

# Numerical Performance Investigation of Hybrid PV/Thermal System

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## Abstract

Promoting reduction of PV temperature plays crucial role in increasing electrical performance. The present work deal with different types of absorber shape for analysing heat transfer phenomena. Serpentine and spiral absorber are using to verify this purpose with different boundary conditions of inlet mass flow rate and inlet temperatures. The recent study was conducted to evaluate the effect of some operating and designing parameters such as solar radiation levels, flow rates, absorber shape and cooling water temperature on the performance of PVT system numerically. Performance of PVT system determined by thermal efficiency, electrical efficiency and the summation of both known as total or PVT efficiency. Solar radiation ranging from 500 W/m<sup>2</sup> to 1000 W/m<sup>2</sup> was introduced and at each, flow rates of water ranging from 0.016 kg/s to 0.05 kg/s. The results show that the performance of PVT increases with a flow rate at all radiation levels. Also the spiral flow absorber gives a higher performance than serpentine absorber where the value of  $F_R$  of spiral absorber is increased by about 5.2% compared to the value of serpentine absorber, on the other hand, the rate of heat loss ( $U_L$ ) decreased by about 10%. Increasing initial cooling water temperature degrades electrical efficiency of PVT system.

**Keywords:** photovoltaic thermal collector, Hybrid PV/T collector, electrical performance; thermal performance, Numerical Study.

## 1. Introduction

Photovoltaic is a device that converts light (usually solar radiation) directly into electrical energy using semi-conductive materials that exhibit the photovoltaic effect. Most commercial photovoltaic cells convert less than 20% of the solar radiation falling on them into an electrical energy output depending on the type of technology and the environmental parameters, and the rest of the solar radiation (more than 80%) reflected or absorbed by the solar panel [1].

High electrical output can be obtained from a PV panel by increasing the amount of solar radiation falling on it, which at the same time increase the amount of energy absorbed and thus increase the temperature of the solar panel and this reduces their efficiency [3].

Where the temperature of the solar panel in the sunny days can reach as high as 35°C above ambient temperature [2].

Therefore Photovoltaic cells must be cooled to improve their efficiency and this is done by connecting them with thermal absorber adhesive on the back side this unit is known as PV/Thermal system so it can produce electrical power and at the same time, hot water or air [3].

Many researchers were interested in studying PV/Thermal system, M. Boubekri et al 2009 [4] developed a numerical study aimed to investigate the effect of collector inclination angle and rates flow of water on the thermal and electrical performances of hybrid PV/T water collector. The results showed that as the tilt angle increase, the electrical power output decreased. Also the cells temperature will decrease with increasing in flow rates of water, and it results an increase in the maximum power from it.

Anderson TN et al,2009[5] Theoretically and experimentally investigate the performance of PV/thermal system. Theoretical analyses were based on a modified Hottel–Whillier model. The results showed that the design parameters significantly effecting the electrical and thermal efficiency of the PV/T system.

Hongbing Chena et al,2011[6] conducted an experimental study on a hybrid micro PV panel-based heat pump system. Because of having a low evaporating temperature, R134a refrigerant was used to cool the PV modules in order to achieve better electrical performance of the PV modules than using air and water working fluids. The results show an improvement in electrical efficiency of PV panel reaches up to 1.9% when cooling with heat pump w used.

A. Fudholi et al,2014[7] Investigated the performance of PV/Thermal water system. Solar radiation levels of 500–800 W/m<sup>2</sup> and a flow rates ranging from 0.011 kg/s to 0.041 kg/s were used. The results show that, the spiral absorber offered the highest performance among the absorbers used, where a PVT efficiency of 68.4%, a PV efficiency of 13.8%, and a thermal efficiency of 54.6% were produced at flow rate 0.041 kg/s and 800 W/m<sup>2</sup> irradiance.

Amna A. Alzaabi et al,2014[8] Experimentally investigates the performance of Water Hybrid Photovoltaic Thermal (PV/T) system (electrically and thermally) under the meteorological conditions of SHARJAH, UAE. The results shows increasing in electrical power output reaches 15 to 20 % when cooling is used, also from 60% to 70% thermal efficiency were achieved.

A. A. Ghoneim and A. M. Mohammedin, 2016[9] Theoretically and experimentally investigate the performance PV/T in Kuwait climate. A Hybrid PVT solar system with hot water storage tank simulation model was developed by TRNSYS. The results showed that the combined PVT collector gives a higher production than the individual PV and solar collector of the same aperture area,

and the PVT with monocrystalline silicon cells obtains the highest energy production. radiation levels, flow rates, absorber shape and initial water temperature on the performance of PVT system.

