is high correlation between the outputs from the model with the experimental findings. A computer simulation of a water-based PV/T solar collector system was constructed using energy models. Greater economic benefits were noticeable compared to that of a conventional PV system. Compared to normal building façade, the annual average thermal and cell conversion efficiencies of a particular PV/T system was 37.5% and 9.39%, respectively. The PV/T system was mounted on a vertical wall of a completely air-conditioned building with collectors that were fixed with a flat box-version thermal absorber and polycrystalline silicon cell [14]. There was development and experimental validation of a computational fluid dynamic (CFD) model for a new PV/T collector [15, 16]. The findings showed that the PV cell efficiency may be raised to 5.3% and that the collector's outlet water temperature was appropriate for domestic hot-water utilization. Also, the CFD analysis showed that the absorber design in PV/T system have direct impact on the distribution temperature on the PV panel surface. There were also investigations done on the impact of flow distribution on the PV/T water collector's PV performance [17]. The results indicated that flow distribution was influenced by parameters such as the array geometry, mass flow rate, manifold flow direction and manifold to-riser pipe ratio, which in turn influenced the PV conversion.

Recently, there were innovative applications of PV/T collector [18]. It was reported that hybrid PV/T solar systems' thermodynamic modelling utilized a modular approach by Simulink/Matlab software with benefits of PV/T technology instead of 'side by side' thermal and PV solar systems. Results of their investigation highlighted a global overall efficiency of 24% (i.e. 9% electrical and 15% thermal), and an average annual solar fraction of 67% [19]. The PV/T applications are cost-effective solar energy applications. Nonetheless, there should be more studies, especially on the design of new thermal absorber collectors and materials of collector fabrication [20-22]. This paper presents alternative designs of PV/T solar collectors. A prototype of this new absorber has been developed. Up to today, there has only been a few investigations on water-based PV/T collectors. Thus, there should be more studies and analytical research to enhance the thermal and electrical performance of water-based PV/T solar collectors via utilization of novel absorber collector designs.

A new design of PV/T (serpin- direct) is shown in Figure 1. Modeling, validation and simulation of the model are presented in this paper using theoretical data by utilizing program MATLAB and comparative study with another design of PV/T (Serpentine Flow Design) shown in Figure 2.

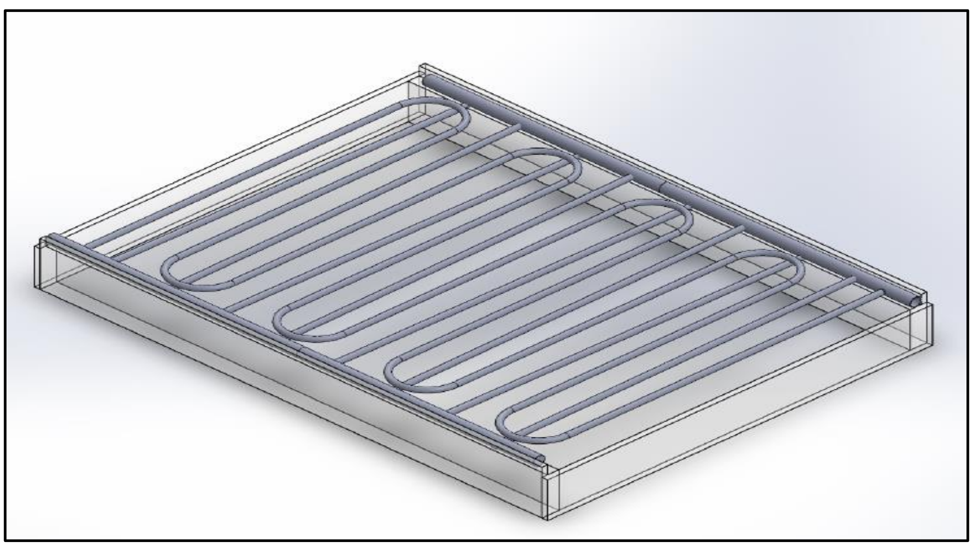

Fig. 1. Serpin- Direct Design of PV/T

Fig. 2. Serpentine Flow Design of PV/T [23]

2. Methodology

The validate simulation of the two models are then presented using theoretical data by utilizing program MATLAB and comparative results of the new design of PV/T (Serpin- direct) shown in Figure 1 with another design of PV/T (Serpentine flow design) shown in Figure 2. Variation of cell temperature with mass flow rate with different solar radiation range (300-1100) W/$\mathbf{m^2}$ and mass flow rate range between (0.01-0.1) kg/s. had been carried out. Evaluation of the PV/T modules' performance was based on PV and thermal efficiencies, while validation was based on design parameters and basic energy balance equations.

