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Energetic study of hybrid solar PV/T collectors

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Abstract - *The hybrid solar thermal (PV/T) offer an attractive option because the absorbed solar radiation is converted into heat and electricity. The ongoing conflict is well known between temperature and photovoltaic systems by the increase in solar irradiance, and thus the increase in ambient temperature, the cells become less efficient. For to stabilize in the operating temperature; the simple solution is to cool the cell even though it requires a refrigeration system power consumption, with which the overall performance also low.*

Résumé - *Le capteur thermique hybride (PV/T) offre une option intéressante, car le rayonnement solaire absorbé est convertie en chaleur et en électricité. L'incompatibilité existante est bien connue entre la température et les systèmes photovoltaïques ce qui signifie que selon l'augmentation de l'irradiation solaire, et donc l'augmentation de la température ambiante, les cellules deviennent moins efficaces, pour la stabiliser à la température de fonctionnement, la solution simple est de refroidir la cellule même si elle demande une consommation d'énergie du système de réfrigération, avec lequel le rendement global sera faible.*

Keywords: Hybrid - Collector - Photovoltaic - Thermal efficiency.

1. INTRODUCTION

Global demand for energy is growing rapidly due to industrial growth, population growth and the unorganized use of electricity. As human needs know no bounds, today, most countries in the world have experienced the problem of lack of electricity, which push toward investment in the different sources of renewable energy such as energy solar, wind ... these renewable energy resources, because of their very regionalized nature can contribute to a large extent, to achieve this energy deficit.

The photovoltaic/thermal hybrid system (PV/T) which converts the incident solar energy into both electrical and thermal is one of the best options regarding his work. In a typical PV panel, only 5-20 % of the incident sunlight is converted into electricity, while over 80 % is converted into heat is lost [1]. A PV/T unit, the heat can be extracted and used efficiently by attaching a heat exchanger to the rear of the photovoltaic module with air or water as the heat transport fluid. This will allow the PV component to operate at its optimal power and avoided the problem of the degradation of solar cells due to overheating.

Research in PV/T systems has been ongoing since the 1970s, and various system designs have been developed and studied theoretically, numerically and experimentally

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[2, 3]. The most recent work on these systems is based on the research of system design and the factors that could lead to an increase in electrical and thermal operating performance [4, 5].

The researchers conducted to date have exposed the potential of hybrid technology for a variety of applications [6]. In this study, a thermal model of hybrid solar collector water has been studied, the results are compared with those or both sensors are installed separately to see the behavior, energy performance of each system.

Early experimental studies involving PV/T systems were performed by modifying a commercial PV panel and retrofitting it with a heat collection apparatus [7, 8]. Retrofitted PV modules were also used by researchers during their efforts to evaluate the economic viability of the technology, since commercial products were not available at the time [8].

All researchers conclude that an economic study using actual commercial products is required for the accurate evaluation of a PV/T system's practicability [7]. A few localized studies have been performed, yet on experimental level and without taking into account the characteristics of commercially available products; therefore their applicability to commercial applications is limited [9].

In 2005, Zondag [10] proposed a state of the art solar PV/T hybrid based on the report of the European project PV Catapult [11]. Among the first studies identified by Zondag [10], some focus on the development of geometry and other components of the modeling methods. Thus, the work of Wolf [12] in 1976 parses a solar collector having PV system and coupled to heat storage modules.

Thereafter, the study by Kern *et al.*, in 1978 gives the basic principles of solar collectors using water or air as a coolant. Hendrie, 1982 [13] developed a theoretical model of PV/T hybrid based on correlations associated with conventional solar collectors.

In 1981, Raghuraman [14] presents numerical methods for performance prediction of solar PV/T of water or air. Later in 1985, Cox *et al.*, [18] developed simulation software to study the performance of PV/T hybrid air and emphasize the influence of the optical properties of the glazing on the thermal performance and electrical components of these solar. In 1986, Lalovic *et al.*, [16] proposed a new type of a-Si cells transparent as an economic solution for the construction of PV modules.

Various experimental and theoretical studies have been done then, for the development of PV/T hybrid [17]. Most research in this area for the purpose of evaluating the thermal and electrical performance and to analyze the economics of hybrid systems through the estimation of solar coverage provided. For this, some authors put the focus on the development of analytical thermal models or made following an electrical analogy.

