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Numerical Investigation and Performance Analysis of Photovoltaic Thermal PV/T Absorber Designs: A Comparative Study

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ABSTRACT

The term of PV/T refers to the solar energy system which is associate the photovoltaic and solar collector with each other in order to improve the photovoltaic efficiency. This system generates both thermal and electrical energy simultaneously. The aim of this work is to investigate numerically and comparing the performance of PV/T system with two absorber designs. A new photovoltaic thermal (PV/T) collector called serpen-direct is designed and compared with serpentine PV/T design. Theoretically, the PV/T performance for serpen-direct flow is validated and compared with the conventional serpentine flow design using MATLAB Simulink. Parameters, such as outlet water temperature, cell temperature and PV and thermal efficiency, were tested under various mass flow rates that range from 0.01 kg/s to 0.1 kg/s and two-level solar irradiance 300 W/m² and 700 W/m². Results show that the serpen-direct flow absorber design provides a better system performance than the serpentine flow design under the same operating conditions. The maximum PV and thermal efficiencies are 12.51% and 57.66%, respectively, for the serpen-direct flow and 12.43% and 54.68%, correspondingly, for the serpentine flow design.

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1. Introduction

Solar energy systems can be utilised for various applications, such as cooling, preheating, electricity generation and integrated buildings with photovoltaic (PV) systems [1]. In general, solar systems comprise thermal collectors that are used for air or water heating production and PV systems that are used to convert the solar irradiation to electricity. Normally, a solar thermal system and a PV module are used separately. The low efficiency of PV systems and limitation of space on roofs of

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buildings for simultaneous installation of two systems (PV technology and thermal system), these two points represent issues of separate use of these technologies [2]. A term called Photovoltaic thermal (PV/T) solar collector system, which combines both systems, is used for simultaneous water heating and electricity generation. Therefore, the current development will minimise the high installation cost and limited roof space of buildings. This issue has been motivated the researchers to develop the PV/T system. Many techniques are applied to PV/T systems; these methods include using different types of fluids as a heat transfer medium in solar collectors [3-6], various materials in fabricating the solar collector [7] and designs of solar collectors [8-10]. The literature proposes that future studies must focus on designing absorbers as a basis for developing the PV/T system performance.

Studies have been developing new absorber designs; Adnan [11] proposed many novel absorber design configurations, as illustrated in Figure 1; this author investigated and compared the system performance of these configurations. A simulation was conducted to distinguish the optimal absorber design performance that provides the maximum thermal and electrical efficiencies. In the simulation, the PV/T systems are analysed under different parameters, such as ambient temperature, solar irradiance and mass flow rate condition. The collector is a flat-plate PV/T with a single glazing sheet. The results reveal that the web and serpentine flow designs have achieved thermal efficiencies of 42.5% and 42.5%, respectively. Similarly, Tripathi *et al.*, [12] mathematically analysed a specially designed absorber PV/T system with a rectangular tube. The simulation result reveals that the absorber collector produces an electrical efficiency of 11.4% and a combined efficiency (thermal and electrical) of 64.8% at a mass flow rate of 0.045 kg/s, an ambient temperature between 28.6 °C and 33.55 °C and sun irradiance in the range of 700–800 W/m². Furthermore, [13] presented a three-dimension modelling for new absorber design of PV/T collector to predict the PV efficiency with different operating conditions.

A new absorber design called split flow has been presented for the PV/T system [14]. The new absorber design has achieved a thermal efficiency of as high as 51.4%. Theoretically, Al-Shamani *et al.*, [15] modelled and investigated a new ellipse design of collectors to produce electricity and hot water. The absorber was assumed to be fixed underneath the PV solar module, and water acted as a heat removal medium in the collector. The simulation results revealed that the new ellipse collector produces an electrical efficiency of 13.78% and a combined PV/T efficiency of 74.3%.

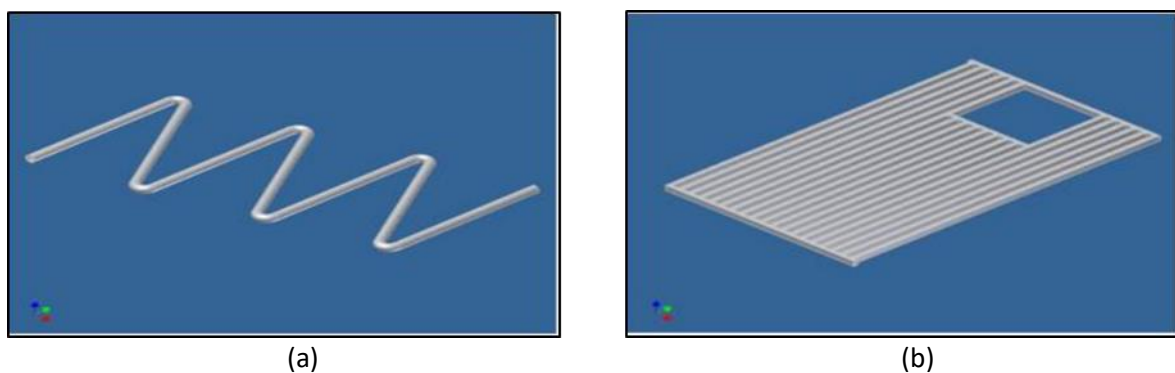


Fig. 1. (a) serpentine flow design (b) direct flow design [11]

The basic idea for a PV/T collector system combines solar a PV module and a heat collector to address the area factor. Priya *et al.*, [16] developed an effective PV/T collector sizing and illustrated the steps for solving the mathematical model. The author observed that PV/T collector sizing is governed by thermal and electrical demands.

