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Investigation CFD Analysis of Photovoltaic Thermal Collector (PVT) With Different Configuration Absorber Cooling Design

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Abstract.The solar irradiation is one of the major factors must be taken into consideration in the design and employment of photovoltaic system. On other side, another major factor is surface temperature of photovoltaic panels which effect their conversion effectiveness. The produced power of PV system is reducing in the same situation of solar irradiation, while the operating temperature is high. Photovoltaic thermal collector (PVT) is a new hybrid technology for PV system that output heat and electricity together, so employment of this technology must be taken into consideration to improve the performance of PV system. The present study purpose is to estimate the impact of using water and air collector on the performance of PV/T system. Employment a water riser tube and absorber plate in the suggest of models to consider the conduction and convection heat transfer mechanisms. By employment of computational fluid dynamics (CFD), the numerical results were obtained by employing conjugate heat transfer. This paper presents thermal performance analysis of different designed configurations as spiral flow, oscillatory, direct and web flow air collector heat exchanger employed in hybrid solar PV/T system. A numerical way of the decreasing of temperature of photovoltaic panel is offered in this research. By utilizing ANSYS-FLUENT software for laminar and turbulent flow, the numerical model was recognized, and the outcome is offered for the average temperature of photovoltaic panel.

Keywords: Photovoltaic panel (PV), Serpentine, Water collector, Numerical, CFD.

1. INTRODUCTION

Solar irradiation or solar energy is the term of electromagnetic energy which is emitted from the sun. sun emits massive amount of energy but just a little amount of this energy reaches earth. This hold over the conventional temperature of each forever. By the measure of sun directed energy arriving to the surface of earth, the energy demanded of the world could be achieved nevertheless that's not economical or practical because low concentration of solar energy. The expense of systems that capture solar energy and present useful energies is high compared to traditional energy sources such as coal, oil, and natural gas. In another hand solar energy is to be more expensive than renewable energies such as geothermal, wind, hydro and biomass[1].A solar cell is consisting essentially of p-n intersection fabricate in a thin wafer of semiconductor. Photovoltaic effect could upright change the electromagnetic irradiation which powered by sun energy over to electrical power as long as photons with energy more than band gap energy of semiconductor is directed to the sunlight, it produces some electron gap sets identical to the incident solar radiation. At the spotwherethe photon gets in a photovoltaic material, it tends to be absorbed, reflected or transmitted. The amount of energy of the photon when this photon consumed by a valence electron of the automotive the energy of the electron will jump in the conduction band when the energy of photons is more eminent than the band gap of the semiconductor, where it can move freely. The free electrons are output in the n-layer of semiconductor by the bounce of photon at the point where photons of sunlight shot the surface of sun-based cell and are absorbed by semiconductor. Some of them make groups of electronics and gaps. If these pairs are sufficiently near the p-n junction, its electric field makes the charges to separate, electrons move to the n-type layer and holes to the p-type layer. If the two layers of the sun-oriented cell are presently associated through a load, an electric current will stream if daylight strikes the cell.

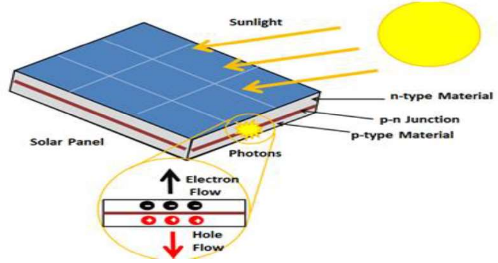


Fig.1 A diagram showing the photovoltaic effect [2]

The transformation of efficiency is the most considerable normal for a photovoltaic board, which contacts the portions of sun-based irradiation that is changed into electric power, in specific conditions. The ideal maximum values of the efficiency arrive to somewhere in the range of 14% and 17%, in the event of mono-crystalline silicon sun-oriented cells. The sunlight-based radiation that isn't changed over into electrical power is for the most part changed into heat. The reliance between the change efficiency and the temperature of photovoltaic cell speaks to a vital investigation area for scientists. The estimation of the current created by PV cell has an irrelevant ascent when the temperature of the cell is more noteworthy, yet the voltage has in essential decrease, causing a drop of the most extreme electrical power produced.

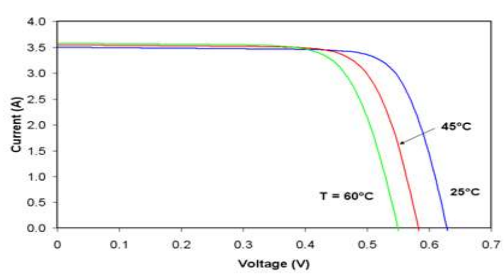


Fig. 2 The influence of PV panel temperature over output parameters[3]

Energy which is not transformed to electricity by the PV cells should be removed to prohibit too much cell heating as temperature cause impairment of performance of PV cells. Subsequently, solar cell cooling should be an integrated part of PV systems. Practically in a concentrated PV designs to lower the impact of panels. Various cooling methods for PV systems could be categories as Figure 3.

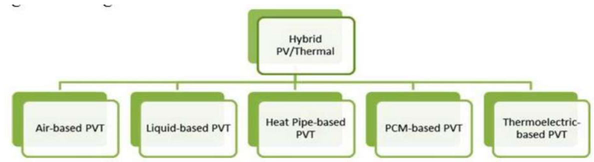


Fig.3 Classification of PVT modules based on heat extraction mechanism.