## 2. Mathematical Modeling

### 2.1 System Description

The system under study consists of a conventional PV module, which is made of polycrystalline silicon cells. At the back, a metal plate is welded to form the absorber plate. In order to exploit the absorbent thermal energy, water is recycled through a tube. The absorber then covered with a thermal insulator to prevent the heat from escaping. Two shapes of absorber were used named as: spiral flow and serpentine flow. Each of them made of a round copper tube with a length 5.9m and a diameter 0.01m, as shown in Fig.1

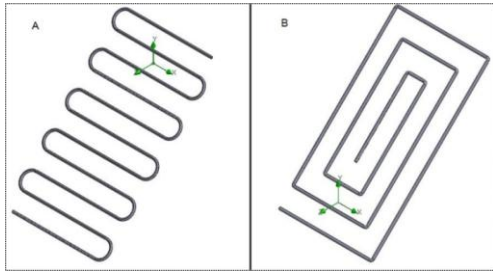


Fig. 1: (A) serpentine absorber, (B) spiral absorber

### 2.2 Energy Transfer Phenomina

In this section , the equations of energy transfer in the various parts of the system were developed.

❖ The energy transfer from the sky to the outer glass surface is given by [4]

$$l_g \rho_g \frac{C_{Pg}}{2} \frac{\partial T_{go}}{\partial t} = \frac{l \alpha_g}{2} + h_{r,g-sky} (T_{sky} - T_{go}) + h_w (T_a - T_{go}) + h_{c,g} (T_{gi} - T_{go})$$

$T_{sky}$  ,  $T_a$  are temperatures of sky and ambient air respectively,  $T_{gi}$  ,  $T_{go}$  the inner and outer surface glass temperatures.

The coefficient heat transfer by radiation ( $h_{r,g-s}$ ) between glass cover and sky given by[10]:

$$h_{r,g-s} = \sigma \epsilon_g (T_{go}^2 + T_{sky}^2) (T_{go} + T_{sky})$$

The wind forced convection heat transfer coefficient ( $h_w$ ) is given by [11]

$$h_w = 2.8 + 3.0 V_w$$

$V_w$  is wind velocity (m/s)

The sky temperatures is given by[12]

$$T_{sky} = 0.037536 T_a^{1.5} + 0.32 T_a$$

$h_{c,g}$  is the heat transfer coefficient by conduction in the glass cover.

❖ The energy then flow to inner surface of glass [4]

$$l_g \rho_g \frac{C_{Pg}}{2} \frac{\partial T_{gi}}{\partial t} = \frac{l \alpha_g}{2} + (h_{PV-g} + h_{r,PV-g}) (T_{PV} - T_{gi}) + h_{c,g} (T_{go} - T_{gi})$$

$h_{PV-g}$ ,  $h_{r,PV-g}$  are the heat transfer coefficients by convection and radiation respectively between the glass and PV panel.

$h_{PV-g}$  is given by:

$$h_{PV-g} = \frac{Nu K_{air}}{b}$$

This study is aimed to numerically evaluation the effect of some operating and designing parameters such as solar Where  $K_{air}$  is the thermal conductivity of the air and  $b$  is distance from the glass to PV panel.  $Nu$  is the ‘‘Nusselt number’’, and is can be calculated from the following correlations [13]

$$G_r < 1700 + 47.8 \theta N_u = 1.013$$

$$G_r > 80000 N_u = 2.5 + 0.0133(90 - \theta)$$

Otherwise

$$N_u = [0.06 + 3.1^{-4}(90 - \theta)] G_r^{0.33}$$

$\theta$  The tilt angle of the collector,  $G_r$ : is the Grashof number defined by:

$$G_r = \frac{g \beta \Delta T b^3}{\nu^2}$$

Where  $g$  is gravitational acceleration,  $m/s^2$ ,  $\nu$  is kinematic viscosity of the fluid,  $m^2/s$ .

❖ Energy transfer in PV module is given by [4]

$$l_{PV} \rho_{PV} C_{PPV} \frac{\partial T_{PV}}{\partial t} = I(\alpha \tau)_{PV} - \dot{W}_{el} + h_{c,P-PV} (T_P - T_{PV}) + (h_{PV-P} + h_{r,PV-P}) (T_{gi} - T_{PV})$$

Where,  $\dot{W}_{el}$  is the output electrical power of PV panel and it depends on the temperature of the cells  $T_{PV}$  and can be calculated from [14].

$$\dot{W}_{el} = I P \tau_g \eta_o [1 - \varphi(T_{PV} - 25)]$$

Where,  $\eta_o$ ,  $\varphi$ , are the reference efficiency, temperature coefficient and packing factor respectively.

