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Numerical and experimental evaluation of a photovoltaic thermal air collector's performance (PVT) under Tunisian climatic conditions

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Abstract—

In this work we present a numerical simulation and mathematical model of a hybrid photovoltaic/thermal (PVT) collector. The hybrid collector has two purposes: 1) The cooling of the PV module, 2) the recover of heat dissipated therein consequently the provision of hot-air used to dry the agriculture products. The proposed model is used to evaluate the thermal energy performance and to determine the optimum air speed, A 2D transient heat conduction model was developed in COMSOL Multiphysics (3.4.b). The model considers the outside temperature, solar irradiation, and air velocity. The simulation shows a good agreement with experimental data for the photovoltaic cell temperature, air temperature inside the channels and the outlet temperature.

Keywords—component; Photovoltaic thermal air collector (PVT),Pperformance evalution, Experiments, Simulation,

I. Introduction

Among the renewable energy resources, solar energy is considered the most promising and highly reliable clean energy technology. Solar energy may be harnessed and utilized in two forms, such as heat and electricity. Solar thermal energy is collected by solar thermal collectors and electrical energy is produced by photovoltaic (PV) modules. Among the sources used to provide the needs is the solar energy [1]. Solar energy is universally accepted as the most potential alternative power source due to its inexhaustible availability, diverse conversion technology and environmental friendly. A solar thermal (PT) collector may be connected in series, parallel, or a series-parallel combination. A configuration in series results in a larger system but higher temperature whereas a parallel connection would result in a smaller configuration but with lower temperature. A decreases in the thermal transfer coefficient diminish the cooling effect on the absorber plate which allows a higher plate temperature and lower air stream temperature, then the efficiency is reduced [2]. The heating curves of a new flat-plate, sandwich-like solar collector with serpentine ducts were experimentally measured and compared to those of a commercial collector with parallel ducts. The serpentine geometry is seen to show a better performance than the parallel one in what the heating curve of the storage tank water is concerned [3]. Secondly The photovoltaic collector (PV) provides only electricity but only around 10–20% of the solar radiation can be converted into electricity by the PV cells, and most of the rest is rejected as heat in the module, meanwhile, the heat will increase the PV temperature and reduce the PV conversion efficiency [4].

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Thirdly the solar hybrid photovoltaic-thermal collector (PV/T). Is used to ameliorate the energetic efficiency of photovoltaic by the removal of the waste heat from the PV cells at the same time cooling the PV module and increases their electrical efficiency. An optimized solar energy system that produces electricity and thermal energy simultaneously from the same physical configuration, which provides the utmost usage of solar energy [5]. Compared with the solar thermal collector (PT) or the photovoltaic-collector (PV), the market for the PV/T collectors is still very small today, but the interest in this technology has been increased in last year's [6]. Ooshaksaraei *et al* (2017) affirm the total output energy and total output exergy of the PVT collector proposed are two key parameters for evaluating the performance of a PVT collector [7]. A temperature gradient on the PVT collector allows a variation in the efficiency due to a non-uniform temperature distribution on the PV cells [8]. Ibrahim et al. Studies the performances of a water-based PV/T system with a spiral flow absorber, the results showed the PV/T energy and exergy efficiencies of this system were 55–62% and 12–14%, respectively [9]. Several geometries have been suggested for PVT solar collectors, ranging from the most frequently used fin-and tube collector to sandwich-like collectors with ducts where the fluid directly contacts the absorbing surface [10]. Othman *et al* studied the performance analysis of PV/T combination flat plate collector of water and air heating system. They concluded the advantage of the having two types of cooling medium in one system PV/T, the temperature of PV panel will be reduced and cell efficiency will be greatly improved at instant [11]. Hasila Jarimi et al [number?] studied, a novel design of a hybrid solar collector which integrates the use of both water and air as the working fluids, they are concluded, that simultaneous use of both fluids led to the decrease in the temperature of the PV panel. This fact leads to the increase in electrical performance more significantly. The increment of solar intensity contributes to enhancement of outlet temperature of both fluid and electrical power of the whole system. Mass flow rate plays an important element for cooling effect on PV solar cells by reducing the outlet temperature in the channel and tubes [12]. In this sense, in the past year's numerical simulation has been revealed as an important tool in order to provide an insight into physical industrial processes allowing to improve systems performance and process optimization [13].

