Thermal performance of a photovoltaic thermal collector

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Abstract - the hybrid solar photovoltaic thermal PV/T offers an interesting option now; because the absorbed solar radiation is converted into electric energy and heat (the conversion can be performed simultaneously or separately). The objective of this work is to study numerically and of the hybrid collector PVT for measuring the thermal performance. The results suggest that this type of collector is a good alternative to conventional photovoltaic modules and thermal collectors installed separately.

Résumé – les capteurs hybrides solaires photovoltaïque thermique PV/T offrent une option intéressante; le rayonnement solaire absorbée est convertie en deux formes d'énergie électrique et thermique (la conversion peut être effectuée simultanément ou séparément). L'objectif de ce travail est d'étudier numériquement un capteur hybride PVT pour mesurer les performances thermique. Les résultats suggèrent que ce type de collecteur est une bonne alternative aux modules photovoltaïques classiques et capteurs thermiques séparément installés.

Keywords – Photovoltaic, Hybrid System, Solar Collector, Thermal Efficiency

Nomenclature

G	Solar radiation intensity [W/m²]
A_c	Collector area
F_R	Heat removal efficiency factor
$(\tau\alpha)_{PV}$	The product of absorptivity and transmittivity
U_L	Overall back loss coefficient [W/m^2 K]
T_{in}	Inlet temperature
T_a	Ambiant temperature
$\dot{m}$	Mass flow rate (kg/s)
C_p	Specific heat capacity [kJ/kg K]
F'	The corrected fin efficiency

1. Introduction

   Photovoltaic panel are known to produce electricity; and thermal collectors that provide heating systems. The two systems are independent and different, but they are not absolutely incompatible, that can be completed using a hybrid design that allows using both techniques, thermal and electrical, in a process called (PV/T). Essentially this is of interest in this work, connect a photovoltaic panel with another refrigeration system which is used as well as the thermal system, a cooling fluid can later produce hot water means of a heat exchanger.

   Most research in this field is intended to assess the thermal and electrical performance or analyze the economic aspect of hybrid systems through the estimation of solar coverage provided [1], [2].

   In 2005, Zondag [3] offers a state of the art solar PV/T hybrid based on the report of the European project PV Catapult [4]. Among the first studies identified by Zondag [1], some focus on the evolution of the geometric configuration of components and other methods of modeling.

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Performance analysis of a hybrid collector PV/T using a dynamic explicit model was proposed by Chow [5]. That the model is suitable for applications in the simulation of dynamic systems

Tiwari and Sodha [6] developed a thermal model for an integrated thermal solar collector (IPVTS) and compared to the classical model of a photovoltaic module heater Solar byHuang and other reference [7].

Chow et al [8] showed that the addition of water flow tubes in transparent photovoltaic module can be a good choice for greater solar efficiency. However, the hybrid collector PV/T (sheet and tube) Single glazing is considered the most promising model because it has high efficiency and is easy to build.

Kalogirou and Tripanagnostopoulos [9], [10] have a simulation of a system of water storage hybrid collector (PV/T) and found that the economic viability of PV/T water guy was much better than the PV/T air type…

Elswijk et al [11] set up large tables PV/T on residential buildings and stated that the use of PV / T would save about 38% of the roof surface over a photovoltaic system with a side of solar thermal.

Ji et al [12] studied an integrated façade (PV/T) collector for residential construction in Hong Kong. Thermal annual returns were found about 48% for thin film silicon and 43% in the case of silicon crystalline, respectively, in addition to the integrated construction system has been able to reduce the cooling requirements of the building significantly due to the absorption of heat by the walls of the small ...

In this study, the main focus is on the development of PVT model studied by Touafek [2] using Comsol to validate the results obtained by analytical modeling PVT collector.