2.1 New design of absorbers

Two PV/T water collector designs are shown in Figure 1,2. Table 1 lists the properties of these simulation design configurations. A new design serpin- direct flow absorber is shown in the first collector (Figure 1) while the second collector- Serpentine flow absorber is shown in Figure 2. Front view of new design (Serpin- direct) of PV/T showed in Figure 3. The new design system consisted of the PV panel and bellow PV, absorber collectors made of copper plate. The copper water tube was linked at the bottom of the absorber plate. The thermal insulator was fixed at the bottom of the absorber collector, which was made up of two segments of tubes for water to flow- direct and serpentine flow tubes as illustrated in Figure 1, 4. At the bottom of the standard PV module, a solar absorber of dimension 1.6 m long, 1 m width and 0.03 m thick was fixed. The absorber collector assists in ensuring a more uniform temperature within the system and to avoid further escape of heat. The standard PV module was denoted as a flat-plate single sheet of monocrystalline silicone that was laminated and bonded via high-temperature silicone adhesive and sealant. The design of the absorber collector was in the shape of a configured tube or continuous coil, and was made up of at least one outlet and inlet to permit the medium, which was water, to leave and enter a coil, respectively.

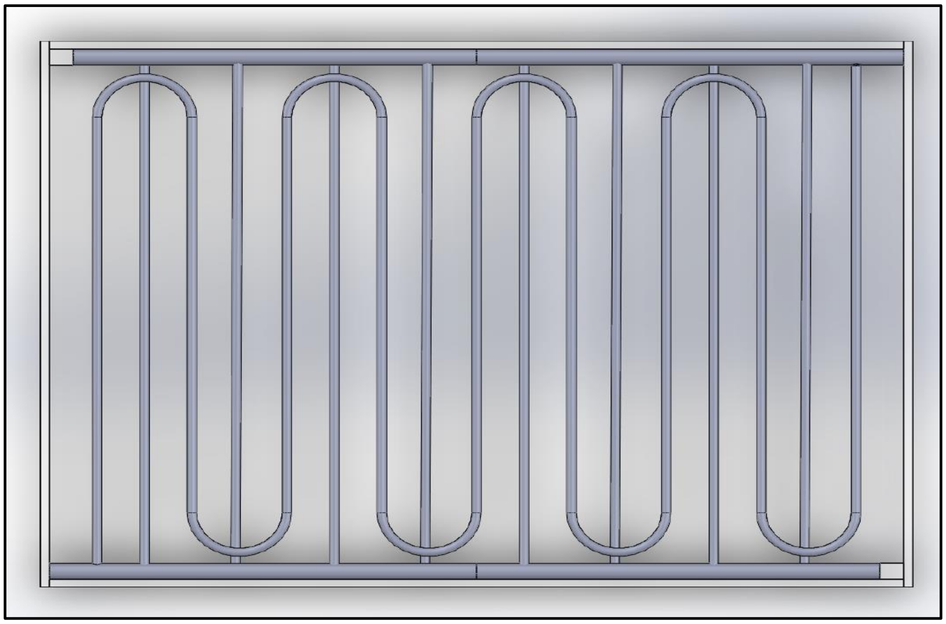

Fig. 3. Front view of new design (serpin- direct) of PV/T

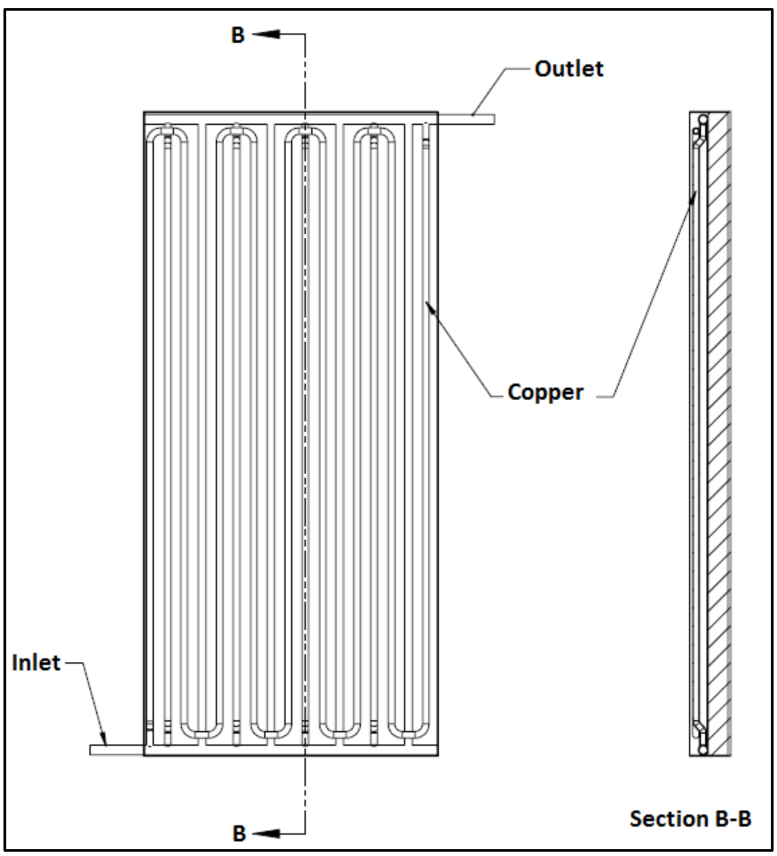

Fig. 4. Cross section view of a new design (serpin- direct) of PV/T

The medium (water) flowed in and out via the outlet and inlet tube arrangements. It also covered the whole PV module. The following is the configuration: a cold (low temperature) medium (water) gets into the coil, flows in and out, and exits the absorber collector as hot water, which may be utilized or stored for later use. In this way, solar energy may be completely used. Usually, the hot-water storage tank in a PV/T system is situated in close proximity to the ground level, whereas the solar module is located above the roof.