Other research aims to optimize the performance of existing solar components by improving the operating conditions (slope, orientation of the component ...) or by proposed innovative geometric configurations. Thus, they are based on the change in the dimensions or material properties of Incorporation (thermal insulation, absorber, PV cells ...) or heat transfer fluids (air, water ...).

These improvements are intended to increase the amount of solar energy absorbed and the heat transfer between the coolant and the absorber to reduce heat losses with the outer. The performance of the sensor can be calculated taking into account the temperature distribution between two tubes of the sensor, and assuming that the temperature gradient in the flow direction is negligible.

2. THEORETICAL STUDY OF THE COLLECTOR

We produced a prototype of the thermal photovoltaic hybrid collector to central solar power stations of the Unit for Applied Renewable Energy located at Ghardaïa in the south of Algeria (Fig. 1).

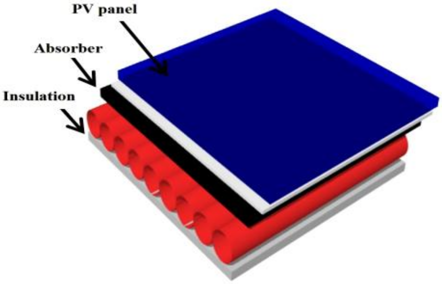

Fig. 1: Design of collector PVT

This hybrid collector of new design is primarily made up of photovoltaic module of single-crystal type UDTS 50 in technology and an absorber thickness 2 cm stuck below the photovoltaic module, a coolant (liquid or air) can circulate inside this absorber and collects the heat emitted by the solar cells, there will be thus also cooling of the cells and thus the electric output will increase. One speaks about the total output of conversion for the hybrid sensors photovoltaic thermal which is equal to the sum of the electric output and the thermal efficiency.

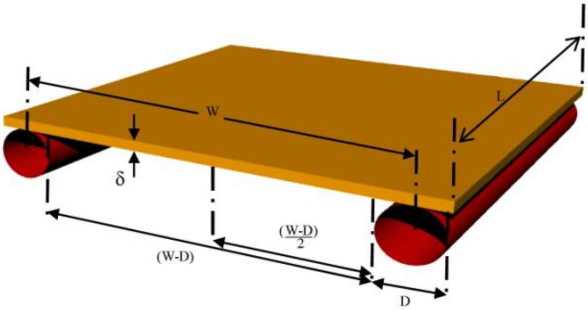

Fig. 2: Geothermal collector absorber PVT

Under steady-state conditions, the rate of useful heat delivered by a solar collector is equal to the rate of energy absorbed by the heat transfer fluid minus the direct or indirect heat losses from the surface to the surroundings, As shown in Figure 2, the absorbed solar radiation is equal to $G_{\tau\alpha}$, which is similar to Equation (1). The thermal energy lost from the collector to the surroundings by conduction, convection, and radiation is represented by the product of the overall heat loss coefficient, U_L times the difference between the plate temperature T_p, and the ambient temperature T_{amb}.

Therefore, in a steady state, the useful energy from a collector of area A_c can be obtained from:

$$Q_u = A_c \times [G_{glo}(\tau\alpha) - U_L(T_p - T_{amb})] = \dot{m} \times C_p \times (T_s - T_e) \quad (1)$$

An elemental region of width Δx and unit length in the flow direction is shown in Figure 3. The solar energy absorbed by this small element is $S \times \Delta x$ and the heat loss from the element is $U_L \times \Delta x (T_x - T_{amb})$, where T_x, the local plate temperature.

Therefore, an energy balance on this element gives:

$$S \times \Delta x - U_L \times \Delta x \times (T - T_{amb}) + \left(-\lambda\delta \times \frac{dT}{dx} \right)\Bigg|_x - \left(-\lambda\delta \times \frac{dT}{dx} \right)\Bigg|_{x+\Delta x} \quad (2)$$

Where S is the absorbed solar energy. Dividing through with Δx and finding the limit as Δx approaches 0 gives:

$$\frac{d^2T}{dx^2} = \frac{U_L}{\lambda\delta} \times \left(T - T_{amb} - \frac{S}{U_L} \right) \quad (3)$$