$h_{c,P-PV}$  Is the coefficient of conduction heat transfer through the adhesive layer.

❖ In plate absorber the energy flow is given as [4]

$$l_P \rho_P C_{P,P} \frac{\partial T_P}{\partial t} = h_{c,P-PV} (T_{PV} - T_P) + \frac{A_{pt}}{A_p} h_{c,P-t} (T_t - T_P)$$

$h_{c,P-t}$  : Conduction heat transfer coefficients between plate absorber and tubes.

❖ From the plate absorber ,energy is transferred to tubes [4]

$$l_t \rho_t C_{P,t} \frac{\partial T_t}{\partial t} = \frac{A_{pt}}{A_p} h_{c,P-t} (T_P - T_t) + \frac{A_f}{A_t} h_{t-f} (T_f - T_t) + \frac{A_{is}}{A_t} h_{c,is-t} (T_{is,i} - T_t)$$

$h_{t-f}$  is the coefficients of tubes to fluid convective heat transfer,  $A_f$  is the tube to fluid contact surface and  $A_{is}$  is the insulation surface.

$h_{t-f}$  can be calculated from [15]:

• Fully developed laminar flow ( $Re < 2300$ )

$Nu = 3.66$  for  $T_{sur}$  constant

$Nu = 4.36$  for  $\dot{q}_{sur}$  constant

Where  $T_{sur}$ ,  $\dot{q}_{sur}$  the surface pipe temperature and heat flux respectively.

• Turbulent flow ( $3000 < Re < 5 \times 10^6$ ) Nusselt number can be calculated using[15]

$$\left( \frac{f}{8} \right) (Re - 1000) Pr$$

$$Nu = \frac{1}{1 + 12.7 \left( \frac{f}{8} \right)^{0.5} (Pr^{0.666} - 1)}$$

$h_{t-f}$  can then be calculated from:

$$h_{t-f} = \frac{Nu K_w}{D_t}$$

❖ The energy transfer in fluid as [4]

$$\dot{m}C_{p,f}(T_f - T_f^*) = A_t h_{t-f}(T_t - T_f) + A_{isf} h_{is-f}(T_{is,i} - T_f)$$

With  $h_{i-f}$  is the coefficient of fluid\_insulation convective heat transfer,  $T_f^*$  the temperature of at the previous section,  $A_{isf}$  the imaginary surface of the fluid flow on insulation.

❖ From fluid to the inside insulation surface [4]

$$l_{is}\rho_{is} \frac{C_{p,is}}{2} \frac{\partial T_{is,i}}{\partial t} = \frac{A_{if}}{A_{is}} h_{is-f}(T_f - T_{is,i}) + h_{c,is}(T_{is,o} - T_{is,i}) + \frac{A_t}{A_{is}} h_{c,is-t}(T_t - T_{is,i})$$

❖ From inside to outside surfaces of insulation [4]

$$l_{is}\rho_{is} \frac{C_{p,is}}{2} \frac{\partial T_{is,o}}{\partial t} = h_{r,is-sky}(T_{sky} - T_{is,o}) + h_{c,is}(T_{is,i} - T_{is,o}) + h_w(T_a - T_{is,o})$$

### 2-3 Performance of PV/T system

The thermal efficiency of the system is given by

$$\eta_{th} = \frac{Q_u}{I}$$

The heat gained by the fluid is given by:

$$Q_u = \dot{m}C_p(T_o - T_i)$$

The Hottel–Whillier defines the difference between the absorber solar radiation and thermal heat losses [16]

$$Q_u = A_c F_R [I_T(\tau\alpha)_{PV} - U_i(T_i - T_a)]$$

$I_T$  is the solar radiation at Normal Operating Cell Temperature.