Amori and Al-Najjar[4] investigated theoretically the performance of a hybrid PVT air collector for two different case studies under Iraqi climatic conditions. Improved thermo-electrical mathematical model of the PVT air collector considering the effect of radioactive heat transfer in the air duct, and the convective heat transfer coefficient from both the PV module back surface and inner surface of insulation to the working fluid were accounted for. The effective sky temperature correlation for relative humidity was also adopted in the model [5]. Modified boundary conditions for better convergence and accuracy of the electrical model were also considered. The model presented was validated against previously published experimental results and theoretical simulations of similar designs by Joshi et al. [6] and Sarhaddi et al. [7], and better alternative amongst the existing models was observed. The electrical and thermal efficiencies for the two cases considered were 12.3% and 19.4% for the winter day, while that for the summer day were 9% and 22.8% respectively. Although the output power in the summer was observed to be higher than that in the winter (1.7 times at solar noon), the efficiency recorded in winter was higher due to the negative temperature coefficient of efficiency and higher fill factor.

The performance of water-based PVT collectors having different configurations of absorber collectors was studied theoretically by Ibrahim et al. [8]. The PVT collector comprised of poly-crystalline PV cells with hollow tubes attached underneath. Under water flow rate of 0.01 kg/s spiral flow design proved to be the best design with the highest thermal and cell efficiencies of 50.12% and 11.98% respectively and output temperature of 31 °C. Different output temperatures were observed and attributed to the design configuration of the absorber, in which the closer spacing between tubes enabled more heat to be absorbed. In a further study, Ibrahim et al. [9] investigated the water type PVT collector with spiral flow design experimentally and compared it with single pass rectangular tunnel absorber collector for air flow. Electrical and thermal efficiency of 64% and 11% respectively were achieved under same water flow rate in the previous theoretical study. Compared to the single pass rectangular collector absorber with water flow, spiral flow design offers better heat extraction and overall efficiency having low surface temperature.

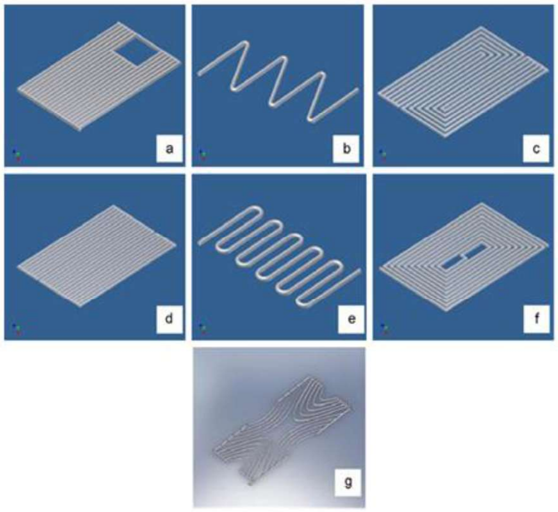


Fig. 4(a) Direct flow design, (b) serpentine flow design, (c) parallel–serpentine flow design, (d)modified serpentine–parallel flow design, (e) oscillatory flow design, (f) spiral flow design, (g) web flow design [8].

1 THERMAL ANALYSIS OF PV MODULE.

To analyze the performance of PV system, a sequential modeling is required, which involves the integration of radiation, thermal and electrical models. The radiation model used to estimate the amount of available radiation is Isotropic Model.

1.1 Absorbance of Photovoltaic cells

The major factor affecting the power output from a photovoltaic (PV) device is the solar radiation absorbed on the cell surface, S, which is a function of the incident radiation, air mass, and incidence angle. Like the situation with thermal collectors the needed radiation data are not normally known on the plane of the PV panel, so it is necessary to estimate the absorbed solar radiation using horizontal data and incidence angle information. The effective absorbed solar radiation S for a PV system consists of beam, diffuse, and ground-reflected components and a spectral effect.

$$S = M\left[G_b R_b (\tau\alpha)_b + G_d (\tau\alpha)_d \left(\frac{1+\cos\beta}{2}\right) + G\rho_g (\tau\alpha)_g \left(\frac{1-\cos\beta}{2}\right)\right] \quad (\mathrm{W/m^2}) \qquad 1$$

$$S = M(\tau\alpha)_n \left[G_b R_b K\tau\alpha_b + G_d K\tau\alpha_d \left(\frac{1+\cos\beta}{2}\right) + G\rho_g K\tau\alpha_g \left(\frac{1-\cos\beta}{2}\right)\right] \qquad 2$$

Where $K\tau\alpha_b = (\tau\alpha)_b/(\tau\alpha)_n$ is the incidence angle modifier at the beam incidence angle, $K\tau\alpha_d$ and $K\tau\alpha_g$ are the incidence angle modifiers at effective incidence angles for isotropic diffuse and ground-reflected radiation, and M is an air mass modifier.

The incidence angle modifier for a PV panel differs somewhat from that of a flat-plate solar collector in that the glazing is bonded to the cell surface, thereby eliminating one air-glazing interface and the glazing surface may be treated so as to reduce reflection losses.Sjerps-Koomen et al. [10] have shown that the transmission of a PV cover system is well represented by a simple air-glazing model. Snell's, Fresnel's, and Bougher's laws;

$$n_1 \sin\theta_1 = n_2 \sin\theta_2 \qquad 1$$

where θ_1 and θ_2 are the angles of incidence and refraction, the reflection of unpolarized radiation on passing from medium 1 with a refractive index n_1 to medium 2 with refractive index n_2 as shown inFig. 5.