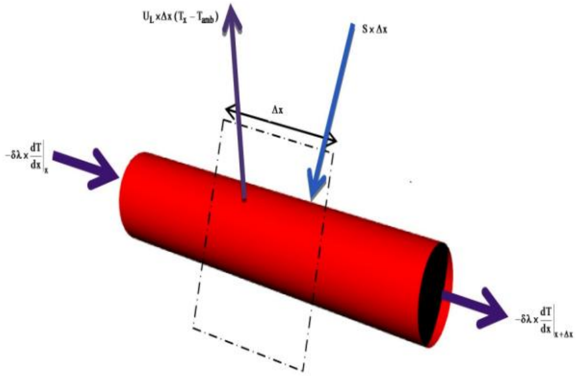

Fig. 3: Energy balance on fin element

The two boundary conditions necessary to solve this second-order differential equation:

$$\frac{dT}{dx}\bigg|_{x=0} = 0 \qquad \text{and} \qquad \frac{dT}{dx}\bigg|_{x=L} = T_b$$

For convenience, the following two variables are defined.

$$m = \sqrt{U_L / \lambda\delta} \quad (4)$$

$$\varphi = T - T_{amb} - S / U_L \quad (5)$$

Therefore, equation (3) becomes:

$$\frac{d^2\varphi}{dx^2} - m^2 \times \varphi = 0 \tag{6}$$

This has the boundary conditions:

$$\left.\frac{d\varphi}{dx}\right|_{x=0} \quad \text{and} \quad \varphi\big|_{x=L} = T_b - Tamb - S/U_L$$

Equation (6) is a second-order homogeneous linear differential equation whose general solution is:

$$\varphi = C_1' \times e^{mx} + C_2' \times e^{mx} = C_1 \sinh(mx) + C_2 \cosh(mx) \tag{7}$$

The first boundary yields $C_1 = 0$, and the second boundary condition yields.

$$\varphi = T_b - T_{amb} - S/U_L = C_2 \cosh(mL)$$

$$C_2 = \frac{T_b - T_{amb} - S/U_L}{\cosh(mL)}$$

With C_1 and C_2 known, equation (7) becomes:

$$\frac{T - T_{amb} - S/U_L}{T_b - T_{amb} - S/U_L} = \frac{\cosh(mx)}{\cosh(mL)} \tag{8}$$

This equation gives the temperature distribution in the x, direction at any given y.

The energy conducted to the region of the tube per unit length in the flow direction can be found by evaluating the Fourier's law at the fin in:

$$q'_{fin} = -\lambda\delta \left.\frac{dT}{dx}\right|_{x=L} = \frac{\lambda\delta m}{U_L} \times (S - U_L(T_b - T_{amb})) \times \tanh(mL) \tag{9}$$

Equation (9) accounts for the energy collected on only one side of the tube; for both sides, the energy collection is:

$$q'_{fin} = (W - D) \times F[S - U_L(T_b - T_{amb})] \times \frac{\tanh[m(W - D/2)]}{m(W - D/2)} \tag{10}$$

Or with the help of fin efficiency:

$$q'_{fin} = (W - D) \times F[S - U_L(T_b - T_{amb})] \tag{11}$$

Where factor F_{in} equation (11) is the standard fin efficiency for straight fins with a rectangular profile, obtained from:

$$F = \frac{\tanh[m(W - D/2)]}{m(W - D/2)} \tag{12}$$

The useful gain of the collector also includes the energy collected above the tube region. This is given by:

$$q'_{tube} = D \times [S - U_L \times (T_b - T_{amb})] \tag{13}$$

Accordingly, the useful energy gain per unit lenght in the direction of the fluid flow is:

$$q'_u = q'_{fin} + q'_{tube} = [(W - D) \times F + D] \times [S - U_L \times (T_b - T_{amb})] \qquad (14)$$

This energy ultimately must be transferred to the fluid, which can be expressed in terms of two resistances as:

$$q'_u = \frac{T_b - T_f}{\dfrac{1}{h_f \times \pi \times D_i} + \dfrac{1}{C_b}} \qquad (15)$$

Where $h_f \times \pi \times D_i$, heat transfer coefficient between the fluid and the tube wall.