The hot-water storage in this PV/T system was situation as close as permissible to the collector to maintain constant water pressure from the pump to the collector, and vice versa. A set of pipes (serpentine and direct tubes) as shown in Figure 3 join the serpin-direct solar collector to the hot-water storage. A pump circulates the water. Heat loss was assuming to be prevented by ensuring proper insulation of the pipes. Only the collector unit absorbed the energy. Water was heated by using the energy absorbed by the collector. It was assumed that only the water storage tank that lost energy. It was assumed that the collector's inlet water temperature was similar to the storage tank's mean water temperature.

3. Mathematical model of the PV/T solar collector

The performance of the PV/T collectors can be expressed by combination of efficiency expressions consisting of thermal efficiency(η_{th}) and electrical efficiency (η_{pv}) [24]. These efficiencies usually include the ratio of the useful thermal gain and electrical gain of the system to the incident solar irradiation on the collector gap within a specific time or period. The analytical parameters of the PV/T collector are presented in Table 1. The total efficiencies, known as total efficiency or PV/T efficiency (η_{PVT}), are used to evaluate the overall performance of the system [25].

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

3.1 Thermal Performance of Collector

The output thermal efficiency of the collector is a measure of the PV/T system performance. It's defined as the ratio of the useful energy gain, Q_u over known time period to the solar radiation, $I(t)$ over the same period [26].

$$\eta_{thermal} = \frac{\int Q_u \, dt}{A_c \int I(t) \, dt} \tag{2}$$

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 (C_P) and temperature difference at the collector inlet (T_i) and outlet (T_o) and can be expressed.

$$Q_u = \dot{m} C_p (T_O - T_i) \tag{3}$$

In additional, useful heat gain can be written with expression as the difference between the absorber solar radiation and thermal heat losses, is determined using the equation [26].

$$Q_u = A_C F_R[G_T(\tau\alpha)_{PV} - U_L(T_i - T_a)] \quad (4)$$

where A_c is the collector area, T_a is the ambient temperature, T_i is the inlet temperature, U_L is the overall collector heat loss, $(\tau\alpha)_{PV}$ is the PV thermal efficiency, G_T is the solar radiation and F_R is the heat removal efficiency factor introduced [26]. This factor is expressed as follows:

$$F_R = \frac{\dot{m}C_P}{A_C U_L}\left[1 - exp\left(-\frac{AcU_L F'}{\dot{m}C_P}\right)\right] \quad (5)$$

where F' is the collector efficiency factor, which is calculated using

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

C_b is the conductance of the bond between the fin and circular tubes, h_{fi} is the heat-transfer coefficient of the fluid, and F is the fin efficiency factor given by.

$$F = \frac{\tanh m(W-D)/2}{m(W-D)/2} \quad (7)$$

The coefficient M in Eq. (9) considers both the thermal conductivity of the absorber and the PV cell. M is calculated using [17, 27].

$$M = \sqrt{\frac{U_L}{k_{abs}\, l_{abs} + k_{pv}\, l_{pv}}} \quad (8)$$

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. The overall loss coefficient (U_L) of the collector is the sum of the bottom (U_b) and top (U_t) loss coefficients and can be expressed as.

$$U_L = U_t + U_b \quad (9)$$

3.2 The Photovoltaic Performance of the PV/T Collector

The photovoltaic cell performance for the PV/T collector is mainly depends on the temperature of the solar cell, T_{cell} that is given by Florschuetz [28].

$$\eta_{cell} = \eta_{ref}\left[1 - \gamma\left(T_{cell} - T_{ref}\right)\right] \quad (10)$$

where T_{ref} is the temperature reference set, η_{ref} is the reference efficiency of the PV module, γ is a temperature coefficient (γ= 0.0045 C°) and T_{cell} is the cell temperature.