In another direction, a novel ceiling ventilation system was integrated with PV/T collectors, and phase change materials (PCMs) were developed and evaluated in terms of performance [17]. The results showed that the proposed PV/T integrated ventilation system can drastically enhance the indoor thermal comfort of passive buildings without using AC systems with the maximum air temperature rise of 23.1 °C from PV/T collectors. The development of the PV/T system has attracted considerable interest of researchers from varying disciplines; a finite element heat flux simulation was conducted and integrated into a theoretical mathematical model [18]. The results were obtained by simulating and solving the numerical models, and the overall performance of the PV/T improved.

The abovementioned literature denotes that absorber design is an important parameter that directly affects the PV/T performance. The present paper reports the modelling and validation of a new absorber design in the PV/T system and conducts a comparative performance study between a new collector called the 'serpen-direct flow' and conventional 'serpentine flow design'. The present study aims to obtain data on the system performance for both collectors under various operating conditions, such as mass flow rate and solar irradiance. Thermal and PV efficiencies are calculated using the basic energy balance equations and PV/T design parameters. MATLAB Simulink is used to calculate the PV/T performance for serpen-direct and serpentine absorber designs. The results show that serpen-direct achieves better thermal and PV efficiencies than the absorber of the serpentine absorber flow design.

2. A New Absorber Design

A water-type PV/T uses the collector plate for absorbing heat and transferring it to the water that circulates in the PV/T tubes. The PV/T performance depends on the collector design. Figure 1 illustrates the two collector designs (serpentine and direct). The serpen-direct design of the PV/T combined the configurations of tubes for both absorber designs, as depicted in Figure 2. Table 1 lists the design parameters for the PV/T system for the serpen-direct flow collector and serpentine flow absorber. Figure 3 demonstrates the suppose schematic and details of the water-type PV/T system. Each collector of the two absorber designs consists of 20 parallel circular copper tubes. The tubes are welded, and the collector is attached underneath a semitransparent monocrystalline PV with a length of 1.18 m and a width of 0.54 m. Table 1 lists the semitransparent monocrystalline PV specifications. The insulating material is attached under the collector. Therefore, the semitransparent PV and collector plate are laminated using a high-temperature silicone adhesive and sealant. The two collectors share one inlet circular channel for water entry to the collector and one outlet circular channel to dispose of the hot water.

The new collector is a combination of serpentine flow and direct flow designs. This design can better maximise the absorbed heat than the serpentine flow, thus improving the performance of the PV/T system, as discussed in the subsequent section. The serpen-direct flow absorber design has one inlet and one outlet circular channel to collect the outlet water from the serpentine. In addition, it comprises direct pipes that enable water to flow in and out. To study the water flow phenomenon of the newly designed collector, the water will simultaneously flow in the serpentine flow absorber and the direct flow. In this case, PV module absorb the solar irradiation and can be transferred to the collector through conductive heat transfer. The new design of the absorber has improved distribution temperatures at the surface of the PV module given the configurations of the tubes (direct and serpentine). This mechanism will be further elucidated in the comparison of results from the PV/T serpentine flow absorber.

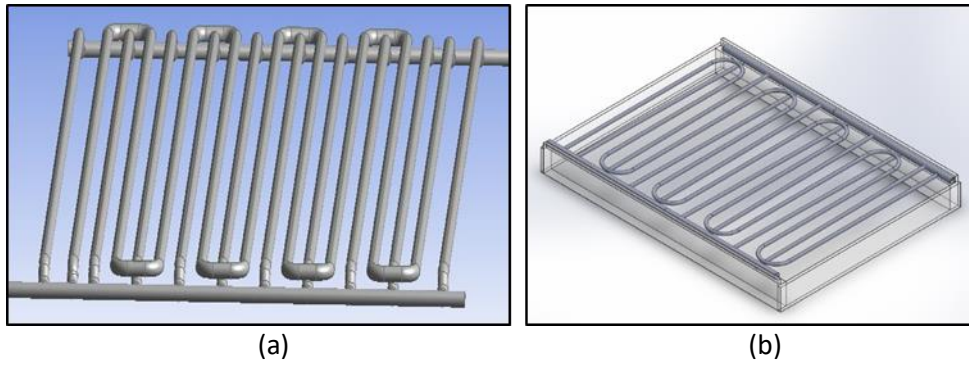


Fig. 2. (a) Front view of a serpen-direct flow design absorber (b) 3D diagram for a serpen-direct flow design absorber

Table 1

PV/T specifications

Parameters	Values (unit)
Ambient temperature	27 °C
Collector area	0.6372 m ²
Water fluid thermal conductivity	0.613 W/m °C
Tube diameter	0.0127 m
Specific heat of water	4180 J/kg °C
Absorber material	copper
Back insulation thermal conductivity	0.045 W/m °C
Insulation material	Polystyrene
Back insulation thickness	0.036 m
Tubes material	copper
Absorber thermal conductivity	385 W/m °C
Absorber thickness	0.0015 m
Absorber transmittivity	0.88
Absorber absorptivity	0.95
PV module type	Monocrystalline
PV area	0.6732 m ²
PV temperature coefficient	0.0045
PV reference efficiency	15.5
Solar cell size	0.125 m x 0.125 m
I_{sc}	6.11 A
V_{oc}	21.6 V
I_{max}	5.55 A
V_{max}	18 V
Max power PV	100 W
parameters	Values (unit)
Ambient temperature	27 °C
Collector area	0.6372 m ²