In the present study, a steady state thermal model of a PV/T air solar collector under forced flow mode was developed, validated with experimental data and then used to study the effects of various parameters on the performance of the system. This simulation program considers the local climate conditions, Tunisia-Sfax, to review and understand the procedure of hybrid solar collector (PVT) and develop a mathematical model for thermal analysis of PVT. To analyse the effect of the airflow in the Outlet temperature and the efficiency of the PV panel for the photovoltaic-thermal collector (PVT).

II. Design of the system

The experimental measurements were carried out using the hybrid solar collector prototype (Figure 1), located at the National Engineering School of Sfax-Tunisia, and tested in several sunny days. This solar collector was designed and constructed in the framework of the European project "ESSORENTREPRISE" according to climatic conditions of Sfax city in Tunisia. The design specifications of PVT solar collector are given in Table 1. This prototype was fixed facing south direction with an angle of inclination of 45°. The inclination of the PVT collector is taken as 45° from horizontal to receive maximum radiation. The PV/T collector absorbs the solar radiation and produce both thermal and electrical energy. The air flux enters in aluminum tubular canals 0.04 m * 0.04 m to provide a heat exchange below the PV panel. A 0.04 m layer of glass fiber was used to isolate the back of the panel. A Gap of 0.02 m was used between the PV panel and the external ultra-transparent glass layer each of 0.008 m thickness.

To simplify calculation, some assumptions have been made below:

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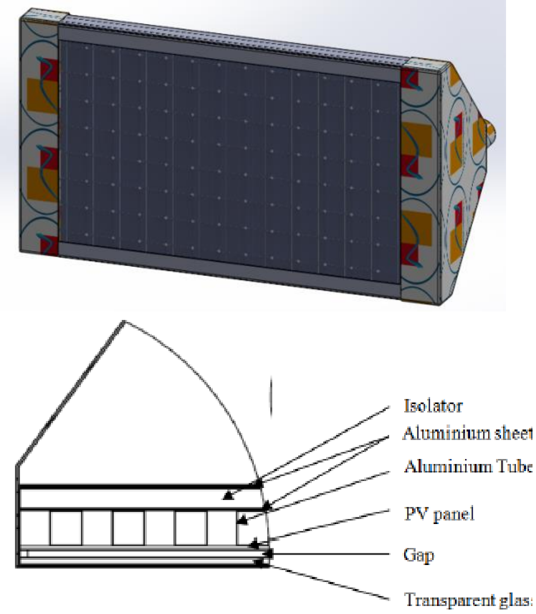

Fig 1. Solar PV/T solar collector

Details of particulars	**Specification**	**Unit**
PV panel		
Length	1.3	m
width	0.88	m
Thickness	0.005	m
Glass Cover		
Length	1.3	m
width	0.88	m
Thickness	0.008	m
Spacing between glass cover and PV panel (Gap)	0.02	m
Aluminium Tubes		
Number	11	
Dimension	0.04*0.04	m
Spacing between two tubes	0.04	m
Aluminum Plate	1.3*0.88*0.002	m

Table 1. Design specifications of PVT solar collector

Conversation Equations

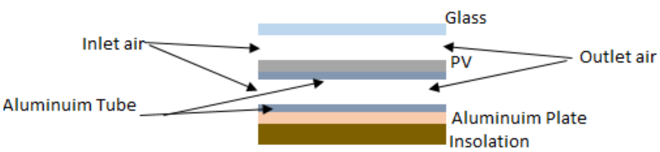

Fig 2. Cross sectional view of PV/T solar collector

III. Assumptions

1. There are two separate phases, fluid and solid, which are not in thermal equilibrium. This was the case for low thermal conductivity fluid and low volumetric heat transfer coefficient between the fluid and solid domains
2. The temperatures at the front side and back side of the bifacial PV panels are assumed to be equal.
3. There are no air leaks from the collector.
4. air can be considered as an incompressible fluid.
5. A laminar regime is developed.