3.3 The energy Balanced Equation for the new serpin- direct design absorber in PV/T system

3.3.1 For the solar cell temperature

The cell temperature equation of the serpentine design will be as follows [29].

$$T_{cell,serpintine} = \left[\frac{(\alpha\tau)_{1,eff}I(t)+U_{tc,a}T_a+U_{tc,p}T_p}{U_{tc,a}+U_{tc,p}}\right]_{Serpintine} \quad (11)$$

where the direct design cell temperature can be expressed as.

$$T_{cell,direct} = \left[\frac{(\alpha\tau)_{1,eff}I(t)+U_{tc,a}T_a+U_{tc,p}T_p}{U_{tc,a}+U_{tc,p}}\right]_{Direct} \quad (12)$$

Since the serpin-direct is a combination of a serpentine and a direct flow design, the solar cell temperature will be as.

$$T_{cell\ serpin-direct} = \frac{T_{cell,serpintine}+T_{cell,direct}}{2} \quad (13)$$

3.3.2 For the plate under the solar cell temperature

The plate temperature equation of the serpentine design will be as below [29],

$$T_{plate,serpintine} = \left[\frac{(\alpha\tau)_{2,eff}I(t)+PF_1(\alpha\tau)_{1,eff}I(t)+U_{L2}T_a+F'h_{pf}\overline{T_f}}{U_{L2}+F'h_{pf}}\right]_{Serpintine} \quad (14)$$

where the direct design plate temperature can be represented as:

$$T_{plate,direct} = \left[\frac{(\alpha\tau)_{2,eff}I(t)+PF_1(\alpha\tau)_{1,eff}I(t)+U_{L2}T_a+F'h_{pf}\overline{T_f}}{U_{L2}+F'h_{pf}}\right]_{Direct} \quad (15)$$

The plate temperature for the serpin-direct flow will be the average of the serpentine and the direct plate temperature is illustrated as

$$T_{plate\ serpen-direct} = \frac{T_{plate,serpentine}+T_{plate,direct}}{2} \quad (16)$$

3.3.3 For the outlet water temperature

For the temperature of water flowing through an absorber below photovoltaic module [29, 30]:

$$(T_{fo}) = \left[\frac{PF_2(\alpha\tau)_{m,eff}I(t)}{U_{L,m}} + T_a\right] \times \left[1 - \exp\left(-\frac{A_m U_{L,m}\ F'}{m_f C_f}\right)\right] + T_{fi}\exp\left(-\frac{A_m U_{L,m}\ F'}{m_f C_f}\right) \quad (17)$$

For the serpentine design, the outlet temperature equation will be written as,

$$T_{outlet,serpintine} = \left[\left[\frac{PF_2(\alpha\tau)_{m,eff} I(t)}{U_{L,m}} + T_a\right] \times \left[1 - \exp\left(-\frac{A_m U_{L,m}\ F'}{m_f C_f}\right)\right] + T_{fi} \exp\left(-\frac{A_m U_{L,m}\ F'}{m_f C_f}\right)\right]_{Serpintine} \quad (18)$$

where the direct design outlet water temperature can be denoted as,

$$T_{outlet,direct} = \left[\left[\frac{PF_2(\alpha\tau)_{m,eff} I(t)}{U_{L,m}} + T_a\right] \times \left[1 - exp\left(-\frac{A_m U_{L,m}\ F'}{m_f C_f}\right)\right] + T_{fi}\ exp\left(-\frac{A_m U_{L,m}\ F'}{m_f C_f}\right)\right]_{Direct} \quad (19)$$

The outlet temperature equation will be expressed for serpin-direct flow as,

$$T_{outlet\ serpin-direct} = \frac{T_{outlet,serpintine} + T_{outlet,direct}}{2} \quad (20)$$

The parameter A_m that mentioned above in both equations for serpentine and direct flow designs represent the area of flow . for serpentine tubes flow ($A_m = L \times w \times N_{seg}$) and for direct tubes flow

($A_m = L \times w$) .

3.4 The thermal performance of the serpin- direct flow absorber in PV/T system

The thermal performance of the Serpin-serpentine can be calculated in two steps. The first step is to calculate the thermal efficiency of the serpentine flow design**,**

$$Q_{u,Serpintine} = m_f C_p [T_{Outlet-Serpintine} - T_{inlet}] \quad (21)$$

Then

$$\eta_{thermal,Serpintine} = \frac{\int Q_{u,Serpintine}\ dt}{A_{c,Serpintine} \int I(t)\ dt} \quad (22)$$

Then, calculating the thermal efficiency of the direct flow design,

$$Q_{u,Direct} = m_f C_p [T_{Outlet-direct} - T_{inlet}] \quad (23)$$

Then

$$\eta_{thermal,Direct} = \frac{\int Q_{u,Direct}\ dt}{A_{c,Direct} \int I(t)\ dt} \quad (24)$$

After that averaging the efficiencies for serpin-direct design will take a place as follows,

$$\eta_{thermal,Serpin-Direct} = \frac{\eta_{thermal,Serpintine} + \eta_{thermal,Direct}}{2} \quad (25)$$