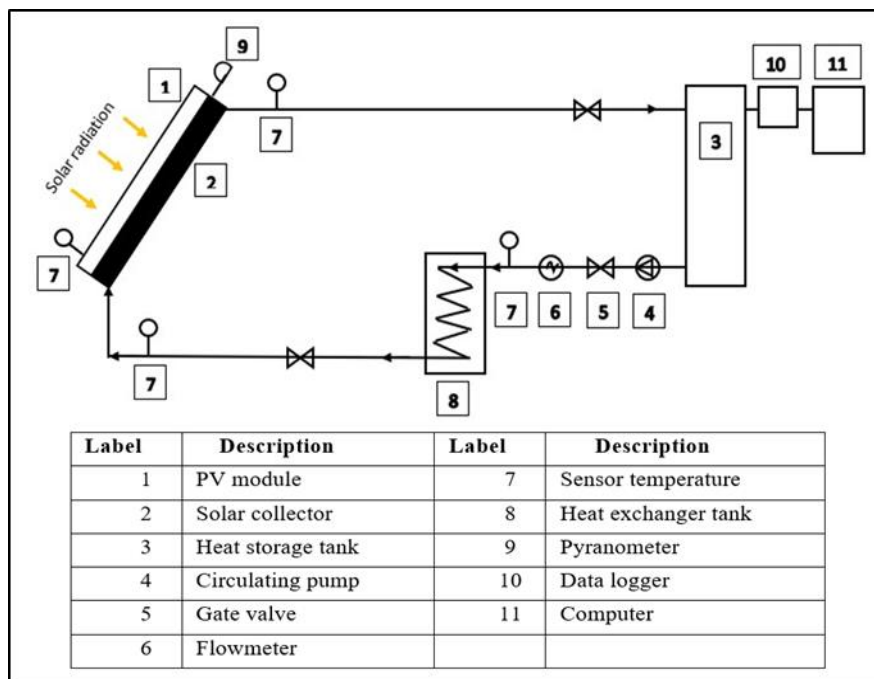


Fig. 3. Schematic of a PV/T Collector

3. Methodology

A Simulink by using Matlab conducted to evaluate the PV/T performance. The mathematical model has been developed based on the new configurations of the serpen-direct flow absorber design of PV/T collector that shown in Figure 2. In accordance with the layers of the PV/T solar collector system displayed in Figure 4, the basic energy balance equation for each component can be written as follows related to the following assumptions.

- i. Neglecting the ohmic losses in the PV module.
- ii. Neglecting the heat capacitance of tedlar, cell and insulation in PV module.
- iii. Neglecting the heat capacity of the PV/T system because it is low value if compared with water storage tank heat capacity.
- iv. The heat conduction in one dimension.
- v. Quasi-steady state for the PV/T system.
- vi. Neglecting the bottom and side collector thermal losses.

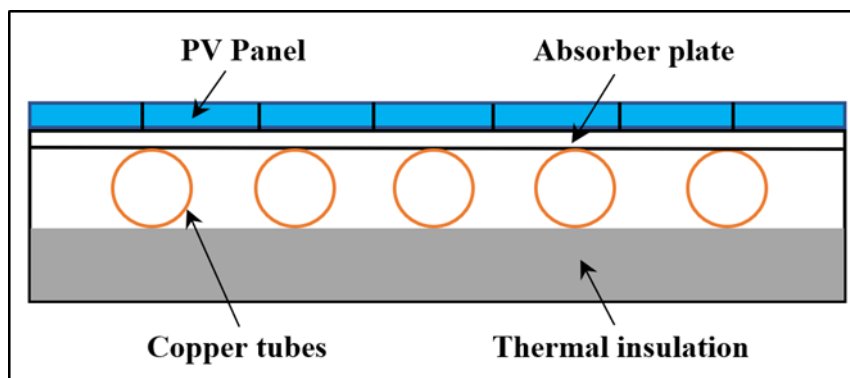


Fig. 4. Cross - sectional view of PV/T system components

4. Thermal Modeling Analysis

4.1 Basic Energy Balance Equations for the PV/T System

4.1.1 For the temperature of a blackened absorber below a PV module [19, 20]

$$\alpha_p(1 - \beta)\tau_g^2 I(t)Wdx + U_{tc,p}(T_c - T_p)Wdx = F'h_{pf}(T_p - T_f)Wdx + U_{tp,a}(T_p - T_a)Wdx \quad (1)$$

Simplify Eq. (1) to derive the plate temperature T_p expression, which can be written as

$$T_p = \frac{(\alpha\tau)_{2,eff}I(t) + PF_1(\alpha\tau)_{1,eff}I(t) + U_{L2}T_a + F'h_{pf}T_f}{U_{L2} + F'h_{pf}} \quad (2)$$

4.1.2 Temperature of water that flows through the absorber below the PV module

The basic energy balance equation of the water flowing through the riser is expressed as [20]

$$F'h_{pf}(T_p - T_f)Wdx = m_f C_f \frac{dT_f}{dx} dx \quad (3)$$

Using Eq. (2) and (3) and after simplifying them with initial conditions at $T_{f,x=0} = T_{fi}$ and at $T_{f,x=L} = T_{fo}$ the outlet water temperature can be rewritten as

$$(T_{fo}) = \left[\frac{PF_2(\alpha\tau)_{m,eff}I(t)}{U_{L,m}} + T_a \right] \times \left[1 - \exp\left(-\frac{A_m U_{L,m} F'}{m_f C_f}\right) \right] + T_{fi} \exp\left(-\frac{A_m U_{L,m} F'}{m_f C_f}\right) \quad (4)$$