IV. Conservation equations

Heat transfer through solid surface to the flow channel is solved by the heat convection.

$$\nabla.(k\nabla T) = 0 \quad (1)$$

In fluid domain inside the flow channel the heat transfer mechanism has been considered as a conjugate heat transfer of conduction and convection. The conjugate heat transfer equation solved for heat transfer in the fluid domain is given in equation (2) taking air as the fluid.

$$\rho C_p \frac{\partial T_2}{\partial t} + \rho C_p u.\nabla T_2 = \nabla.(k\nabla T_2) + Q + Q_{vh} + W_p \quad (2)$$

The mass and momentum conservations for the fluid flow are given below equation (3):

$$\rho\frac{\partial u_2}{\partial t} + \rho(u_2.\nabla)u_2 = \nabla[-\rho I + \mu(\nabla u_2 + (\nabla u_2)^T) - \frac{2}{3}\mu(\nabla.u_2)I] + F \quad (3)$$

$$\frac{\partial \rho}{\partial t} + \nabla.(\rho u_2) = 0$$

The PV/T panel shown in Figure 1 receives energy from the solar irradiance, converts some of it into electricity through the PV effect and the rest is transformed into heat. The objective of attaching the thermal panel underneath the PV cell is to remove as much as this heat as possible in order to increase the efficiency.

The heat absorbed of a PV/T collector can be calculated from Equation (4).

$$Q_n = Q_{ab} + Q_{cv} + Q_{rd} \quad (4)$$

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The heat loss due to forced convection on the top and bottom surfaces of a PV/T collector is given by Equation (5).

$$Q_{cv} = h_w * Ag(T_a - T_g) \quad (5)$$

The long wave radiation heat loss can be calculated from Equation (6).

$$Q_{rd} = \varepsilon * \sigma * Ag(T_a{}^4 - T_g{}^4) \quad (6)$$

The heat source is given by equation (7).

$$Q_{ab} = \alpha_g * G \quad (7)$$

Boundary conditions:

For the fluid domain the inlet boundary conditions were specified as velocity inlet along the z-axis and is expressed by the following condition.

$$u_2 = u_0, v = w = 0$$

$$T_0 = T_{int} \quad (8)$$

Wall boundary conditions were used to bound fluid and solid regions. Wall is at no slip condition and the outlet condition is kept at zero-gauge pressure and no viscous stress.

Non-slip condition

$$u_2 = 0 \quad (9)$$

Thermal insulations are taken:

$$-\mathrm{n}.(-k\nabla T_2) = 0 \quad (10)$$

V. Numerical simulation

The model consists of five solid domains for PV/T collector: front cover (glass), PV cells, Aluminum tube, back sheet aluminum, and the Insulation.

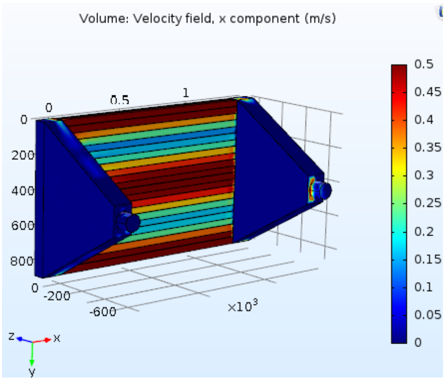
The cross section of the considered PV/T model is shown in Fig. 2. The system consists of eight layers (including solid and liquid layers) for the PV/T module. A non-isothermal laminar flow and conjugate heat transfer physics module was used. The three modes of heat transfer are involved when considering a PV / T model. Heat is transferred to the solid domain by conduction, heat is transferred between the solid and fluid by convection and a forced convection and radiation between ambient medium and the upper surface of the collector. The finite element method was used in comsol multiphysics.

VI. Results-Simulation

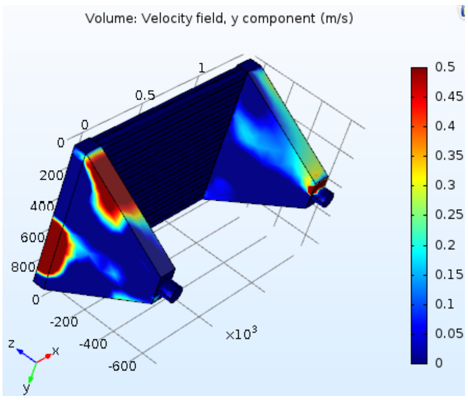
To run the program, various properties of the materials must be adjusted according to a real case scenario. The actual values used, are shown in Table 2.