$F_R$  is the collector heat removal factor and is given by [17]:

$$F_R = \frac{\dot{m}C_p}{A_c U_L} \left[ 1 - \exp\left(-\frac{A_c U_L F'}{\dot{m}C_p}\right) \right]$$

where  $F'$  is a constant which refers to the collector efficiency factor [17].

$$F' = \left[ \frac{\frac{1}{U_L}}{U_L(D_h + (W - D_h)F)} \right] + \frac{1}{C_b} + \frac{1}{2(a + b)h_{fi}}$$

The overall loss coefficient ( $U_L$ ) of the collector is the sum of the edge ( $U_e$ ) and top ( $U_t$ ) loss coefficients, and can be expressed [16] as:

$$U_L = U_e + U_t$$

$$U_e = \frac{K_e P l}{L_e A_c}$$

$$U_t =$$

$$= \left\{ \frac{N}{\frac{C}{T_{pm}} \left[ \frac{T_{pm} - T_a}{(N+f)} \right]^e h_w} \right\}^{-1} + \frac{\sigma(T_{pm} + T_a)(T_{pm}^2 + T_a^2)}{(\varepsilon_p + 0.00591N h_w)^{-1} + \frac{2N+f-1+0.133\varepsilon_p}{\varepsilon_g} - N}$$

Where

$$C = 520(1 - 0.000051\theta^2)$$

$$f = (1 + 0.089h_w - 0.1166h_w\varepsilon_p)(1 + 0.07866N)$$

$$e = 0.43\left(1 - \frac{100}{T_{pm}}\right)$$

$$T_{pm} = T_i + \frac{Q/A_c}{F_R U_L} (1 - F_R)$$

PV module electrical efficiency ( $\eta_{el}$ ) is given by [18]:

$$\eta_{el} = \eta_r(1 - \varphi(T_c - T_r))$$

Where  $\eta_r$  is the reference efficiency of the PV module,  $\varphi$  is a temperature coefficient,  $T_c$  is the cell temperature, and  $T_r$  is the reference temperature.

The total efficiency “or known as PVT efficiency ( $\eta_{PVT}$ )” which is a combination of electrical and thermal efficiencies, is given by [19]

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

The energy-grade difference between electricity and thermal energy is considered as another performance indicator known as the primary energy-saving efficiency ( $\eta_f$ ) and is given by [19]

$$\eta_f = \frac{\eta_{el}}{\eta_p} + \eta_{th}$$

Where  $\eta_p$  is the normal power plant electrical power generation efficiency.

Based on the above mathematical model, a computer program elaborated and developed in MATLAB and the results are given in the next section. The inputs of the program are given in Table 1.

Table 1: Inputs of the simulation model program

Description	Symbol	Value	Unit
Ambient temperature	$T_a$	35	°C
Collector area	$A_c$	0.7	m <sup>2</sup>
Number of glass cover	$N$	1	
Glass emittance	$\varepsilon_g$	0.88	
Plate emittance	$\varepsilon_p$	0.95	
Collector tilt	$\theta$	45	
Thermal conductivity of water	$k_f$	0.613	W/m °C
Specific heat of water	$C_p$	4.18	Kj/kg °C
Conductivity of back insulation	$K_b$	0.045	W/m °C
Thickness of back insulation	$l_b$	0.05	m
Conductivity of edge insulation	$K_e$	0.045	W/m °C
Thickness of edge insulation	$l_e$	0.025	m
Conductivity of absorber insulation	$k_{abs}$	51	W/m °C
Thickness of absorber insulation	$l_{abs}$	0.002	m
PV conductivity	$k_{PV}$	237	W/m °C
PV collector thickness	$l_{PV}$	0.002	m
Transmittance	$\tau$	0.88	
Absorbance	$\alpha$	0.95	
Packing factor	$P$	0.97	
Reference efficiency	$\eta_r$	0.12	K <sup>-1</sup>
Temperature coefficient	$\varphi$	0.0045	m/sec
Wind speed	$v$	2	W/m <sup>2</sup> · K <sup>4</sup>
Stefan–Boltzmann constant	$\sigma$	5.67 × 10 <sup>-8</sup>	
electric-power generation efficiency	$\eta_p$	0.38	

### 3. Results

Figs. 2–6 and simplified in Tables 2 show the effect of water rates flow on the performance of PVT system for different solar radiation levels. Solar radiation ranging from 500 W/m<sup>2</sup> to 1000 W/m<sup>2</sup> was introduced and at each, flow rates of water ranging from 0.016 kg/s to 0.05 kg/s.

We can observe from Fig. 2 that by increasing the flow rate, the temperature of PV will drop for solar radiation levels, also for constant flow, the PV temperatures increase with radiation. The temperature of PV decreased from 40.76°C to 39.2°C when the flow rate changes from 0.016 kg/sec to 0.05 kg/sec under 500 W/m<sup>2</sup> irradiance, and from 45.15°C to 42.2°C at 1000 W/m<sup>2</sup>.