The basic energy balanced equation for the average water temperature is

$$\bar{T}_f = \frac{1}{L} \int_{x=0}^L T_f(x) dx \quad (5)$$

4.1.3 For the solar cell in the PV module [11,12]

$$\alpha_c \tau_g \beta I(t)Wdx = [U_{tc,a}(T_c - T_a) + U_{tc,p}(T_c - T_p)]Wdx + \eta_c \tau_g \beta I(t)Wdx \quad (6)$$

Simplify Eq. (6) to obtain the following solar cell temperature expression.

$$T_c = \frac{(\alpha\tau)_{1,eff}I(t) + U_{tc,a}T_a + U_{tc,p}T_p}{U_{tc,a} + U_{tc,p}} \quad (7)$$

4.2 Thermal Performance of the PV/T Collector

The output thermal efficiency of the PV/T system can be referred as the ratio of useful energy gain, Q_u , over the solar radiation, $I(t)$ at the same time period [21, 22].

$$\eta_{thermal} = \frac{\int Q_u dt}{A_c \int I(t) dt} \quad (8)$$

where, Q_u is the useful energy gain and difference between the incident solairradiance and collector losses, which can be expressed as follows [21-23].

$$Q_u = A_c F_r [(\alpha\tau)_n \cdot I(t) - U_L(T_{fi} - T_a)] \quad (9)$$

where F_r , is the collector removal factor and can be calculated as [18, 23].

$$F_r = \frac{m_f C_f}{A_c U_L} \times \left[1 - \exp\left(-\frac{A_c U_L F' t}{m_f C_f}\right) \right] \quad (10)$$

4.3 PV Performance of the PV/T Collector

The PV cell performance of the PV/T collector mainly depends on the cell temperature T_{cell} , that shown in the following expression [24, 25].

$$\eta_{cell} = \eta_c [1 - 0.0045(T_c - T_{ref})] \quad (11)$$

where T_{ref} is the temperature reference set.

4.4 Modelling Development of the PV/T System for the New Serpen-Direct Flow Absorber Design

Figure 2 exhibits that the combined configurations of the tubes in the new design serpen-direct (serpentine and direct tubes) led to modifying the collector area of serpen-direct absorber design, it is obvious that the area of collector is an important factor in equations of heat removal factor and useful heat gain as shown in Eq. (9), (10), so the equations of Q_u , F_r have been modified related to area calculation modified, thereby indicating that the collector area is an important parameter in calculations of PV/T performance. Sopian *et al.*, [14] calculated the collector area for different absorber designs as follows:

$$A_{c-serpentine} = L \times W \times NS \quad (12)$$

$$A_{c-direct} = L \times W \quad (13)$$

where L is the collector length, W is the collector width and NS is the number of tube segments in the serpentine configuration.

4.4.1 Heat removal factor for serpentine-direct absorber design

F_r will be calculated as

$$F_{r-serpentine} = \frac{m_f C_f}{A_{c-serpentine} U_L} \times \left[1 - \exp\left(-\frac{A_{c-serpentine} U_L F' t}{m_f C_f}\right) \right] \quad (14)$$

$$F_{r-direct} = \frac{m_f C_f}{A_{c-direct} U_L} \times \left[1 - \exp\left(-\frac{A_{c-direct} U_L F' t}{m_f C_f}\right) \right] \quad (15)$$

4.4.2 Useful heat gain for serpentine-direct absorber design

Useful heat gain can be written as

$$Q_{u-serpentine} = A_{c-serpentine} F_{r-serpentine} [(\alpha\tau)_n \cdot I(t) - U_L(T_{fi} - T_a)] \quad (16)$$

$$Q_{u-direct} = A_{c-direct} F_{r-direct} [(\alpha\tau)_n \cdot I(t) - U_L(T_{fi} - T_a)] \quad (17)$$

For Serpen-direct design absorber Q_u will be expressed as

$$Q_{u-serpen-direct} = Q_{u-serpentine} + Q_{u-direct} \quad (18)$$

4.4.3 Thermal performance for serpentine-direct absorber design

The thermal performance of PV/T serpen-direct flow absorber design can be calculated as

$$\eta_{thermal, Serpin-Direct} = \frac{\int Q_{u-serpen-direct} dt}{A_c \int I(t) dt} \quad (19)$$

5. Results and Discussions

This section presents the results of the study of the PV/T performance of the serpen-direct and serpentine flow absorber designs under various operating conditions for extensive mass flow rate and solar irradiance on the outlet water temperature, PV cell temperature and thermal and PV efficiencies for both designs are demonstrated. Also, the validation for the new model of serpen-direct absorber design have been done in the following section.

5.1 Model Validation

The data collected from the previous research [26] as shown in Table 2 in order to validate the new PV/T absorber design. There are two comparisons in this validation, first was compared the previous simulation results with the author simulation results (present work) in term of electrical efficiency by using the same input data and parameters condition with PV/T serpentine absorber design of the previous study [26] in order to validate the Matlab Simulink code of the present work. Second, was compared the experimental results of the previous study of PV/T serpentine absorber design with the simulation results of the present work of the serpen-direct absorber design in term of electrical efficiency, based on the data and the parameters condition of the previous study.