2. Description of the system

Fig. 1.(a) shows the simplified diagram of the new proposed PVT hybrid collector. It consists of a monocristallin's photovoltaic module (with its three layers: tempered glass, layer of the cells with the ethylene vinyl acetate (EVA), and lay down Tedlar) type (UDTS50) of 1.29 m length and 0.33 m width, and galvanized steel absorber placed at the lower part of the module, and this absorber is an enclosure containing the coolant, which can be air, water, or glycol. An insulation of the hybrid collector is necessary, it allows better thermal performances, and this insulation is ensured by glass wool.
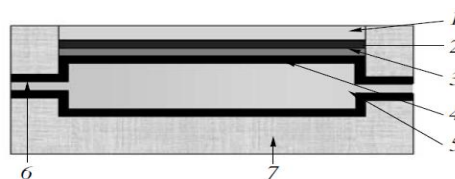

Figure 1 : Simplified diagram of new PVT collector:
1—tempered glass;2—photovoltaic cells;3—tedlar; 4—the absorber;
5—exit of the coolant; 6—entry of the coolant; 7—insulation.

3. Mathematical formulation

The energy balance equations of the PV module are modified from Cox and Raghuraman [13]:

The total energy, E_c, absorbed by the PV cell is given by the following equation:

$$E_c = \tau_g \alpha_c \frac{A_c}{A_T} G \qquad (1)$$

Due to solar irradiation, the electrical energy, E_{ce}, produced by the PV cell is expressed by the following equation:

$$E_{ce} = \tau_g \eta_{pv} \frac{A_c}{A_T} G \tag{2}$$

The amount of solar energy available to the heat system level will be reduced by the extraction of electric energy from PV cell is as follows:

$$S = \left((\tau_g \alpha_c) - \tau_g \eta_{pv} \frac{A_c}{A_T} \right) G \tag{3}$$

The η_{pv} is the cell efficiency represented as a function of the module temperature [14]

$$\eta_{pv} = \eta_0 \left(1 - 0.0045(T_c - T_a) \right) \tag{4}$$

Energy balances on the cell, the plate, and the fluid yield the following equations:

$$\begin{cases} S + U_2(T_{abs_h} - T_c) + U_1(T_a - T_c) = 0 & (5) \\ U_2(T_c - T_{abs_h}) = h_{rad}(T_{abs_h} - T_{abs_b}) + h_1(T_{abs_h} - T_f) & (6) \\ \quad h_{rad}(T_{abs_h} - T_{abs_b}) = U_b(T_{abs_b} - T_a) + h_2(T_{abs_b} - T_f) & (7) \\ h_2(T_{abs_b} - T_f) + h_1(T_f - T_{abs_h}) = q_u & (8) \end{cases}$$

These four equations are solved so that the useful again is expressed as a function of U_1, U_2, $h_{rad(absh\_absb)}$, h_1, h_2, U_b and T_a , leads us to determine the U_L and F_R for the collector coefficient of overall loss.

Depending on the mass of the heat flow, inlet and outlet temperatures of the heat exchanger, respectively T_{fo} and T_{fi}, the useful power recovered by the fluid is given by:

$$q_u = \dot{m} C_f (T_{fo} - T_{fi}) \tag{9}$$

Hottel *et al.* [15] modified the above relation and proposed the expression of the useful heat gain can be calculated as follows:

$$q_u = A_c F_R \left[(\tau\alpha)_{pv} G - U_L (T_{fi} - T_a) \right] \tag{10}$$

Where U_L for this collector is not just the top loss coefficient in the absence of back losses but also accounts for heat transfer between the top and bottom of absorber surface , it value is calculated using the concept of heat balance by electrical mapping of heat transfer [16].

The heat removal Factor F_R can be calculated using the winglet equation; it also explains the mass flow rate in the collector m and specific heat of the fluid C_p:

$$F_R = \frac{\dot{m} C_f}{A_c U_L} \left[1 - exp\left(-\frac{F' A_c U_L}{\dot{m} C_f} \right) \right] \tag{11}$$

In calculating total loss coefficient occurs the heat transfer coefficient by convection: h_f which depends on many parameters which are a function of the geometry of the heat exchange surface and the characteristics of the fluid as the mass flow which is a factor estimates the thermal performance.