Table 1
PV/T system characteristics

Parameter	Value	Unit
α_c	0.9	---
τ_g	0.96	---
β	0.83	---
L_g	0.03	m
K_g	1	W/m.K
L_p	0.002	m
K_p	204	W/m.K
L_c	$300X10^{-6}$	---
K_c	0.036	W/m.K
$U_{tc,a}$	7.14	$W/m^2.K$
$U_{tc,p}$	150	$W/m^2.K$
$U_{tp,a}$	6.81	$W/m^2.K$
L	1.6	m
W	0.7366	m
PF1	0.973	---
PF2	0.83	---
U_{L1}	8.99	W/m2.K
U_{L2}	17.35	W/m2.K
F'	0.8576	---
T_a	20	c
εg	0.88	---
k_f	0.613	$W/m\ C^{\circ}$
I_b	0.05	m
C_p	4180	$J/kg\ C^{\circ}$
k_e	0.045	$W/m\ \_C^{\circ}$
l_e	0.025	m
l_{abs}	0.002	m
k_f	84	$W/m\ C^{\circ}$
h_{ca}	45	$W/m\ \_C^{\circ}$
h_{fi}	33	$W/m\ \_C^{\circ}$
τ	0.88	---
α	0.95	---

4. Results and Discussions

The thermal and electrical properties of PV/T collectors influence their efficiency and performance. There are three sections of the PV/T collector's analysis: thermal efficiency, cell efficiency and combination of both. The analysis results of the PV/T collectors are shown in Figure 5-12 following exposure to 300-1100 W/m^2 of solar radiation at 0.011–0.1 kg/s mass flow rates. The results indicate that under distinct cell temperature and mass flow rates, the collector's cell efficiency altered significantly.

Figure 5 shows the relationship between cell temperature and mass flow rate at radiation700 W/m^2 and the comparison between the two designs in which data suggested that cell temperature decreases by increasing the mass flow rate. And range value cell temperature for design serpentine 40 Ċ at 0.01kg/s and value 37.8 Ċ at 0.1 kg/s and for serpin-direct design 38.8 C° at 0.01kg/s and 37.3 Ċ at 0.1kg/s.

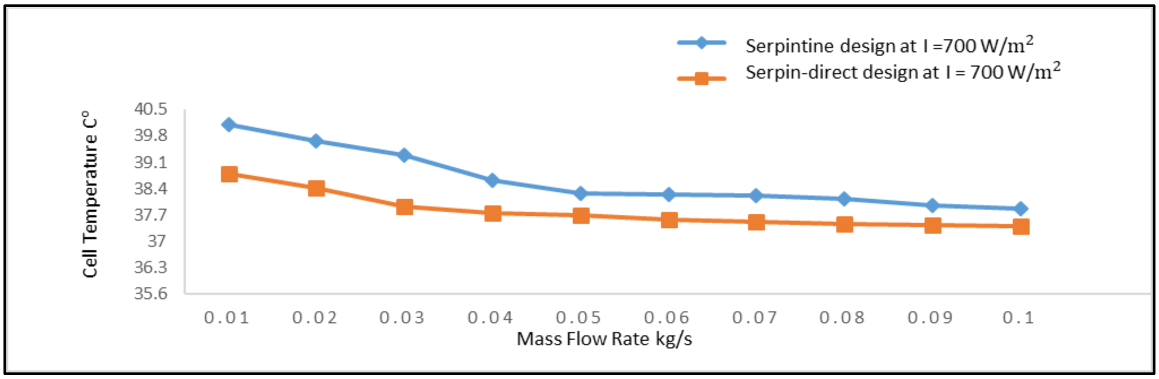

Fig. 5. Variations in Cell temperature of the PV/T collectors under 700 W/m^2 of solar radiation

Figure 6 illustrates the link between cell temperature and mass flow rate at radiation 900 W/m^2 and the comparison between the two designs whereby the results show the cell temperature dropping as the mass flow rate rises. The range value for cell temperature for design serpentine 40.1 Ċ at 0.01kg/s and value 37Ċ at 0.1 kg/s and for serpin-direct design 38 Ċ at 0.01kg/s, and 35 Ċ at 0.1kg/s.

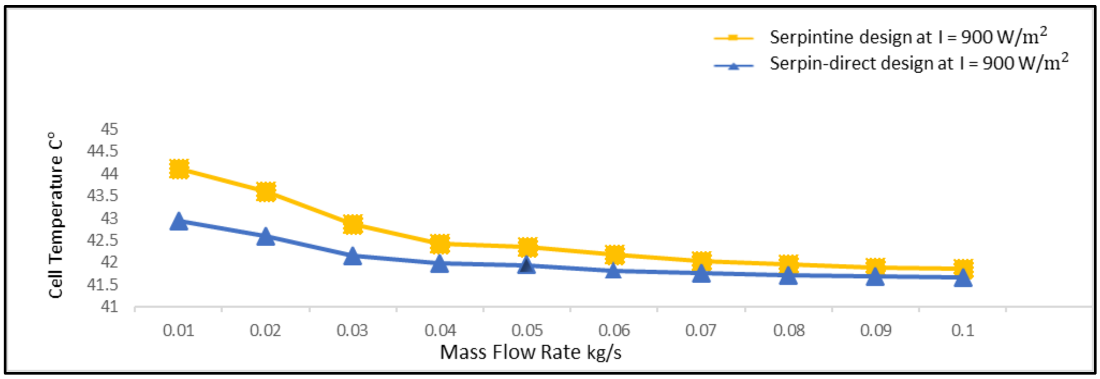

Fig. 6. Variations in Cell Temperature of the PV/T collectors under 900 W/m^2 of solar radiation

Figure 7 shows the relationship between cell temperature and mass flow rate at value range radiation from 500 to 1100 W/m^2 for design serpin-direct. The result displayed increase in Cell temperature with increase solar radiation, maximum solar Cell value was 44.05 Ċ at 1100 W/m^2 and minimum value was 36.86 Ċ at 500 w/m^2.