The radiation absorbed by a cell with a glass cover calculated as

$$(\tau\alpha)_{(\theta)} = e^{-(KL/\cos\theta_r)}\left[1 - \frac{1}{2}\left(\frac{\sin^2(\theta_r - \theta)}{\sin^2(\theta_r + \theta)} + \frac{\tan^2(\theta_r - \theta)}{\tan^2(\theta_r + \theta)}\right)\right] \qquad 4$$

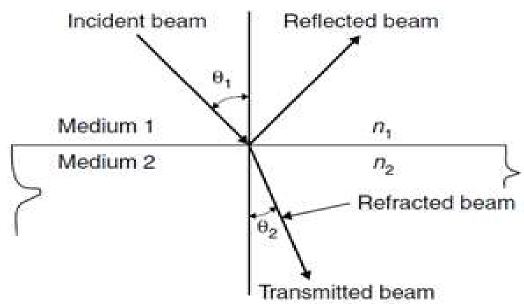


Fig. 5 Angles of incidence and refraction in media with refractive indices n1 and n2.

Where θ and θ_r are the incidence and refraction angles (called θ_1 and θ_2 as shown in Fig. 5, K is the glazing extinction coefficient, and L is the glazing thickness. For most PV systems a typical value for K is 4 m^{-1}, the value for ''water white'' glass, a typical value for the glazing thickness is 2 ~ 3 mm, and the refractive index is set to 1.526, the value for glass. At normal incidence the radiation absorbed by a cell is;

$$(\tau\alpha)_n = e^{-KL}\left[1 - \left(\frac{n-1}{n+1}\right)^2\right] \qquad 2$$

The refraction angle for glass cover of PV can be calculated from Snell's law as;

$$\theta_r = \sin^{-1}\left(\frac{\sin\theta}{1.526}\right) \qquad 3$$

The effective incidence angle of isotropic diffuse radiation and isotropic ground-reflected radiation on sloped surfaces. From Brande Muehl and Beckman [11] the incidence angle of diffuse radiation is;

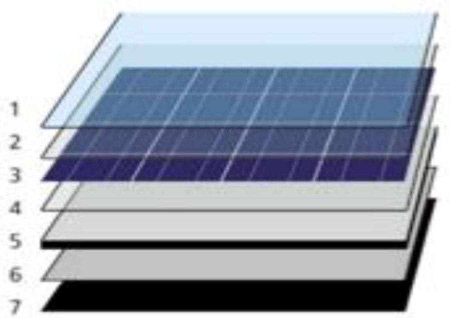
$$\theta_d = 59.7 - 0.1388\beta + 0.001497\beta^2 \qquad 4$$

And the incidence angle of ground-reflected radiation is;

$$\theta_g = 90 - 0.5788\beta + 0.002693\beta^2 \qquad 5$$

1.2 Theoretical model of PV/T module

Thermal modeling based on the basic governing equation has been offered to investigate the performance of PV arrangement, based on factors such as fluid temperature at the outlet, thermal gain the temperature of the PV cells and thermal efficiency. A schematic diagram and cross-sectional view of the PV/T arrangement are shown exhibited in



1 Anti-reflective glass.
2 EVA (Ethyl Vinyl Acetate).
3 Solar PV cells.
4 EVA (Ethyl Vinyl Acetate).
5 Back sheet (Polyvinyl Fluoride (PVF)).
6 Heat exchanger.
7 Insulation

Figure 6Schematic of a hybrid (PVT) solar collector

The following assumptions were considered while promoting the thermal model

1) The quasi-steady-state condition is used for the system.
2) The transmittance of ethyl vinyl acetate (EVA) is 100%.
3) The mean temperature of each layer of the PV panel is considered in the analysis.
4) The differentiation in temperature along the cell layers are small enough to be negligible.
5) Heat capacity is disregarded for all solar cell materials, Tedlar, and insulation.
6) The CPC is free from manufacturing errors and can be considered as an ideal one.
7) There is a constant flux distribution onto the PV panels, and the end-losses impact is ignored.

Considering the assumptions as mentioned above, energy balance was employed for the components of the PV collector to get analytical expressions concerning thermal variables and the thermal efficiency of the arrangement. Figure 7 gives the thermal resistance circuit and network of the different sections of the CPC-PV configuration.

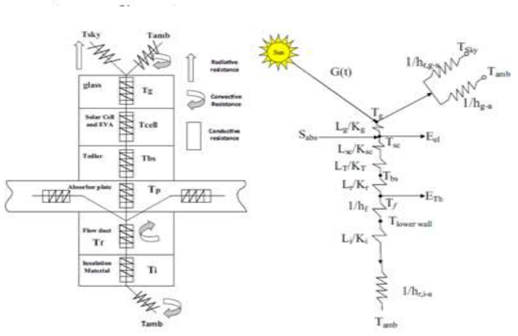


Fig. 7 Thermal resistance circuit and thermal network diagrams for a PV/T collector.