When the PV temperature changes (increasing or decreasing), the electrical efficiency will be affected accordingly positively or negatively. Fig 3 shows the effect of cooling water flow rate and radiation on electrical efficiency, it can be seen the electrical

efficiency increasing by 0.8% when flow rate increase from 0.016kg/sec to 0.05 kg/sec at 500 W/m<sup>2</sup> radiation level, and increasing by 1.4% at 1000 W/m<sup>2</sup> radiation levels. It can clearly concluded from this figure that when radiation increase, electrical efficiency will decrease .It well means the increasing in solar radiation does not necessarily lead to increase electrical efficiency of PV panel, where higher irradiance leads to increase PV panel temperature which reduced the efficiency although increased radiation results in increased electrical output. Where the efficiency dropped by 1.54% at 0.016kg/sec and by 1.44% at 0.05kg/sec when the radiation increased from 500 W/m<sup>2</sup> to 1000 W/m<sup>2</sup>.

Fig. 4 shows that thermal efficiency increases with increasing flow rate under all solar radiation levels, where thermal efficiency increased from 49.35% at 0.016 kg/sec to 54.54% at 0.05kg/sec under 500W/m<sup>2</sup> and from 55.98% at 0.016kg/sec to 61.23% at 0.05kg/sec under 1000W/m<sup>2</sup> . Also it can be noticed that solar radiation increased thermal efficiency for constant flow rete, at 0.016 kg/sec the efficiency increase from 49.35% to 55.98% when radiation increase from 500 W/m<sup>2</sup> to 1000 W/m<sup>2</sup> , and at 0.05kg/sec it increased from 54.54% to 61.23% .

The overall performance of PVT system is evaluated by PVT efficiency which is the sum of both electrical and thermal efficiencies. As previously shown in Figs 3, 4 that electrical and thermal efficiencies increased with flow rate, so their summation (total efficiency) as well as primary energy saving efficiency will also increase by increasing flow rate, where they increased by 8.7% and 6.8% respectively when flow increase from 0.016 to 0.05 kg/sec at 500 W/m<sup>2</sup> radiation, and by 8% , 6.69% at 1000 W/m<sup>2</sup> radiation.as shown in Figs5,6 and Table 2.