Figure 8 shows the relationship between cell temperature and mass flow rate at value range radiation from 300 to 1100 W/m^2 for design Serpentine. The result showed an increase in cell temperature with the increase in solar radiation when the solar cell temperature was at 1100 W/m^2 were 47.5 Ċ and value 35.6 Ċ at 500 w/m^2.

Figure 9 shows the relationship between thermal efficiency and mass flow rate at radiation 900 W/m^2 and the comparison between the two designs whereby the data indicates that when the mass flow rate rises, thermal efficiency rises as well. The range value for thermal efficiency for design Serpentine 49.12% at 0.01kg/s and value 53 % at 0.09 kg/s and for Serpin-direct design 50 % at 0.01 kg/s, and 52 % at 0.09 kg/s.

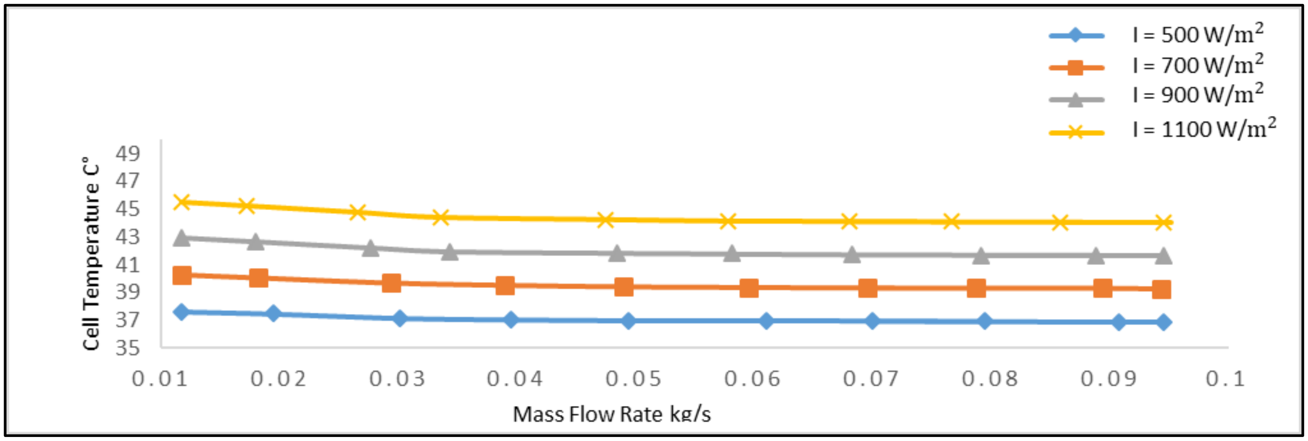

Fig. 7. Variations in Cell Temperature of Serpin-direct design with the mass flow rates under different solar radiation levels

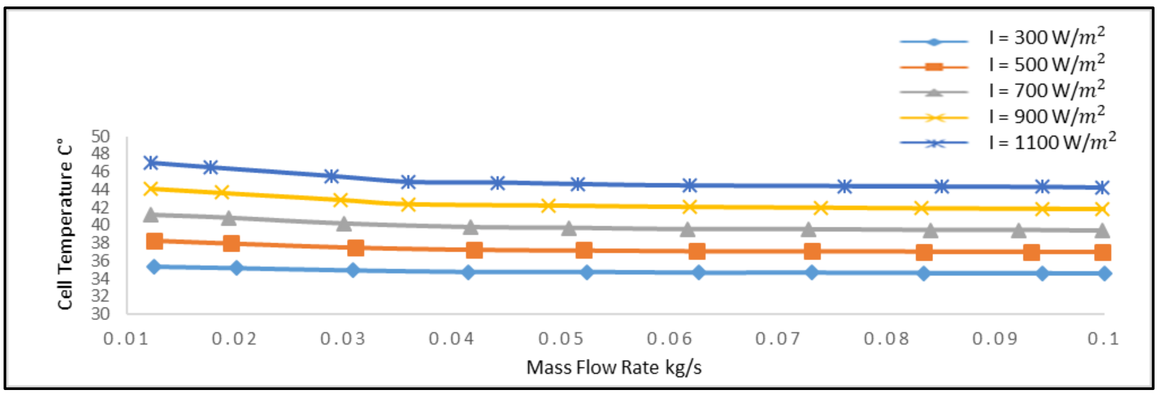

Fig. 8. Variations in Cell Temperature of Serpentine design with the mass flow rates under different solar radiation levels