In Equation (15), C_b is the bond conductance, which can be estimated from knowledge of the bond thermal conductivity, λ_b the average bond thickness δ, and the bond width b. The bond conductance on a per unit length basis is given by (Kalogirou, 2004).

$$C_b = \lambda_b \times b / \delta \qquad (16)$$

The bond conductance can be very important in accurately describing the collector performance. Generally it is necessary to have good metal-to-metal contact, and preferably the tube should be welded to the fin.

Solving Equation (15) for T_b, substituting it into Equation (14), and solving the resultant equation for the useful gain, we get:

$$q'_u = W \times F' \times [S - U_L \times (T_f - T_{amb})] \qquad (17)$$

Where F' is the collector efficiency factor, given by:

$$F' = \frac{1 / U_L}{\dfrac{1}{h_f \times \pi \times D_i} + \dfrac{1}{C_b} + \dfrac{1}{W[D + (W - D)F]}} \qquad (18)$$

A physical interpretation of F' is that it represents the ratio of the actual useful energy gain to the useful energy gain that would result if the collector absorbing surface had been at the local fluid temperature. It should be noted that the denominator of Equation (18) is the heat transfer resistance from the fluid to the ambient air.

The collector efficiency factor is essentially a constant factor for any collector design and fluid flow rate.

The ratio of U_L to C_b, the ratio U_L of to ($h_f \times \pi \times D_i$), and the fin efficiency F are the only variables appearing in Equation (18) that may be functions of temperature.

3. COLLECTOR EFFICIENCY

The main parameter to describe the solar collector performance is the instantaneous efficiency.

The collector efficiency is defined in steady-state conditions as:

$$\eta_{collector} = Q_u / Q_{in} \qquad (19)$$

Or, using the formula [18]:

$$\eta_{collector} = F_R \left((\alpha\tau)_{eff} - U_L \frac{T_s - T_{amb}}{G_{tot}} \right)$$

Where Q_u the useful heat power is provided from the collector to the working fluid and Q_{in} is the input heat flux provided by the solar radiation.

The useful heat power Q_u is obtained as:

$$Q_u = \dot{m} \times C_p \times (T_s - T_e) \quad (20)$$

Where $\dot{m}$ the mass flow rate flowing through the tube welded in the absorber element T_e and T_s is the inlet and outlet fluid temperatures and C_p is the specific heat of the working fluid.

The input heat flux Q_{in} is defined as:

$$Q_{in} = G_{tot} \times A_{collector} \quad (21)$$

Where Q_{tot} is the global solar irradiance and $A_{collector}$ the reference area of the collector.

To describe the collector efficiency is so necessary to define the reference area.

Three kinds of area are defined for a solar thermal collector:

- the absorber area is the area of the absorber element
- the aperture area is the area of the cover surface where the solar radiation enters the collector;
- the gross area is the total area occupied from a collector module.

In Figures and are reported the reference areas in the most common solar thermal collector: flat-plate collector, evacuated tube collector with and without external reflector.

4. RESULTS OBTAINED

The preceding equations describe the model electric and thermal photovoltaic hybrid sensor thermal news configuration; we worked out a data-processing program which enabled us to simulate the dynamic behavior of our hybrid sensor and the two other collectors in non-stationary mode (according to time).

4.1 Test bench procedure

The testing bench is realized in URAER (Fig. 4), consists of three collectors: the solar hybrid collector and two witness collectors. The objective is to see the behavior of the hybrid solar collector to other traditional collector (photovoltaic module and thermal collector).

4.2 Distribution of temperatures

The profile of temperature in different the layers from hybrid collector PVT studied is given on figure 5. The three layers of the photovoltaic module are the pane, the layer of the solar cells as well as the layer of tedlar, is added to that the high layer of the absorber, the fluid and the low layer of the absorber.