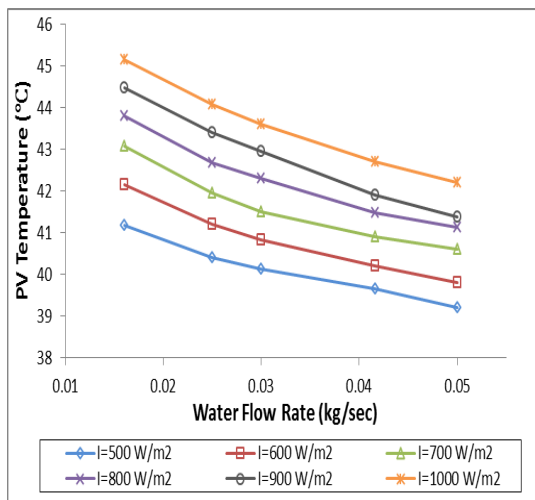


Fig. 2: Changes in PV Temperature with mass flow

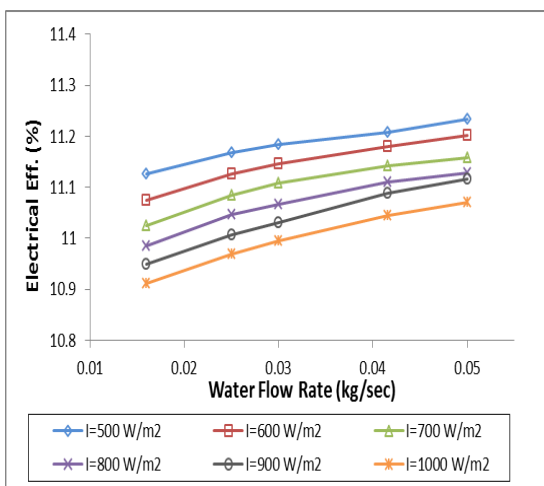


Fig. 3: Changes in electrical efficiency with mass flow

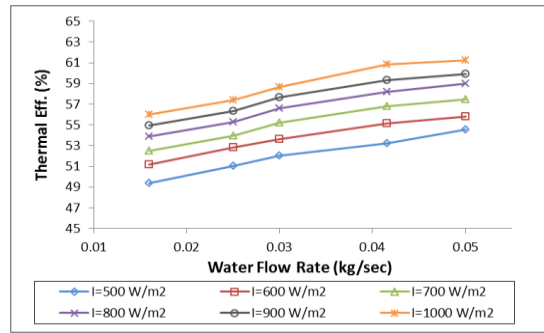


Fig. 4: Changes in thermal efficiency with mass flow

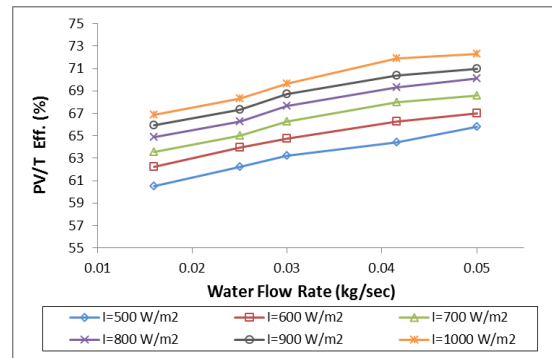


Fig. 5: Changes in total efficiency with mass flow

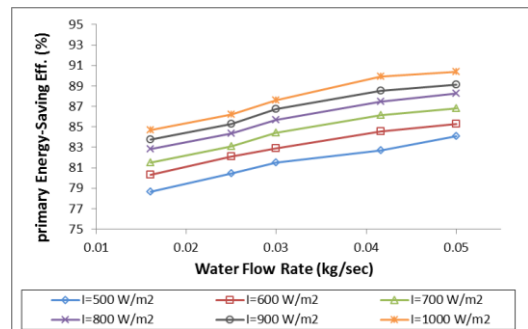


Fig. 6: Changes in primary energy-saving efficiency with mass flow

Table 2: The effecting of flow rates on the performance of PVT system

$\dot{m}$ (kg/sec)	$T_{pv}$ (°C)	I=500 W/m <sup>2</sup>			
		$\eta_{el}$ (%)	$\eta_{th}$ (%)	$\eta_{pv}$ (%)	$\eta_f$ (%)
0.016	40.76	11.14	49.35	60.5	78.69
0.025	40.42	11.16	51.35	62.51	80.73
0.03	40.13	11.18	53.04	64.22	82.47
0.041	39.66	11.2	53.21	64.41	82.7
0.05	39.2	11.23	54.54	65.78	84.11
$\dot{m}$ (kg/sec)	$T_{pv}$ (°C)	I=600 W/m <sup>2</sup>			
		$\eta_{el}$ (%)	$\eta_{th}$ (%)	$\eta_{pv}$ (%)	$\eta_f$ (%)
0.016	42.15	11.07	51.16	62.24	80.31
0.025	41.2	11.13	53.14	64.26	82.42
0.03	40.83	11.15	54.40	65.54	83.73
0.041	40	11.19	55.11	66.30	84.56
0.05	39.4	11.22	55.80	67.03	85.34
$\dot{m}$ (kg/sec)	$T_{pv}$ (°C)	I=700 W/m <sup>2</sup>			
		$\eta_{el}$ (%)	$\eta_{th}$ (%)	$\eta_{pv}$ (%)	$\eta_f$ (%)
0.016	43.07	11.02	53.14	64.17	82.15
0.025	41.95	11.08	55.09	66.17	84.26

0.03	41.5	11.11	56.19	67.30	85.42
0.041					
6	40.9	11.14	57.23	68.38	86.55
0.05	40.6	11.16	57.45	68.61	86.81

$\dot{m}$ (kg/sec)	$T_{pv}(^{\circ}C)$	I=800 W/m <sup>2</sup>		$\eta_{pv}(\%)$	$\eta_r(\%)$
		$\eta_{el}(\%)$	$\eta_{th}(\%)$		
0.016	44.02	10.97	54.17	65.15	83.05
0.025	42.67	11.05	55.25	66.30	84.32
0.03	42	11.08	56.57	67.65	85.73
0.041	41.47	11.11	58.49	69.60	87.73
6	41.13	11.13	59.32	70.45	88.61

$\dot{m}$ (kg/sec)	$T_{pv}(^{\circ}C)$	I=900 W/m <sup>2</sup>		$\eta_{pv}(\%)$	$\eta_r(\%)$
		$\eta_{el}(\%)$	$\eta_{th}(\%)$		
0.016	44.97	10.92	54.98	65.90	83.72
0.025	43.4	11.01	56.12	67.12	85.08
0.03	42.95	11.03	57.68	68.71	86.71
0.041	41.89	11.09	59.12	70.21	88.30
6	8	11.09	59.12	70.21	88.30
0.05	41.37	11.12	59.69	70.81	88.94