For getting accurate thermal analysis of CPV, is important to know the structure of the photovoltaic panel. A typical example of the structure is presented in [12]. Therefore, the main layers are: exterior glass, anti-reflexive coating (ARC), PV cells, ethylene vinyl acetate (EVA), metal rear contact and polyvinyl fluoride (PVF) film. The thermo-physical properties of these layers are presented in Table 1. The photovoltaic panels can have different layers, depending on the technology of conception and producer.

Table 1Properties of the layers of PV.

Layer	Thickness (mm)	Thermal conductivity (W/m.K)	Density (kg/m³)	Specific heat capacity (J/kg.K)
Glass	3	1.8	3000	500
EVA	100×10⁻⁶	32	2400	691
PV Cells	0.225	148	2330	677
EVA	0.5	0.35	960	2090
Rear	0.01	237	2700	900
PVF	0.1	0.2	1200	1250

1.3Energy conservation

The equivalent thermal resistant circuit diagram for the PV/T collector is illustrated in Fig. 7. According to the first law of thermodynamics, the energy conservation equations can be written as follows:

1.3. 1The total energy conservation equation.

$$G_{rad} + G_{conv} + E + Q_C = S \qquad 6$$

Where G_{rad} is the radiation loss of the glass cover (W), G_{conv} is the convection loss of the glass cover (W), E depicts the system output power (W), Q_C represents the heat that the cooling removes (W) and S is the total solar energy absorbed by the system (W).

1.3.2The energy conservation equation of the glass cover.

$$CC_g M_g \frac{dT_g}{dt} = U_{gp}(T_{PV} - T_g) - h_{convg-amb}(T_g - T_{amb}) - h_{radg-s}(T_g - T_s) + S_g(t)$$

…….9

The convective and radioactive heat transfer coefficients from the glass cover to the atmosphere depend on the wind speed and sky temperature, respectively, and can be written as follows;

$$h_{convg-amb} = 5.7 + 3.8v_a \qquad 7$$

$$h_{radg-s} = \sigma\, \varepsilon_g\, (T_g^4 - T_s^4)$$

11

By assuming the sky as a black body, sky temperature T_s could be estimated using the following equation

$$T_s = 0.0552 T_a^{1.5} \quad 12$$

The overall heat transfer coefficient between the glass cover and PV panel, which can be calculated as follows:

$$U_{gp} = \frac{1}{\frac{\delta_g}{K_g} + \frac{\delta_{EVA}}{K_{EVA}} + \frac{\delta_{PV}}{K_{PV}}} \quad 13$$

1.3.3The energy conservation equation of the PV panel.

$$C_{PV} M_{PV} \frac{dT_{PV}}{dt} = S_{PV}(t) - U_{PV-PVF}(T_{PV} - T_{PVF}) - U_{gp}(T_{PV} - T_g) - E$$

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The overall heat transfer coefficient between the PV cell and back sheet of panel

$$U_{PV-PVF} = \frac{1}{\frac{\delta_{PV}}{K_{PV}} + \frac{\delta_{EVA}}{K_{EVA}} + \frac{\delta_{PVF}}{K_{PVF}}} \quad 15$$

The radiant energy absorbed by the PV cell.

$$S_{PV}(t) = CG(t) \tau_g \rho_m \left(\alpha_{PV} + \frac{\alpha_{PV} \rho_{PV} \rho_g \rho_m^{2\bar{n}}}{C} \right)$$

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1.3.4The energy conservation equation of heat exchange.

$$C_M M_M \frac{dT_M}{dt} = U_{PVF-M}(T_M - T_{PVF}) - h_f(T_M - T_f)$$

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The convective heat transfer coefficient between the heat exchange material and cooling fluid

$$h_f = \frac{N_U K_f}{D_h} \quad 8$$

Where N_U is Nusselt number, K_f is the thermal conductivity of fluid (W/m K) and D_h is the equivalent diameter of the flow channel (m).

While the **Reynolds number** R_e **< 2300**

Geometry	a/b	N_U	Friction Factor
Circle	--	4.36	64/R$_e$
Rectangle	1	3.61	55.92/R$_e$
	2	4.12	62.2/R$_e$
	3	4.79	68.36/R$_e$
	4	5.33	72.92/R$_e$
	6	6.05	78.80/R$_e$
	8	6.49	82.32/R$_e$
	∞	8.24	96/R$_e$

While the **Reynolds number** R_e **> 2300.**

$$N_U = 0.023\, R_e^{0.8} Pr^{0.4} \quad 9$$

1.3.5Thermal efficiency of the module

The thermal efficiency of the module can be expressed as follows:

$$\eta_{th} = \frac{Q_{th}}{CGA} \quad 10$$

Where Q_{th} is the heat production which is removed by the cooling (W), G is the solar radiant intensity (W/m^2) and AThe area of the PV panel (m^2).