4. Performance of PVT collector using COMSOL

The hybrid collector PVT consists primarily of single crystal silicon photovoltaic module and device for the discharge from the heat of the water produced by the conversion of solar radiation by the module.

In order to validate the results obtained by analytical modeling PVT collector, a numerical simulation with commercial software has been implemented; A choice was a commercial finite

element software-COMSOL MULTIPHYSICS; taking into account the radiation and natural convection. The temperature profile is given below for an irradiation of 1000W/m²

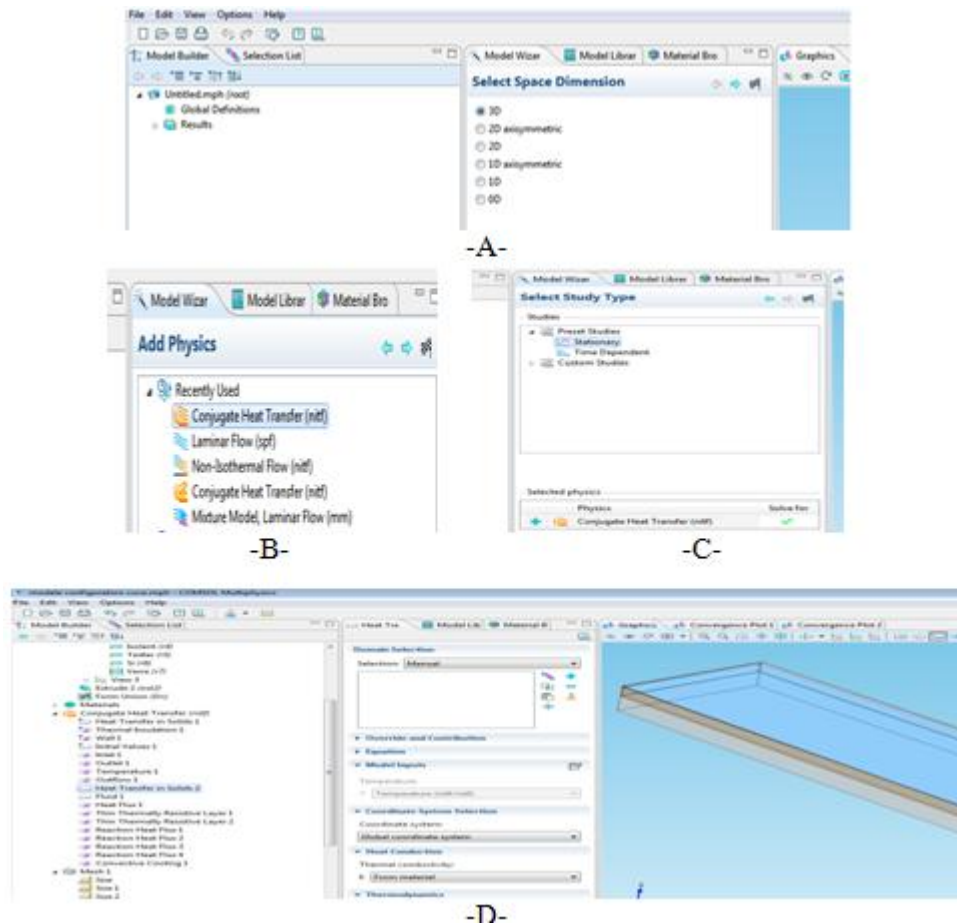➢ First you must choose the space dimension (3D) and add a physical

Figure 2 : (A, B, C, D) Different step for creating the model of simulation

➢ Choosing conjugate heat transfer (nitf), After choosing the type of study on selecting stationary, After clicking wane finished one is following this window see Figure1 (A, B, C, D).