Materials	*Density [kg/m^3]*	*Thermal Conductivity [(W/mK)*	*Heat capacity at constant pressure [(I/KgK)]*
Glass	*3000*	*1.8*	*500*
PV-Panel	*1500*	*134*	*677*
Aluminuim	*2700*	*160*	*900*
Air	rho(pA[1/Pa], T[1/K])	*0.0262 [W*(m^ - 1)*(K^ - 1)]*	Cp(T[1/K])

Table2. Properties of the various construction components



(a) Axis X



(b) Axis Y

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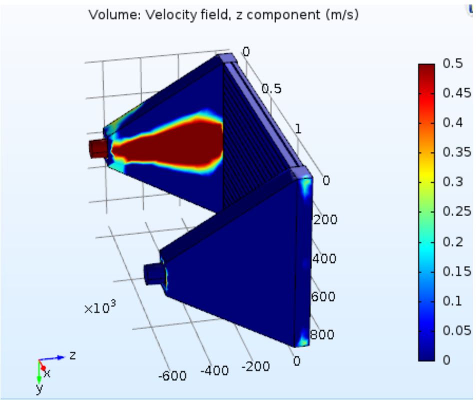

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Fig 3. 3D air distribution in PV / T following the three axes with Vint = 1.5 m/s

In figure 3, we show airflow distribution in non-homogeneous, a higher air velocity is observed at the center of the collector, then our physical configuration must be modified

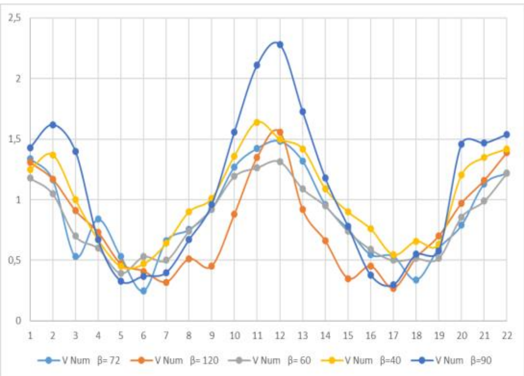


Fig 4. Speed profiles in tubes along the X-axis With Ve = 3.4 m / s four several β angle

Figure 4 depicts the air velocity inside the tubes. An important difference of the velocity at different locations show variations near from 1.5 m/s. this fact enhance the heat transfer in some locations, but diminish the transfer in another tubes.

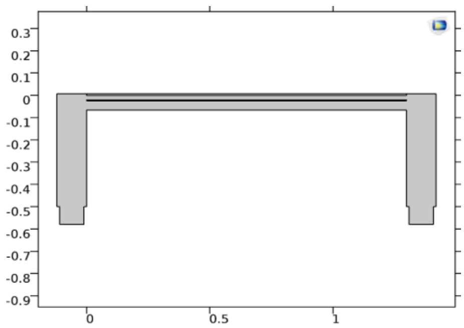


Fig 5. 2D Geometry of PV/T

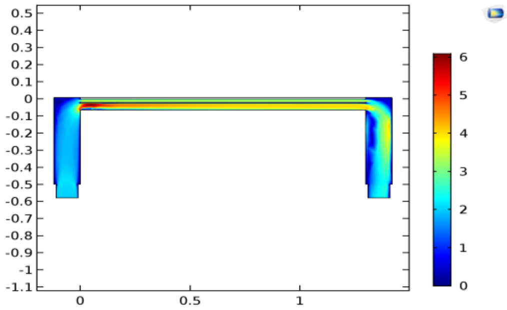
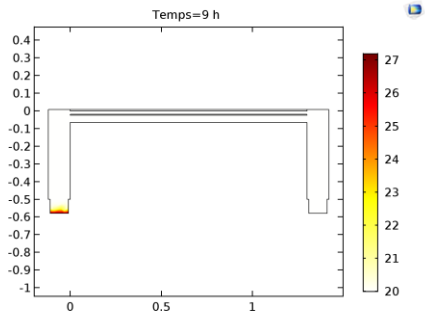
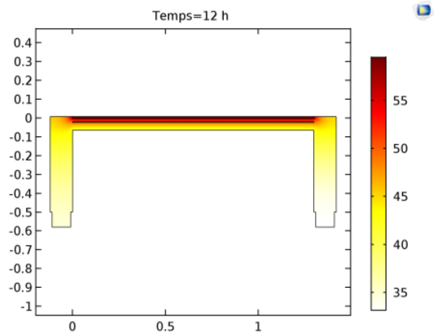