Figure 5 illustrate the difference of the electrical efficiency between the previous simulation results and the author simulation results not exceed 6.1% and the lowest percentage difference was 0.2% and root mean square is only 1.45%, that approved a good agreement with the results in the previous comparative study [26].

Figure 6 indicates to the comparability of the electrical efficiency between the experimental results of PV/T serpentine absorber design in the previous research and the simulation results of PV/T serpen-direct absorber design in the present work based on the same data and parameters condition that collected from the previous comparative research. It is obvious that the results of serpen-direct absorber design provide electrical efficiency a better than serpentine absorber design. The higher

difference has been achieved at the value of the term $(T_i - T_a)/G$ was $0.013 \text{ k.m}^2/\text{W}$ was obtained 14.5% and 13.3% for the serpen-direct and serpentine absorber designs, correspondingly.

Table 2

PV/T specifications [26]

Parameters	Values (unit)	Parameters	Values (unit)
Collector area	1.626 m ²	PV reference efficiency	15.67
Water fluid thermal conductivity	0.613 W/m °C	Solar cell size	0.156 x 0.156 m
Specific heat of water	4180 J/kg °C	I_{sc}	8.89 A
Absorber material	Aluminium	V_{oc}	37.77 V
Tubes material	copper	I_{max}	8.37 A
Absorber thermal conductivity	202.4 W/m °C	V_{max}	30.47 V
PV module type	Polycrystalline	Max power PV	225 W
PV size	1640x992x40 mm		

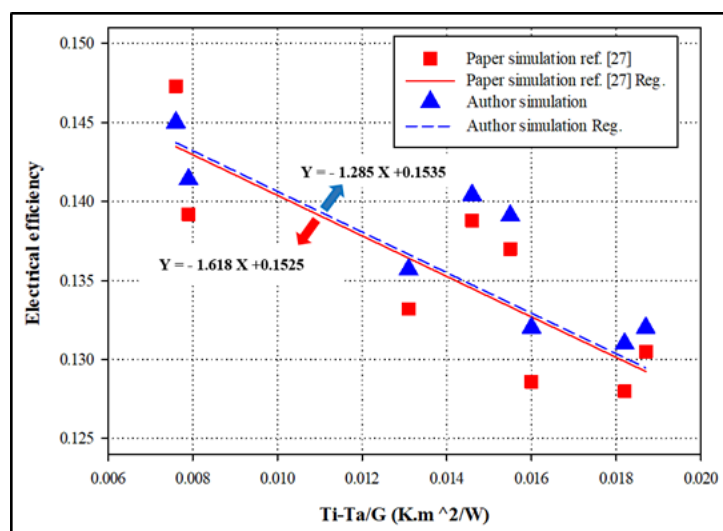


Fig. 5. Comparison of simulation results of electrical efficiency according to the reduced temperature between the previous study and the Author work

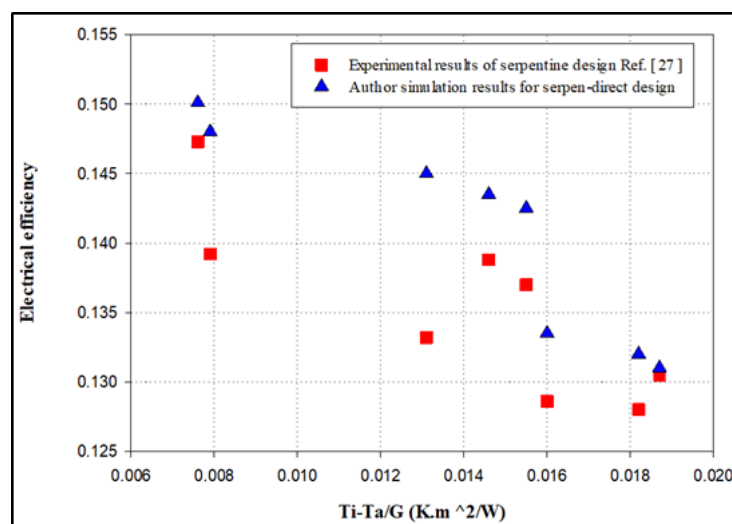


Fig. 6. Comparison of simulation results of electrical efficiency for author design according to the reduced temperature with experimental results of previous study design

5.2 Effects of Mass Flow Rate and Solar Irradiance on the Solar Cell Temperature of the PV/T System

Figures 7 and 8 illustrate the numerical data of the temperature of the PV/T solar cells at solar irradiance that ranges from 300 W/m^2 to 700 W/m^2 and water mass flow rate that ranges from 0.01 kg/s to 0.1 kg/s for the serpentine and serpen-direct flow designs. The results show that the temperature of the solar cell of the PV/T changes in accordance with solar irradiance and water mass flow rate for both collector designs.

Figure 7 displays that the temperature of the solar cell for the serpentine flow design decreases with the increase in mass flow rate for all values of solar irradiance. For example, the temperature reaches $35.4 \text{ }^\circ\text{C}$ at a mass flow rate of 0.012 kg/s for water and solar irradiance of 300 W/m^2 . The temperature of the solar cell decreases to $34.7 \text{ }^\circ\text{C}$ with the increase in the water mass flow rate to 0.056 kg/s and at solar irradiance of 300 W/m^2 . Alternatively, for the serpen-direct flow design depicted in Figure 7, the temperature of the solar cell decreases from $34.48 \text{ }^\circ\text{C}$ to $34.20 \text{ }^\circ\text{C}$ at solar irradiance of 300 W/m^2 for the water mass flow rates of $0.012\text{--}0.056 \text{ kg/s}$.