Tableau 1 : Geometry Statistics

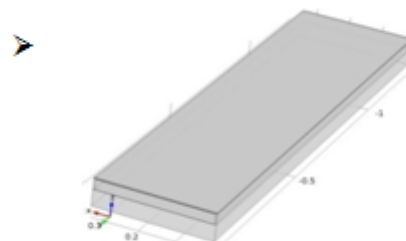| Property	Value
Space dimension	3
Number of domains	6
Number of boundaries	32
Number of edges	56
Number of vertices	32

Figure 3 : Geometry of PVT system

➢ The material used for both the absorber plate and the tube is copper; the input parameters used in the analysis are shown in Table 2

Tableau 2 : Data used for simulation

Layer	λ(W/m.K)	C(J/Kg)	Rho(kg/m³)	Value
Glass Cover	1	840	2500	0.88
PV Cell	131	700	2330	0.8
Layer of Tedlar	0.035	560	1200	/
Absorber Plat (Steel)	65	400	7800	/
Insulation	0.035	1000	1.127	0.1

Tableau 3 : Propriety of Water, liquid

Name	Value	Unit
Heat capacity at constant pressure	Cp(T[1/K])[J/(kg*K)]	J/(kg*K)
Density	rho(T[1/K])[kg/m^3]	kg/m^3
Thermal conductivity	k(T[1/K])[W/(m*K)]	W/(m*K)

Tableau 4 : Boundary conditions

Name	Expression	Unit	Description
P	0	Pa	Pressure
U	0.001	m/s	Inlet velocity
Tin	298.15	K	Inlet Temperature
Heat Flux	1000	W/m²	Solar irradiation
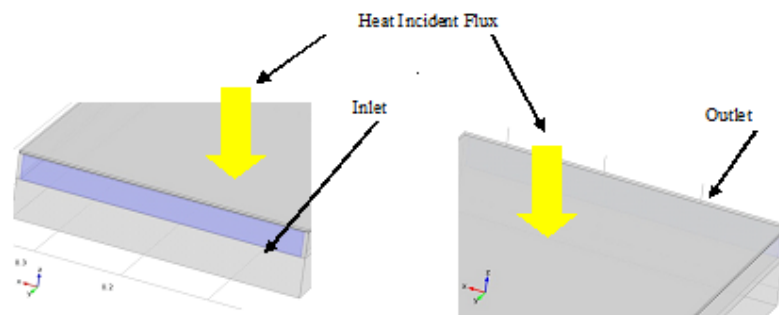
Figure 4 : Boundary conditions

Mesh 1

Tableau 5 : Mesh statistics

Property	Value
Minimum element quality	2.027E8
Average element quality	0.5238
Tetrahedral elements	302942
Prism elements	49552
Triangular elements	40766
Quadrilateral elements	320
Edge elements	1952
Vertex elements	32

5. **Experimental study**

To study experimentally the PVT hybrid solar collector, a prototype is made at the Unit of Applied Research in Renewable Energy. It is constituted by the monocrystalline photovoltaic module (UDTS 50 type) below which circulates the air.
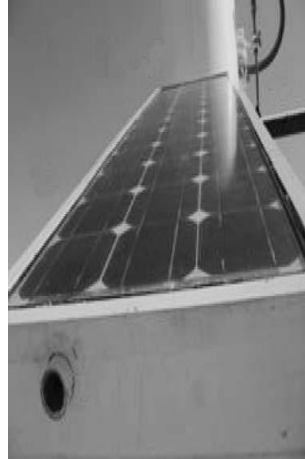

Figure 5 : Photograph of the prototype of hybrid PV/T air collector
at URAER Unity, Ghardaïa.

6. **Results and discussions**

In order to validate the results obtained by analytical modeling PVT collector, a numerical simulation with commercial software has been implemented; A choice was a commercial finite element software-COMSOL MULTIPHYSICS; taking into account the radiation and natural convection. The temperature profile is given below for an irradiation of 1000W/m² Fig.6 and Fig.7.