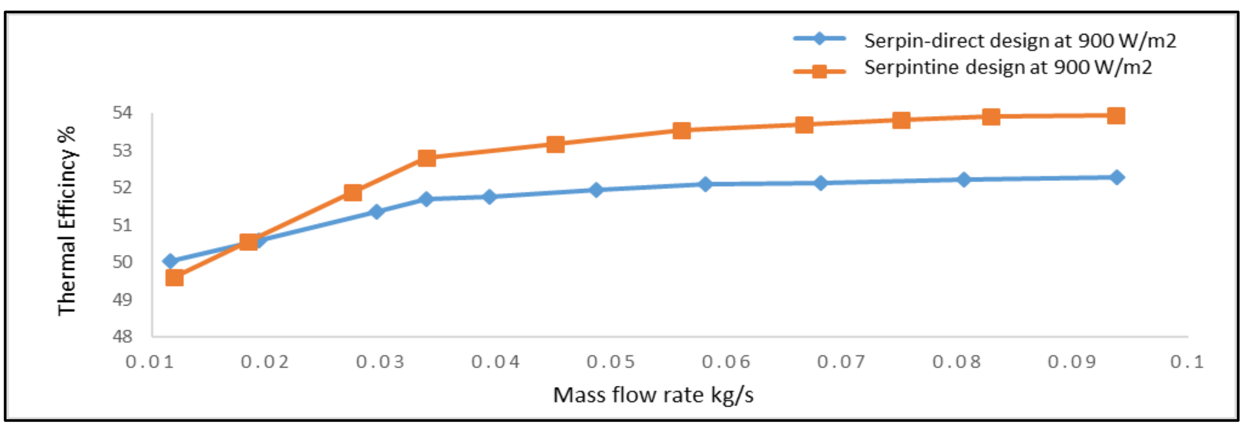

Fig. 9. Variations in Thermal Efficiency of the PV/T collectors under 900 W/m^2 of solar radiation

Figure 10 shows the relationship between cell efficiency and mass flow rate at radiation 900 W/m^2 and the comparison between the two designs indicate that the cell efficiency increases with the rising mass flow rate. Besides, the value cell efficiency for design Serpentine 13.6 % was at 0.1 kg/s and for Serpin-direct design 14 % was at 0.1 kg/s.

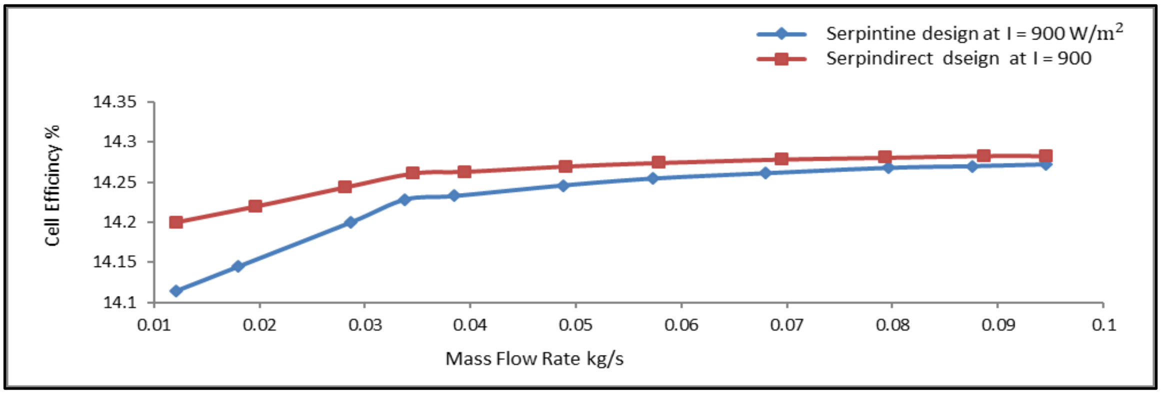

Fig. 10. Variations in Cell Efficiency of the PV/T collectors under 900 $\mathrm{W/m^2}$ of solar radiation

Figure 11 shows the relationship between cell efficiency and mass flow rate at radiation 700 $\mathrm{W/m}^2$and the comparison between the two designs in which the results indicate that cell efficiency increases with rising mass flow rate. Moreover, the value cell efficiency for design Serpentine was 14 % at 0.1 kg/s and for Serpin-direct design was 14.5 % at 0.1 kg/s.