Figure 8 illustrates the variation in solar cell temperatures with water mass flow rates at solar irradiance of 700 W/m^2 for both designs. This figure demonstrates that the solar cell temperature is higher for the serpentine flow design than for the serpen-direct flow at any water mass flow rate. Specifically, temperatures reach $41.2 \text{ }^\circ\text{C}$ and $40.15 \text{ }^\circ\text{C}$ for the serpentine and serpen-direct flow designs, correspondingly, at a mass flow rate of 0.012 kg/s .

From the above, hence the higher mass flow rate led to lower cell temperature, due to higher the volume of water involved in the heat transfer between the PV module and the water inside the tubes, that resulting to Cooling the surface of PV module [10].

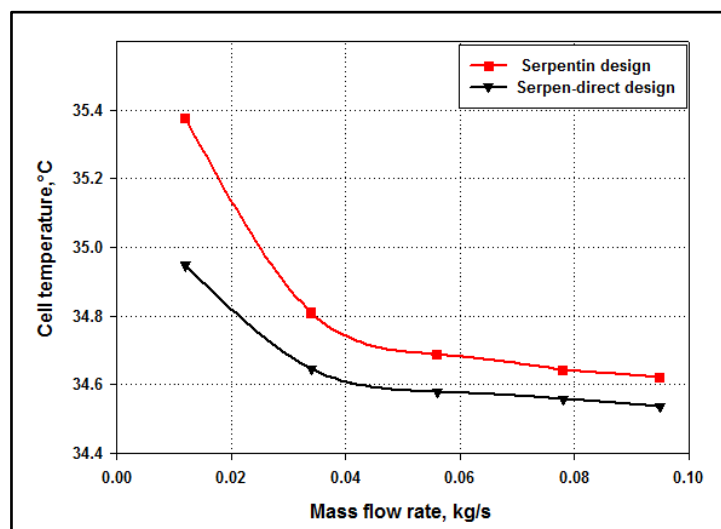


Fig. 7. Variation in cell temperatures with water mass flow rates at solar irradiance of 300 W/m^2

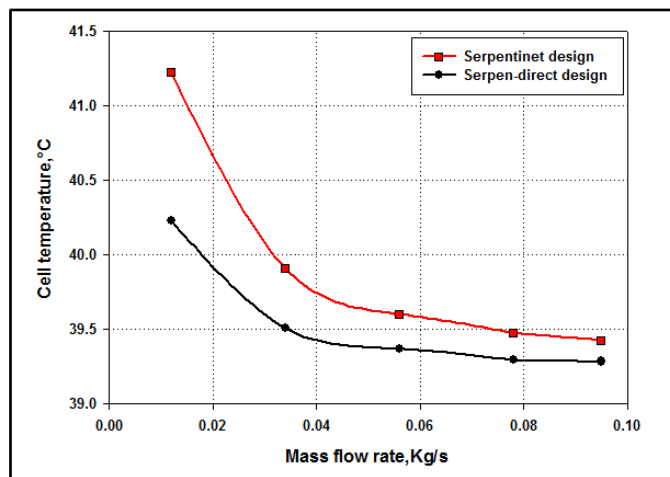


Fig. 8. Variation in cell temperatures with water mass flow rates at solar irradiance of 700 W/m^2

5.3 Effects of Mass Flow Rate and Solar irradiance on the Temperature of the Outlet Water of the PV/T System

Figures 9 and 10 display the changes in the temperature of the outlet water of the serpen-direct and serpentine flow designs against the mass flow rate variation for the constant solar irradiance of 300 W/m^2 and 700 W/m^2 , respectively. The temperatures of the outlet water of the serpen-direct and serpentine flow designs decrease with the increase in the water mass flow rate. Figure 9 exhibits that the temperatures of the outlet water are $35 \text{ }^\circ\text{C}$ and $34.58 \text{ }^\circ\text{C}$ for the serpentine and serpen-direct flow designs, correspondingly, at a mass flow rate of 0.012 kg/s and solar irradiance of 300 W/m^2 . Furthermore, the temperatures reach $34.3 \text{ }^\circ\text{C}$ and $34.2 \text{ }^\circ\text{C}$ for the serpentine and serpen-direct flow designs, respectively, at the water mass flow rate of 0.058 kg/s and solar irradiance of 300 W/m^2 . Moreover, the increment in the water mass flow rate from 0.03 kg/s to 0.057 kg/s has a decreasing effect on the outlet water temperature at $0.7 \text{ }^\circ\text{C}$ and $0.38 \text{ }^\circ\text{C}$ for the serpentine and serpen-direct flow designs, correspondingly.