The heat production which is removed by the cooling can be written as

$$Q_{th} = \dot{m} C_f (T_{f.out} - T_{f.in}) \quad 11$$

Also, when using cooling fluid tubes, the heat production given by

$$Q_{th} = A\, F_R [S - U_L(T_{f.in} - T_a)] \quad 12$$

$$Q_{th} = A\, F_R [G\, (\tau\alpha)_{PV} - U_L(T_{f.in} - T_a)] \quad 13$$

Where F_R heat removal factor

$$F_R = \frac{\dot{m} C_f}{A U_L} \left[1 - exp^{\left(-\frac{A U_L F'}{\dot{m} C_f} \right)} \right] \quad 14$$

where the collector efficiency factor $F'$is given as

$$F' = \frac{1/U_L}{\frac{1}{U_L} + \frac{D_o}{h_f D_i} + \left(\frac{D_o}{2k} ln \frac{D_o}{D_i} \right)} \quad 15$$

Where$D_i$and$D_o$are the inside and outside tube diameters, h_f is the heat transfer coefficient inside the tube, and k is the thermal conductivity of the tube.

2 DESIGN CONFIGURATIONS OF THE ABSORBER WATER COLLECTORS

The water collector conceptual designs, as shown in Fig. 8-12 comprised of five configurations. Table 2shows the parameters of the absorber collectors design. The absorbers in the form of round and rectangular hollow tubes are attached closely underneath the PV module with metallic bonded; this will ensure a zero gap or no gap between the tubes and the module, in which heat can be transferred.

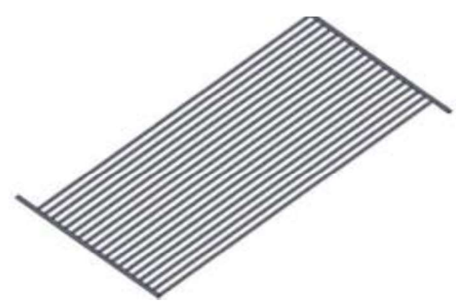

Fig. 8 Direct flow design

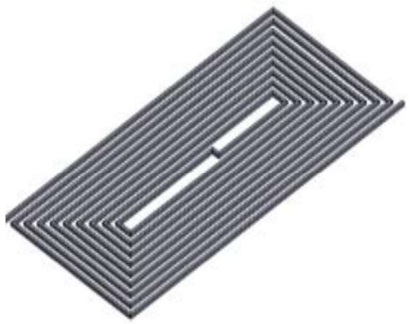

Fig. 9 Spiral flow design square pipe

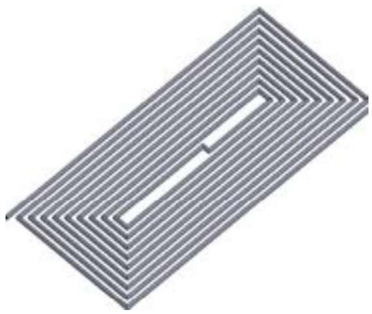

Fig. 10 Spiral flow design Circular pipe

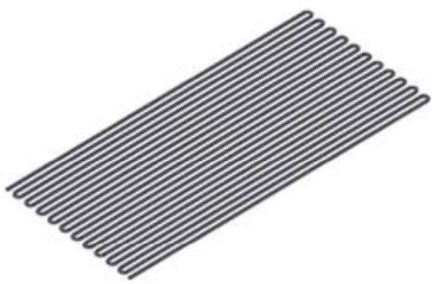

Fig.11 Oscillatory flow design Circular pipe

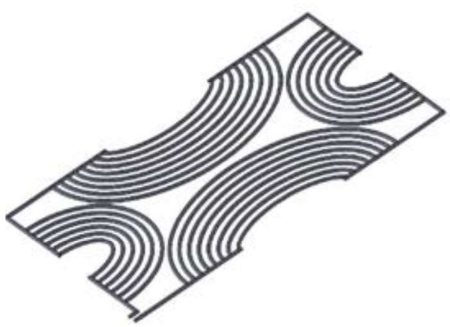

Fig. 12 Web flow design Circular pipe

The PV modules are exposed to the sun, it generates electricity and at the same time absorbed the heat causing the absorber to increase its temperature. During this time, the water fluid passing inside the absorber serpentines tubes that contact with the lower surface of PV module. The water is used as a cooling agent, flows at 0.02 kg/s continuously inside the hollow tubes.

Table 2 Specification of serpentines water collector

1. Direct flow design Figure 8	- Circular hollow tubes of copper materials. - Diameter of pipe Ø= 0.5", Length L=1.6m, width W=0.6m.
2. Spiral flow design square pipe Figure 9	- Square hollow tubes of copper materials. - size of square pipe 0.5"×0.5", Length L=1.6m, width W=0.6m.
3. Spiral flow design circular pipe Figure 10	- Circular hollow tubes of copper materials. - Diameter of pipe Ø= 0.5", Length L=1.6m, width W=0.6m.
4. Oscillatory flow design Figure 11	- Circular hollow tubes of copper materials. - Diameter of pipe Ø= 0.5", Length L=1.6m, width W=0.6m.
5. Web flow design Figure 12	- Circular hollow tubes of copper materials. - Diameter of pipe Ø= 0.5", Length L=1.6m, width W=0.6m.