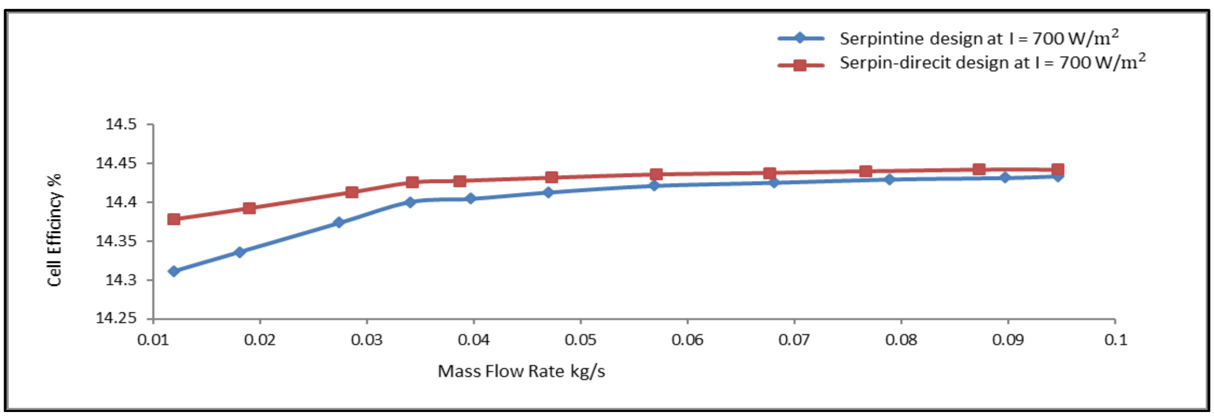

Fig. 11. Variations in Cell Efficiency of the PV/T collectors under 700 $\mathrm{W/m^2}$ of solar radiation

Figure 12 shows the relationship between outlet temperature and mass flow rate at radiation 900 $\mathrm{W/m^2}$ and the comparison between the two designs where the results show the outlet temperature drops as mass flow rate rises. Besides, range value outlet temperature for design Serpentine 43Ċ was at 0.01kg/s and value 40 Ċ at 0.094 kg/s and for Serpin-direct design 40 Ċ at 0.01 kg/s, and 39 Ċ at 0.093 kg/s.

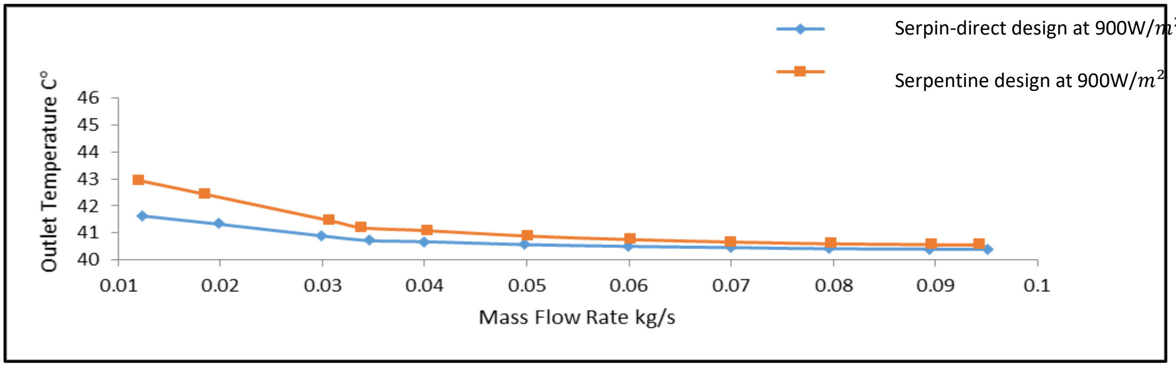

Fig. 12. Variations in Outlet Temperature of the PVT collectors under 900 $\mathrm{W/m^2}$ of solar radiation

5. Conclusions

Two distinct versions of photovoltaic-thermal PV/T modules were validated in this paper by utilizing theoretical results by MATLAB. Also, the design Serpentine's range value thermal efficiency was 49.12 % at 0.01 kg/s and value 53 % at 0.09 kg/s and for Serpin-direct design 50 % at 0.01kg/s, and 52% at 0.09 kg/s at radiation 900 $\mathrm{W/m^2}$. Also, the value cell efficiency for designee serpentine 13.6 % at 0.1 kg/s and for serpin-direct design 14 % at 0.1 kg/s the cell efficiency drops as solar radiation rises. The outlet temperature drops with rising solar radiation and range value outlet temperature for designee serpentine 43 °C at 0.01 kg/s and value 40° C at 0.094 kg/s and for serpin-direct design 40 Ċ at 0.01kg/s, and 39 Ċ at 0.093 kg/s. For design serpentine, the result were increase cell temperature with increase solar radiation the solar cell temperature at 1100 W/m^2 were 47.5 Ċ and value 35.6 Ċ at 500 $\mathrm{w/m^2}$. And for design Serpen-direct the result were maximum solar cell at 1100 $\mathrm{W/m^2}$were 44.05 Ċ and value 36.86 Ċ at 500 $\mathrm{W/m^2}$. Due to these results the Serpen-direct PV/T collector achieved greater performance compared to serpentine PV/T collector design. On the other hand, the results indicate that as cell temperature rises, the PV module's efficiency rises. There is a non-linear relationship between the drop in temperature with the increase of mass flow rate. The enhancement of the electrical and thermal efficiency contributed to the rising efficiency of the PV/T water collectors with mass flow rates under distinct solar radiation levels. This result is attributed to the rise in the PV module cells' cooling factor as the mass flow rate rises. As such, mass flow rate play a significant role in PV/T water collector temperature.

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