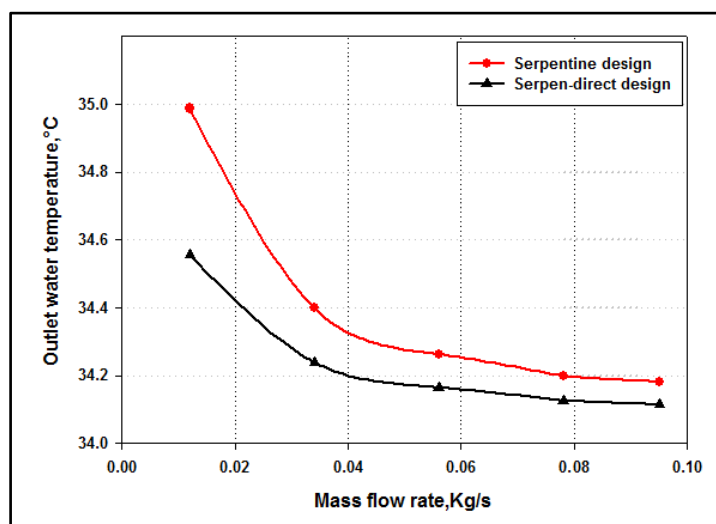


Fig. 9. Variation in outlet water temperature with water mass flow rates at solar irradiance of 300 W/m^2

Figure 10 depicts the temperatures of 40.4 °C and 39.38 °C for the serpentine and serpen-direct flow designs, respectively, at solar irradiance of 700 W/m² and a mass flow rate of 0.012 kg/s. Finally, the temperatures of the outlet water at a mass flow rate of 0.58 kg/s are 38.5 °C and 38.2 °C for the serpentine and serpen-direct flow designs, correspondingly, at solar irradiance of 700 W/m².

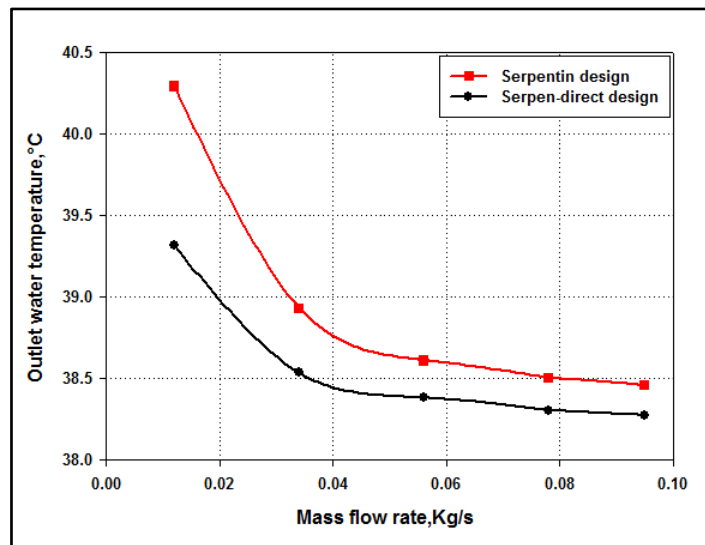


Fig. 10. Variation in outlet water temperature with water mass flow rates at solar irradiance of 700 W/m²

5.4 Effects of Mass Flow Rate and Solar Irradiance on Thermal Efficiency of the PV/T System

The water mass flow rate significantly affects the thermal efficiency and overall PV/T performance. In this section, the influence of diverse water mass flow rates on the thermal efficiency of the serpen-direct and serpentine flow designs is discussed. Figure 11 demonstrates the variation in the thermal efficiency for both designs against the increment in the water mass flow rate at solar irradiance of 700 W/m². The thermal efficiencies of the serpen-direct and serpentine flow designs escalate with the increase in mass flow rate given the proportional relationship between the water mass flow rate and thermal efficiency, as exhibited in Eq. (8) and (9).

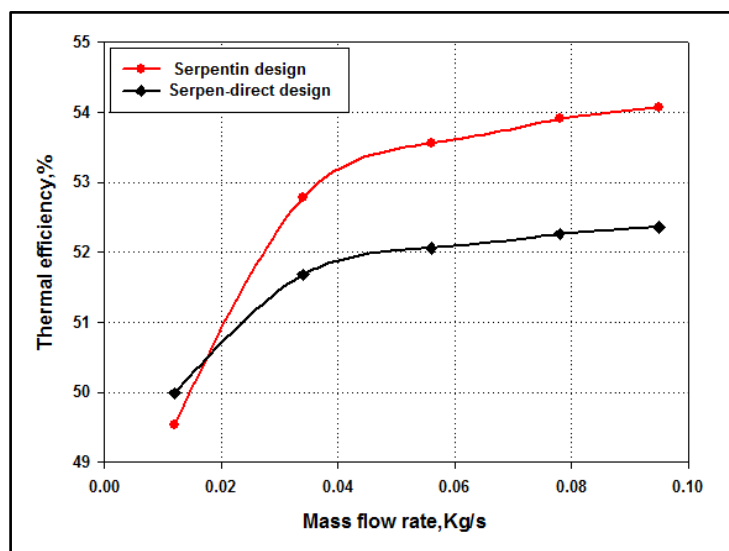


Fig. 11. Variation in thermal efficiency with water mass flow rates at solar irradiance of 700 W/m²

The thermal efficiencies of the serpen-direct and serpentine flow designs are 50% and 49.8%, correspondingly, at a mass flow rate of 0.012 kg/s and solar irradiance of 700 W/m². In addition, if the mass flow rate increases to 0.058 kg/s, then the thermal efficiency will be increased for the serpen-direct and serpentine flow designs at 52.5% and 53.5%, respectively. Therefore, the thermal efficiency is higher in the serpentine flow design than in the serpen-direct flow design at a mass flow rate that is higher than 0.012 kg/s.