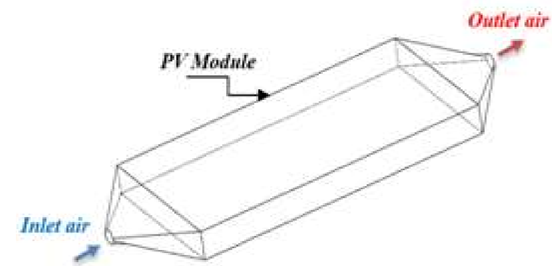

Fig. 13 Air duct for air cooling

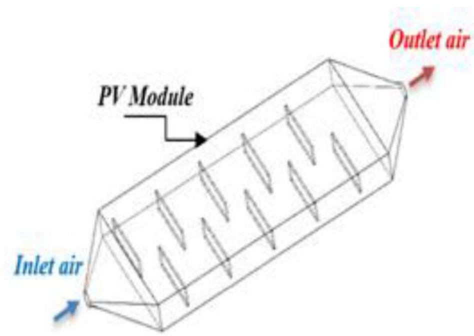

Fig.14 Air duct with horizontal baffles

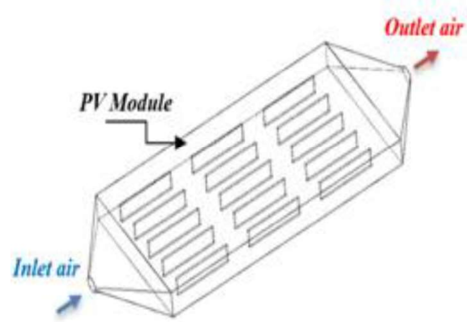

Fig. 15 Air duct with Vertical baffles

Table 3Specification of Air Duct

Duct	Stainless steel material with thickness 1mm, Dimensions L=1.6m, W=0.6m, H=0.15m
Baffles	Dimensions L=350mm, W=1mm, H=0.1m
Insulation	Back insulation (Fiber glass) thickness: 0.05m, insulation Conductivity: 0.045W/m°C

4.PARAMETERS FOR FLUENT CFD SIMULATION MODEL

The absorber collector simulations are performed using Fluent ANSYS software. The system parameters for inputs in the simulation model are shown in Table 4.

Table 4 Fluent solver setup

Model		Steady, Energy Model, Laminar flow Model For flow as Reynolds number doesn't exceed 2300 for all flow rates (water flow through pipe) and turbulent flow model for air cooling.
Boundary Conditions	**Inlet**	- water flow through pipes: mass flow inlet 0.02Kg/s - Air flow through duct: Velocity inlet to maintain 3m/s.
	Outlet	Zero pressure outlet from outlet face.
	Heat Flux	Heat is added on the upper face of (Glass layer) as a constant heat flux for each run time according to the variance of it throughout the day.
	Fluid Material	- For water flow through pipe: Pure water defined as a new single-phase fluid material. - For air flow: Pure air defined as a new single-phase fluid material.
	Solid Material	Materials for layers with specified values were created (5 for the PV cell and 1 for the cooling system).
	Interfaces	Many interfaces are created as coupled walls between PV layers and between cooling system and PV module also between fluid and the cooling system.
Solution Initialize		Hybrid initialize

5.CFD RESULTS

The CFD analysis of water collector conceptual designs, as shown in Figures (16-21). Different configurations of the absorber collectors design have an influence on the heat transfer and water flow inside the channel. A more intense heat transfer is recorded for the web flow serpentine design as the minimum temperature of the photovoltaic is recorded for this case. Pressure drop in web serpentine small than other configuration as P = 281 pa so the cost of pump and energy consumption is best from other configurations, CFD analysis of pressure for different configuration shown in Figures (22-25).