Teo et al. [17] were found that the the maximum temperature of the module occurs at the silicon cell. And explained that it was attributed to the high absorption of solar irradiation in silicon cell. Temperature of Tedlar was found higher than front glass of PV module; to be attributed to the closer location of the silicon cell compared to the front glass even though the thermal diffusivity of the glass is higher than Tedlar.
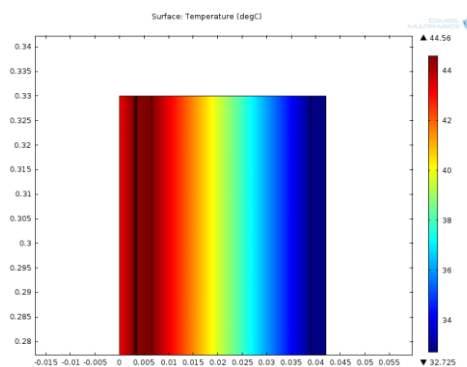
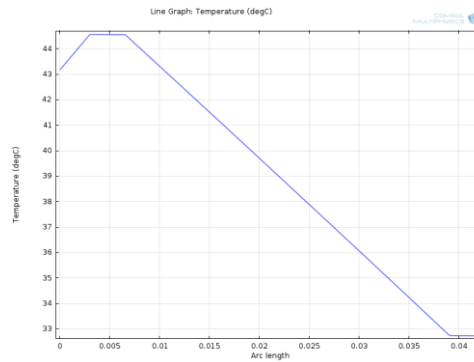*Figure 6: The temperature degraded in the in the prototype*

Figure 7: Curve geometric temperature changes in the studied prototype

The absorber is realized with the galvanized iron of high quality, allowing a good transfer of heat with lower cost compared to copper. Aims to increase its electric and thermal conversion energy effectiveness with a low cost compared to the already existing hybrid collector.

In order to analyze the behavior of the new hybrid PVT collector, a number of variables are required, weather-related, thermal quantities, electrical or fluid flow rates. For example a global radiation, ambient and sky temperature and the wind speed is maintained at 5 m/s.

Fig.8 shows the evolution of the fluid speed to a surface in the duct (A-vertical, B-Horizontal).

The temperature evolution in PVT collector is displayed in Fig. 9 and Fig. 10, its reaches a maximum value equal to 44°C, The maximum temperature occurs at the silicon cell, this is attributed to the high absorption of solar irradiation in silicon cell. Temperature of Tedlar is higher than front glass of PV module; this can be attributed to the closer location of the silicon cell compared to the front glass even though the thermal diffusivity of the glass is higher than Tedlar.

Fig. 11 shows the evolution of the outlet fluid temperature along the canal, it was found to be 33°C at L equal at 1.2 m.
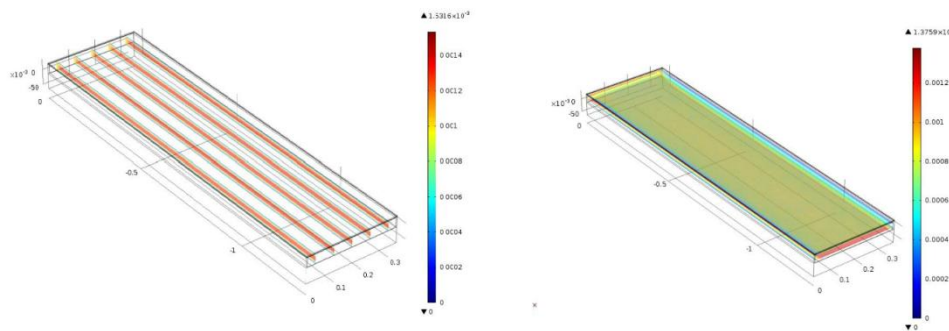