$\dot{m}$ (kg/sec)	$T_{pv}(^{\circ}C)$	I=1000 W/m <sup>2</sup>		$\eta_{pv}(\%)$	$\eta_r(\%)$
		$\eta_{el}(\%)$	$\eta_{th}(\%)$		
0.016	45.15	10.91	55.98	66.89	84.69
0.025	44.08	10.97	57.37	68.34	86.24
0.03	43.6	11.00	58.65	69.65	87.59
0.041	42.7	11.04	60.86	71.91	89.93
6	42.2	11.07	61.23	72.30	90.36
0.05					

Fig.7 shows that the PV temperature when spired absorber used is lower than that of serpentine one at all radiation levels. At 500W/m<sup>2</sup> radiation, PV temperature is drooped from 40.13°C to 39.27°C and at 1000 W/m<sup>2</sup>; the temperature is drooped from 43.6°C to 42.86°C when spiral absorber is used. will be higher than that of serpentine absorber. At 500W/m<sup>2</sup> radiation, electrical efficiency is increased by 0.4% and at 1000 W/m<sup>2</sup> it's increased by 0.36%, as shown in Fig.7.

Fig.8 shows that thermal efficiency as well as total and primary energy saving efficiencies of the spiral absorber PVT system is greater than of serpentine absorber of all radiation levels. At 500W/m<sup>2</sup> thermal, total and primary energy saving efficiencies are increased by 4%, 3.3% and 2.8% respectively and at 1000 W/m<sup>2</sup> they are increased by 3.5%, 3% and 2.47% respectively when spiral absorber is used.

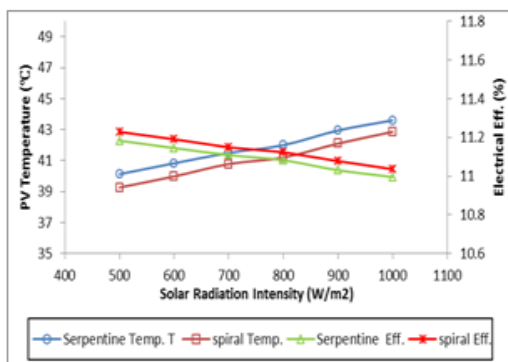


Fig. 7: Changes in PV Temperature and electrical efficiency with solar radiation for different flow absorbers

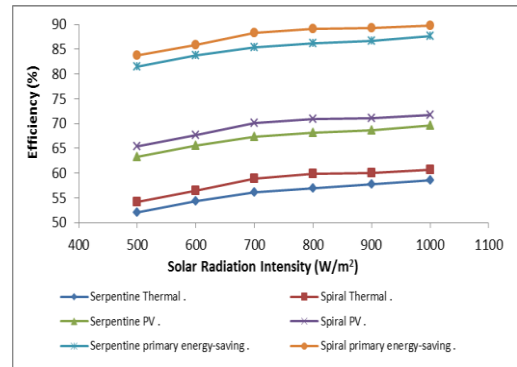


Fig. 8: Changes in thermal, total and primary energy saving efficiencies with solar radiation for different flow absorbers.

Fig.9 shows a comparison of thermal efficiency curves for the spiral and the serpentine absorbers. The lines in this figure represent the equation shown below:

$$\eta_{th} = F_R(\tau\alpha)_{PV} - \frac{F_R U_L(T_i - T_a)}{G}$$

$F_R$  and  $U_L$  can be extracted from the equation of the lines shown in 8 and the values are shown in Table 3. The value of  $F_R$  of spiral absorber is increased by about 5.2% compared to the value of serpentine absorber. On the other hand, the comparison of each absorber shows the rate of heat loss ( $U_L$ ) from the serpentine absorber is greater than that from the spiral, where its increased from 8.69W/m<sup>2</sup>°C to 9.93W/m<sup>2</sup>°C

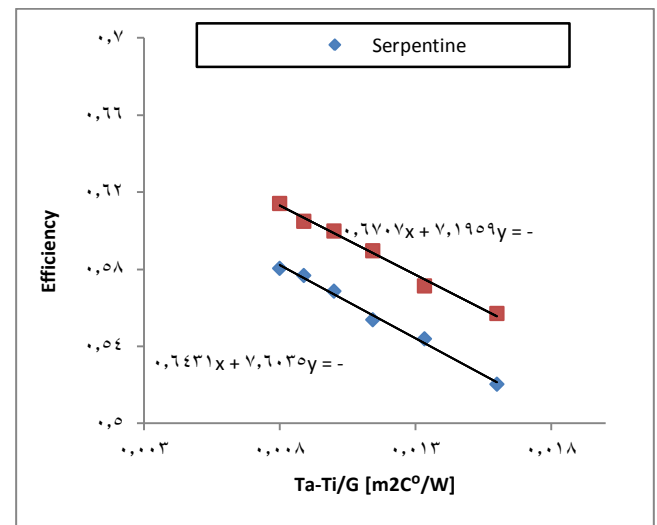


Fig. 9: Thermal efficiency curves for the two collectors

Table 3: Data obtained from the curve.