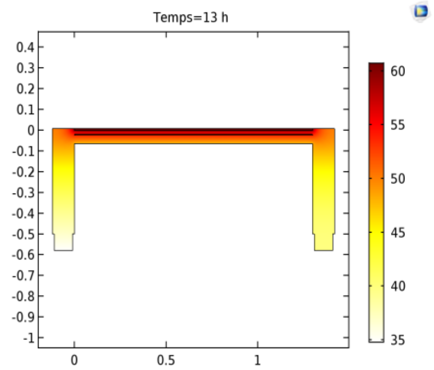
Fig 6. 2D air distribution in the PVT (*Qm=0,0188 Kg/s*)



(a) t= 0 h



(b) t= 12 h



(c) t= 14 h

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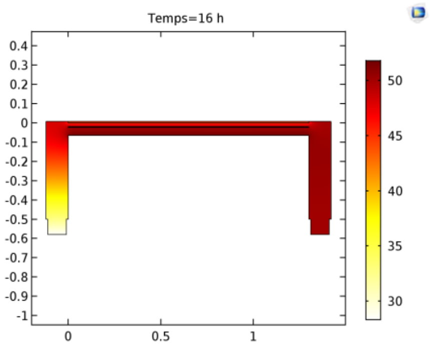

(d) t= 16 h

Fig 7. (a), (b), (C), (d) 2D air distribution of temperature (*Qm=0,0188 Kg/s*) for four time

The influence of level of irradiation on the temperature distribution in the PV/T module has been illustrated in Fig. 8. Fig. 7 shows the numerical temperatures for four time of the day. It seems that the output temperature increases with increasing radiation level

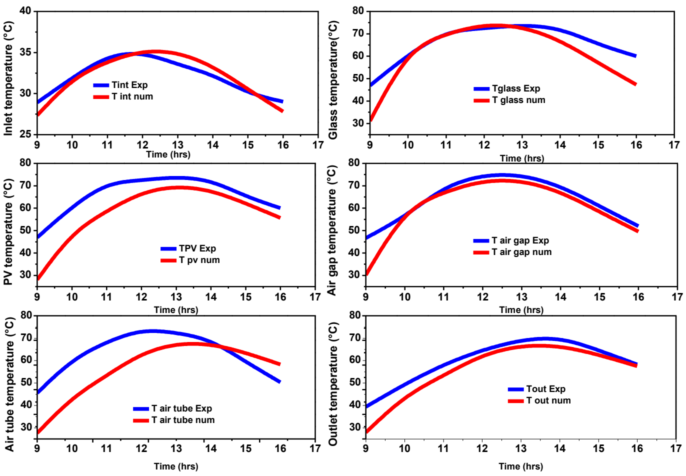

Fig 8. Temperature profiles for mass flow equal *Qm=0,0192 Kg/s*

Temperature variations recorded at 9:00, 12:00, 14:00 and 16 hours are presented in Figure 7. The profile was simulated for a random date in the year 2017. The highest temperature of 70 °C was observed for a glass with absorptivity and emissivity values of 0.85 and 0.15, respectively. Peak temperatures within the range of 45-60 °C was observed for the other field

In Fig. 8, the evolution of temperature increases as irradiation level increases, both for numerical and experimental data.

Fig. 8. shows the thermal and hence the overall efficiencies increase with increasing air inlet velocity through the flow channel. The increase in flow velocity enhances the convective heat transfer coefficient of a fluid. So, under a given temperature difference, more heat is transferred at higher velocities, thereby increasing the thermal efficiency. As both the electrical and thermal efficiencies increase with increasing inlet velocity, so the overall efficiency also increases.

Results from the developed model such as efficiency of the collector for specific flow rate, inlet and outlet temperature of air or temperature lift of the collector are compared with experimental data. It is found that, the Experimental results are in good agreement with the numerical simulation.

VII. Colclusion

This study was carried out with the main objective being to evaluate the performance of photovoltaic-thermal (PVT) air system. A model of PV/T has been presented both numerically and experimentally, was created in COMSOL Multiphysics 3.4.b, we used the heat conjugate (heat transfer and laminaire flow), the experiments are carried out at outdoor conditions.

Note that these estimates are approximate only and accuracy depends on the parameters of the materials and other measurements. The results indicate that the collector was no more significant difference between the experimental data and numerical results. We conclude that the on homogeneous air flow distribution, higher velocity in the center, the air temperature increases as solar radiation increases, furthermore heterogeneous airflow distribution in the tubes and the simulations describe correctly the evolution of temperature inside the collector.

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