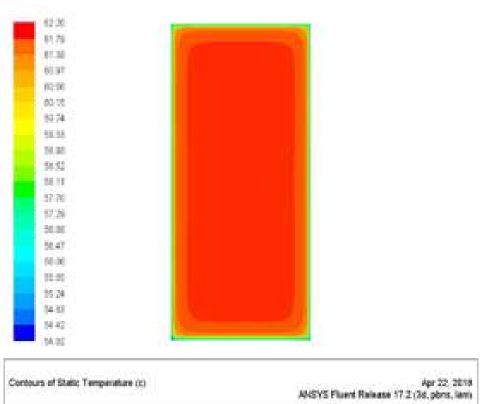

Fig. 16 Surface temperature of PV without cooling absorber

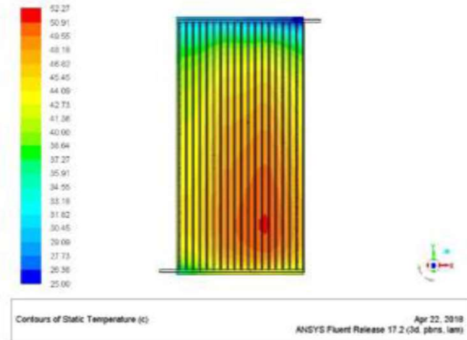

Fig. 17 Surface temperature of PV with Direct flow serpentine design

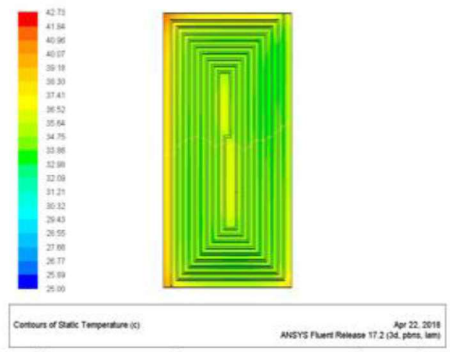

Fig.18 Surface temperature of PV with spiral square pipe serpentine design

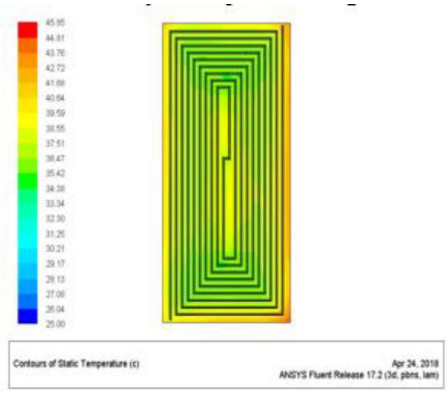

Fig. 19 Surface temperature of PV with spiral Circular pipe serpentine design

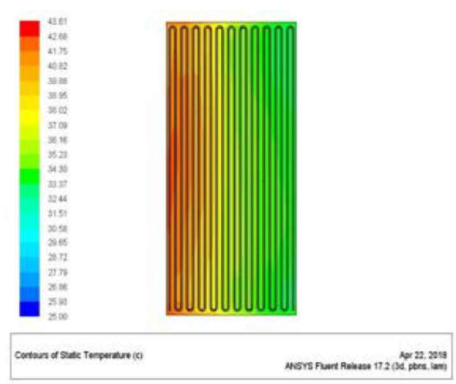

Fig. 20 Surface temperature of PV with oscillatory Circular pipe serpentine design

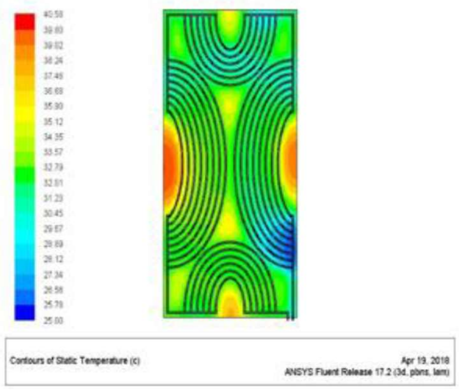

Fig. 21 Surface temperature of PV with web flow serpentine design

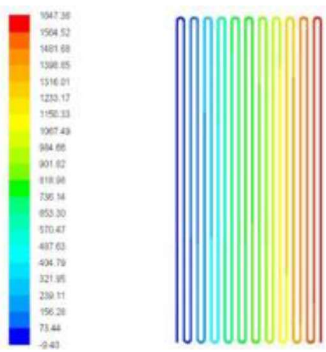

Fig. 22 Pressure in oscillatory Circular pipe serpentine design

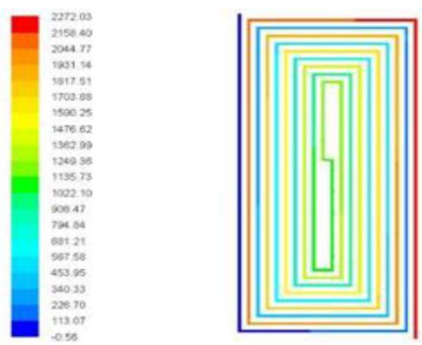

Fig. 23 Pressure in spiral circular pipe

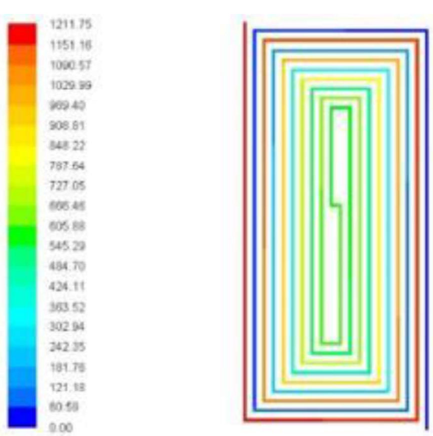

Fig. 24 Pressure in spiral square pipe

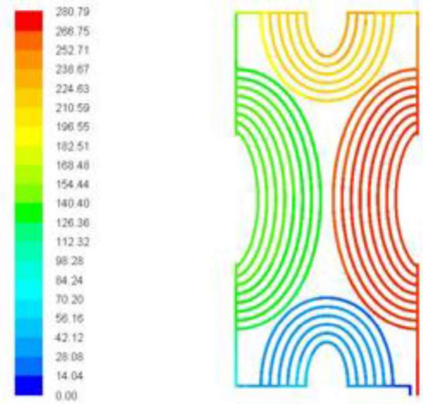

Fig. 25 Pressure in web pipe

CFD analysis of air-cooled collector conceptual designs, as shown. The direction of the baffles has an influence on the heat transfer and airflow inside the ventilated channel

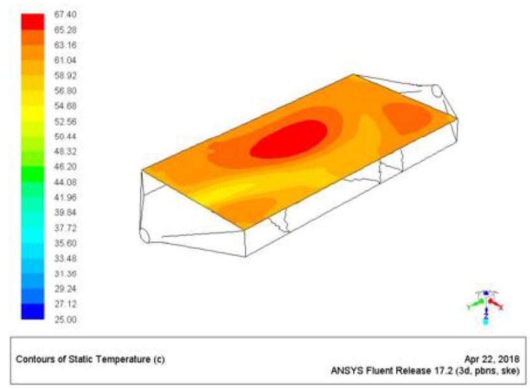

Fig. 26 Surface temperature of PV, air duct without FINS

The Numerical results represent that air cooling of PV system provides a simple way to thermally regulate the temperature of PV cells in order to minimal use of materials and low operating costin comparison to other PV water cooling. Heat extraction results are well enhanced by forced air in further performance of PVT systems are improved when compared with naturally ventilated ones as air blows increase the expense of some power losses. The low density and small heat capacity of air are the reasons for limiting the improvements in the performance of air PVT collectors which make air less favorable option. On the other hand, water cooling presents a good alternative to air cooling using coolant making a more efficient utilization of thermal energy captured. Water collector of PV system is more favorable in temperature distribution on the surface of PV modules as it presents less temperature fluctuations compared to air-based PVT, low temperature has been practically investigated and presented better performance.