Absorber	$F_R$	$U_L(W/m^2^{\circ}C)$
Serpentine	0.76	9.93
Spiral	0.8	8.96

The initial cooling water temperature has an explicit effect on PV temperature, and a result the electrical efficiency will be affected, as shown in Figs 10, 11. Fig.10 shows an increase in PV temperature as the initial water temperature increase at all flow rates. At 0.016 kg/s mass flow and under 1000 W/m<sup>2</sup> irradiance, the PV temperature increased by 8.79%,10.7% and 8.1% as the water temperature increase from 26, 28, 30 and 32°C respectively. So electrical efficiency decreased with initial water temperature, where it's decreased by 1.77%, 2.4% and 2% respectively as the water temperature increase from 26, 28, 30 and 32°C . As the flow rate further increase to 0.05kg/sec, the PV temperature increased by 11.05%,9% and 5.6% ,electrical efficiency was by 2%, 1.85% and 1.29% respectively as the water temperature increase from 26, 28, 30 and 32°C.



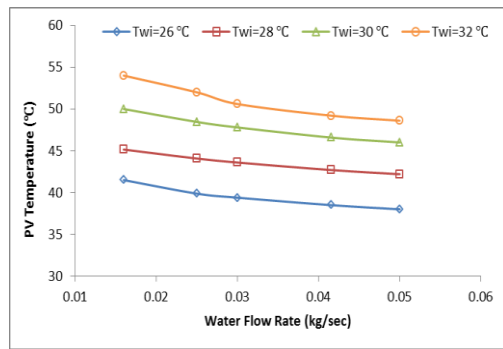


Fig. 10: Effect of water temperature on PV Temperature for different flow rate

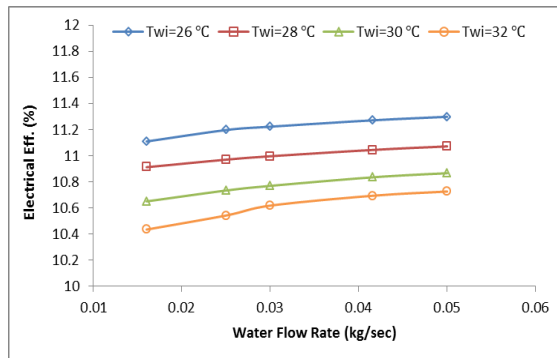


Fig. 11: Effect of water temperature on electrical efficiency for different flow rate

Table 4 shows a comparison between the results obtained from the current work with the previous researchers where we can note that there is acceptable consensus in the results.

Table 4: Comparison between The Results Obtained From The Current Work With The Previous Researchers

Absorber	Performance	Ref.
Spiral flow	$\eta_{el} = 13-13.8\%$ , $\eta_{th} = 45-54.6\%$ , $\eta_{PVT} = 58-68.4\%$ $\eta_f = 79.2-90.9\%$	[7]
	$\eta_{el} = 11.03-11.22\%$ , $\eta_{th} = 49.45 - 61.7\%$ , $\eta_{PVT} = 60.48-72.92\%$ $\eta_f = 78.69- 90.36\%$	Present study
Serpentine flow	$F_R = 0.71$ , $UL = 11.84$	[20]
	$F_R = 0.76$ , $UL = 9.93$	Present study

### 4. Conclusion

The results of the study demonstrated the effect solar radiation level, flow rates, absorber shape and initial cooling water temperature on thermal, electrical and total efficiencies of the system.

It is concluded that:

As PV temperature increasing, electrical efficiency will be decreasing.

Increasing the flow rate leads to a lower PV temperature thus increasing electrical efficiency as well as thermal efficiency, on the other hand the increasing in solar radiation does not necessarily leads to increase electrical efficiency where it leads to increase PV panel temperature which reduced the electrical efficiency.

The spiral flow absorber gives a higher performance than serpentine absorber at all solar radiation levels.

Increasing initial cooling water temperature degrades electrical efficiency of PVT system.

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