5.5 Effects of Mass Flow Rate and Solar Irradiance on the PV Cell Efficiency of the PV/T System

Section 5.2 discussed the effects of water mass flow rate on the PV solar cell temperature. The temperature of the solar cell decreases with the mass flow rate. This effect on the temperature of the solar cell will influence the PV cell efficiency. Considering that the PV module is in contact with the serpentine collector plate, the effect of the water mass flow rate occurs on the collector plate and thus on the temperature of the solar cell. Furthermore, the effect of the temperature of the solar cell is related to the PV cell efficiency of the PV/T in accordance with Eq. 11.

Figure 12 illustrates the PV cell efficiency at water mass flow rates at solar irradiance of 300 W/m². The results demonstrate that the PV cell efficiencies for both designs increase with the water mass flow rate. The PV cell efficiency reaches 14.76% and 14.7% for the serpen-direct and serpentine flow designs, respectively, at a water mass flow rate of 0.012 kg/s and solar irradiance of 300 W/m². Additionally, if the water mass flow rate increased from 0.012 kg/s to 0.058 kg/s, then the PV/T system performance in terms of the PV cell efficiency reaches 14.77% and 14.75% for the serpen-direct and serpentine flow designs, correspondingly, at solar irradiance of 300 W/m².

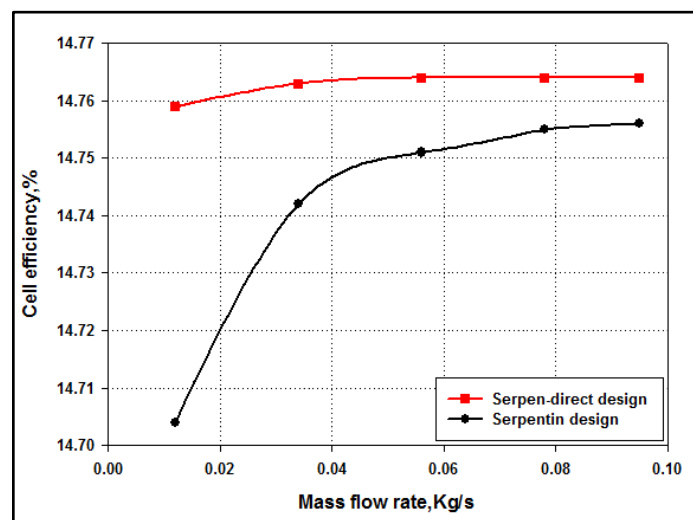


Fig. 12. Variation in the cell efficiency with water mass flow rates at solar irradiance of 300 W/m²

In Figure 13, the PV cell efficiencies reach 14.44% and 14.31% for the serpen-direct and serpentine flow designs, respectively, at a water mass flow rate of 0.012 kg/s and solar irradiance of 700 W/m². Moreover, the escalation of the water mass flow rate to 0.058 kg/s causes an increment in the PV cell efficiencies of 14.45% and 14.42% for the serpen-direct and serpentine flow designs, correspondingly, at solar irradiance of 700 W/m². In summary, the PV cell efficiency is higher in the serpen-direct flow design than in the serpentine flow design under the same operating conditions, such as water mass flow rate and solar irradiance.

From the above It is obvious that the cell efficiency drops with higher solar irradiance. That due to higher cell temperature obtained with higher solar irradiance as shown in Figures 7 and 8, the higher cell temperature led to drops in cell efficiency in accordance with Eq. (11).

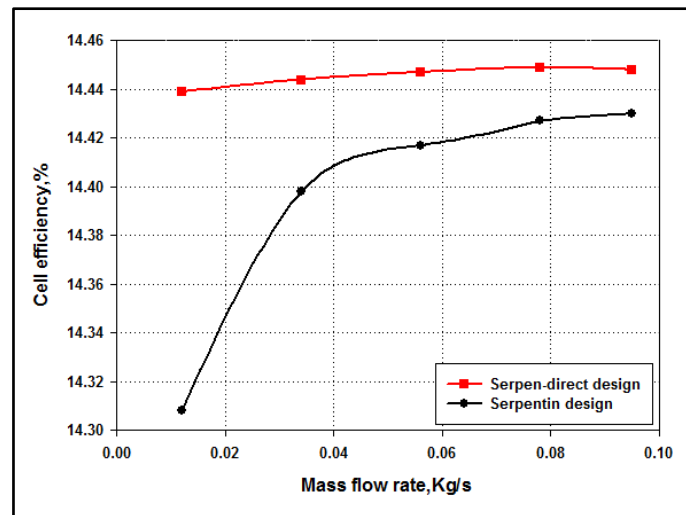


Fig. 13. Variation in the cell efficiency with water mass flow rates at solar irradiance of 700 W/m^2

6. Conclusions

The performance of two PV/T systems based on different absorber designs was determined, and a comparative study of the system performance between the serpen-direct and conventional serpentine flow designs was conducted. The results showed that the increment in water mass flow rate can enhance the PV/T collector performance for both designs in terms of PV cell and thermal efficiencies under various rates of solar irradiance. The PV/T performance increased with the water mass flow rate given the increase in cooling of the PV module. The maximum PV cell efficiencies are 14.8% and 14.7% for the serpen-direct and serpentine flows, respectively, at a water mass flow rate of 0.012 kg/s and solar irradiance of 300 W/m^2 . Therefore, the PV/T performances in terms of thermal efficiency are 52.5% and 53.5% for the serpen-direct and serpentine flow designs, correspondingly. These findings indicate that the serpen-direct flow design performs better than the conventional serpentine absorber flow design in the PV/T system.

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