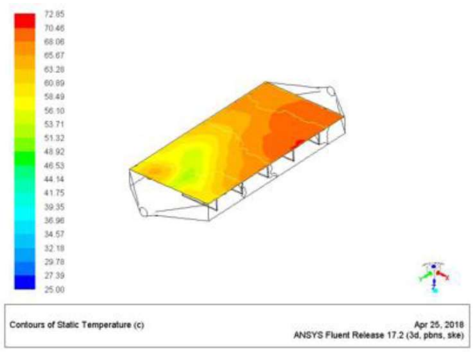

Fig. 27 Surface temperature of PV, air duct with horizontal baffles

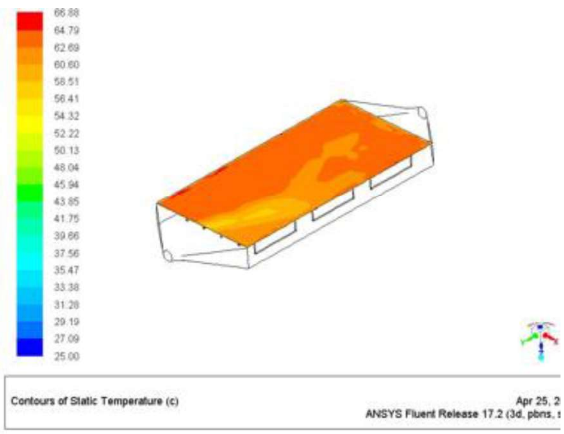

Fig. 28 Surface temperature of PV, air duct with horizontal baffles

The performance and efficiency of the PV/T collectors are determined by their electrical and thermal characteristics. The analyses of the PV/T collectors are segregated into three sections, namely PV efficiency, thermal efficiency, and combination of both. Experimental setup illustrates effect of water and air collector in the efficiency of PV/T system.

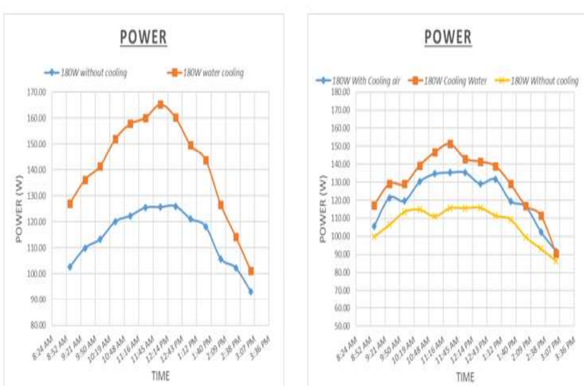

Fig. 29 Effect of cooling in output power of PV

CONCLUSION

PV/T water collector consisting of a combined PV module and an absorber collector were investigated. The performances of PV/T water collectors were determined. The results indicate PV/T efficiency of approximately 75%, a PV efficiency of 30%, and a thermal efficiency of 45%. Overall, the efficiency of the PV/T water collectors increases with the mass flow rates under various solar radiation levels. This result is due to the increase in the cooling factor of the PV module cells when the mass flow rate increases. Therefore, mass flow rate indirectly contributes to the increase in PV/T water collector temperature. It was concluded from the results that a PV system with cooling has more benefits than the normal flat PV system recommended for greater electric power output.

NOMENCLATURE

C	The geometric concentrating ratio of the CPC.
C_g	The specific heat of the glass (J/kg K).
M_g	The surface density of the glass cover (kg/m^2).
T_{amb}	Ambient temperature (K).
T_g	The temperature of the glass cover (K).
T_{pv}	The temperature of the PV panel (K).
$S_{PV}(t)$	The radiant energy absorbed by the PV cell (W).
$G(t)$	total solar energy absorbed by the system, W/m^2
U_{PVF-M}	The overall heat transfer coefficient between the heat exchange material and back sheet of panel (W/m^2 K).
T_s	The effective of sky temperature (K).
h_{radg-s}	The radiation heat transfer coefficient between the glass cover and ambience (W/m^2 K).
$h_{convg-amb}$	The convective heat transfer coefficient between the glass cover and ambience.

U_{gp} The overall heat transfer coefficient between the glass cover and PV panel (W/m^2 K).

$S_g(t)$ The radiant energy absorbed by the glass cover (W).

U_{PV-PVF} The overall heat transfer coefficient between the PV cell and back sheet of panel (W/m^2 K).

$\bar{n}$ the light average reflection number in the CPV.

C_M The specific heat of the heat exchange material (J/kg K).

Greek Letters

ρ_m the reflectivity of the mirror.

ρ_{PV} the reflectivity of the PV panel.

τ_g the transmittance of the glass.

ρ_g The reflectivity of the glass.

α_{PV} The optical absorptive of the PV panel.

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