Figure 8: Evolution of the fluid speed to a surface in the duct (A-vertical, B-Horizontal)
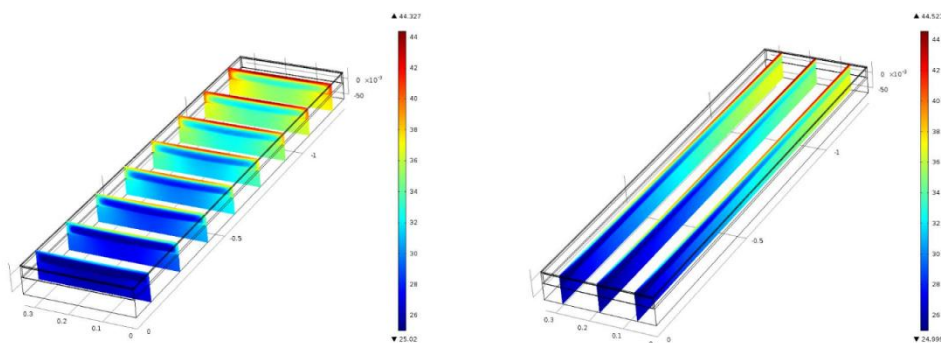

Figure 9: The temperature evolution in several vertical sections of PVT (A- along B- length) of PVT
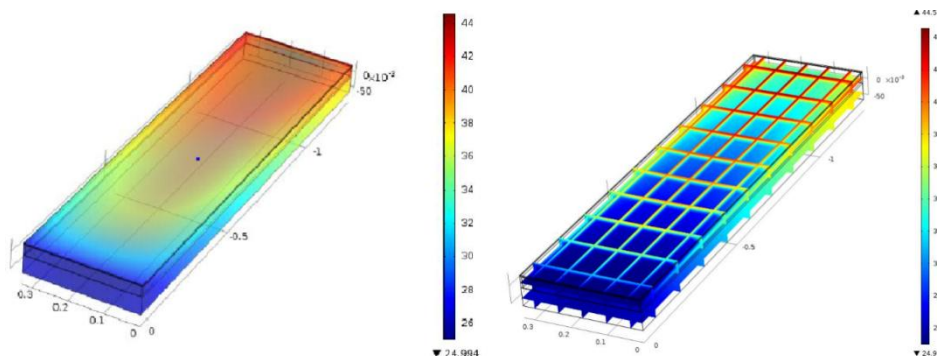
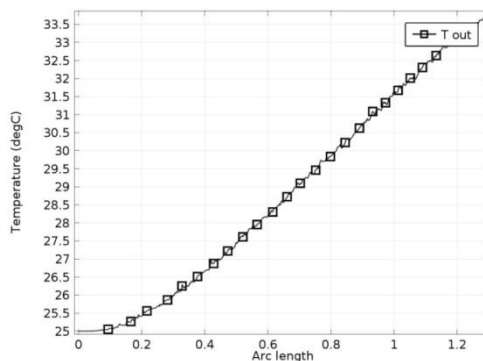Figure 10: Evolution of the temperature in the collector PVT 3D

Figure 11: Evolution of the outlet fluid temperature

Solving the system of equations governing heat transfer in the hybrid sensor allowed us to calculate the temperature change of each of its components in order to estimate the thermal and electrical performance of the collector. The useful thermal output reaches a value equal to 213 W in the mode of water heat exchanger of hybrid PVT collector [18].

The simulated value of outlet temperature has work have been validated by their corresponding experimental values in Ref. [19]. The test measurements were made on September 2008. The output temperature reached $37°$C for an input of $34°$C and an ambient temperature (T_a) of $33°$C. the increase in the temperature of the coolant of an average of $3°$C between the entry and the exit.

7. Conclusion

The hybrid PVT collector is designed to improve the electrical performance of photovoltaic module by lowering its operating temperature by inserting a thermal collector.

A configuration of an enclosure containing the coolant of the PVT collector has been studied to presented the performance thermal, Some results of this new configuration has been presented; these clearly show the direct impact of various parameters, in particular the solar radiation, ambient temperature, mass flow rate on the temperature profile of the collector.

The main of this configuration with galvanized steel absorber is to reduce the cost compared to the others configurations and increase the conversion energy.

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