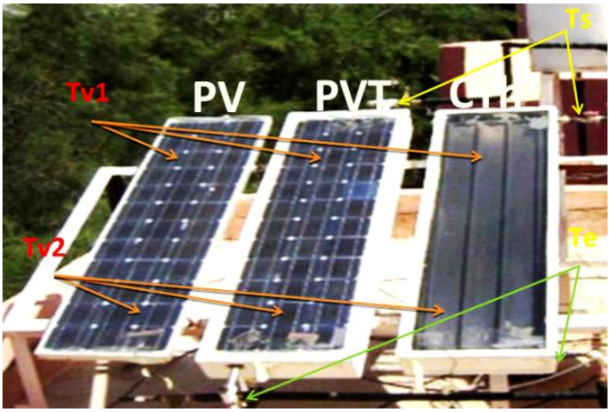

Fig. 4: Experimental test bench

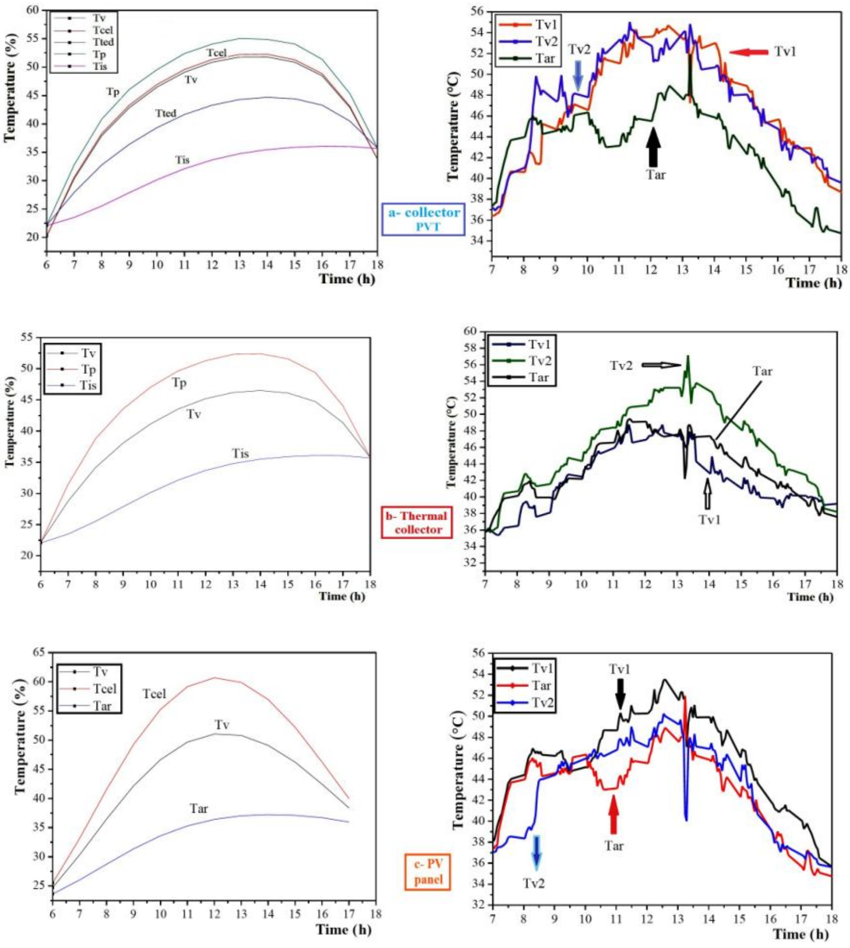

Fig. 5: Distribution of temperature in different collector

Figure 5 shows the variation in the temperature inside the thermal photovoltaic hybrid collector, photovoltaic module and thermal collector, part of the solar radiation absorptive by the solar cells will be transformed into electric power and a part in calorific energy which is transferred by the mechanisms from transfer of heat to the coolant.

5. CONCLUSION

According to the increase in solar irradiation and therefore the increase in ambient temperature, the cells become less efficient, for to stabilize them in at operating temperature. The easy solution is to gool the cell. On the other hand, a disadvantage of solar energy is the need for large surface to obtain significant amounts of energy with this new system we can reduce the surface of the facility required, in addition, the prolongation of the duration of the lives of these systems solar hybrid is one aspect which should also be considered in use, since operating at the small temperature which gives an advantage to the semiconductor as other electronic components, which form cells and the photovoltaic panels.

A final aspect to be considered in favor of the idea of combination of the collector is the reduction of initial production costs of products at the end of the installation, since many thermal elements are common in photovoltaic panels as (reinforcement, insulation, covers, etc.) is not required to reproduce.

For all previously stated, we can say that our goal is to achieve a more efficient technique for exploiting a solar sources for the benefit of the materials and methods used (galvanized steel, water) are reduced cost and required installation area.

In addition to the photovoltaic part we get a better performance of the panel, for which reason its use does not change, with the removal of the evacuate thermal energy, what’s used in various other applications exist (water heating, drying, conditioning, etc.).

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