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Study and modelling of a photovoltaic thermal hybrid solar collector with cylindro-parabolic concentrator

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Abstract— **this study is related to the thermal behaviour of photovoltaic-thermal solar with a solar concentrator. We present the influence of inlet parameters on the electrical and thermal performance of the collector the parameters affecting the PV/T performance such as the glazing, mass flow rate, and temperature of collector element and absorber impedance and also the ratio of compound parabolic concentrator (CPC) design types were discussed in details. The solar radiation intensity have been carried out for slope of collector at 30°C which is a typical day temperature in Constantine (east Algeria) at the surface cell The main results can be summarized as follows. The temperature increases throughout the system with the concentration in comparison with the situation without concentration. Moreover, the concentration increases the thermal efficiency and reduces energy efficiency. When the mass of the fluid increases its temperature and that of the absorber decreases while that of the cell increases.**

Keywords— **photovoltaic- thermal- concentrator-mass flow-performance- temperature of collector- surface cell- cpc-exergy efficiency**

I. INTRODUCTION

The weather conditions of Algeria, with a good level of insulation, should encourage more development of renewable energies, especially those coming from the direct usage of sun, like photovoltaic and solar thermal collectors with CPC concentrator as application of photovoltaic-thermal (PV/T) systems. The main idea is to increase the electrical production of PV by decreasing the normal operating cell temperature by cooling the panel with water (or air), but also to have higher global efficiency with an enhanced use of solar energy.

So PV/T aims to utilize the same area both for producing electricity and heat.

The photovoltaic-thermal technology has been studied since the 1970 when the energy crises increase the development of alternative ways of producing energy to that of fossil fuels. The different types of photovoltaic cogeneration (ventilated, day lighting, PV/T) are well described [1]. To reduce the costs of any photovoltaic system was developed in 1978 a PV / T system with air or water as a coolant in order to increase the photovoltaic efficiency by reducing the temperature cell [14]. The use of heat as the heat transfer fluid enables the indirect reduction of the system costs. This has stimulated a lot of research in simulation of such hybrid systems.

However, the wide application of solar energy hybrid PV/T system is still limited because of its expensive investment. In recent years, in order to reduce the cost of combined PV/T system, considerable research were reported in the literature on new solar concentrating photovoltaic/thermal systems (Garg etal.[6], O'Leary et al. [7], Whitfield et al.[8], Othman etal.[9], Chen et al.[10]).

In this work, we develop a program that simulates the operation of a hybrid system parabolic concentration by introducing the effect of the mass of the fluid temperatures on its various components.

II. DYNAMIC DESCRIPTION OF THE PV/T CPC CONCENTRATORMODE

Hybrid photovoltaic/thermal (PV/T) system with solar concentrator is an effective way to improve solar energy conversion efficiency. In this work, a single-pass PV/T air system with a three-trough compound parabolic concentrator (CPC) (fig.1) is used. The heat transfer models of all main components in this system are developed with the energy balance. The effects of some main designing and operational parameters on the electric-thermal performance of the system are analysed.

III. SYSTEM MODEL

The system schematic model and heat transfer is shown in Figure 1. The system consists of a low iron glass cover, reflectors, solar cells, absorber panel, back panel, fins and insulating material. Passing through the glass cover, the sunlight is concentrated onto solar cells by the CPC. The solar cells are connect and in series along the length direction of the system. The upper channel formed by the glass cover and the absorber panel over which the solar cells are pasted is enclosed to keep cell surfaces clean. The cooling air flows in the lower channel formed by the back plate and the fins attached to the back of absorber panel. The compound parabolic concentrators concentrate solar radiation onto the solar cells. The fins on the back of the absorber panel enhance the heat transfer to the air and improve the efficiency of the system.

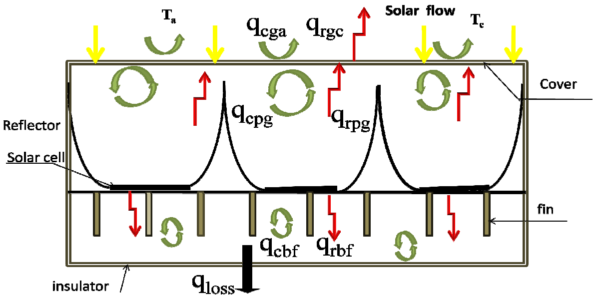

Fig.1 solar collector with CPC concentrator

- Energy balance of Glass cover

$$\mathrm{\alpha_g GC\left(1+\tau_g\rho_p\rho_R^{2\bar{n}}\right)=h_{rgs}\left(T_g-T_P\right)+h_{cgw}\left(T_g-T_w\right)}$$
$$\mathrm{+h_{cpg}\left(T_g-T_P\right)+h_{rgs}\frac{A_{ct}}{A_c}\left(T_g-T_P\right)}\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (1)$$

Where $n=(\frac{A_r}{A_{pv}})E_d$ is the average number of reflection for radiation inside the acceptance angle [12], [5], where A_r and A_{pv} are the areas of reflector and solar cell, respectively; Ed is the fraction of radiation emitted by truncated CPC and goes to the solar cell Photovoltaic/thermal plate:

- Energy balance of Photovoltaic/thermal plate

$$\mathrm{\alpha_p\tau_g G\rho_R^{\bar{n}}d\left[1+\left(\frac{\rho_p\rho_g\rho_R^{2\bar{n}}}{C}\right)\right](1-P)+}$$
$$\mathrm{\alpha_{pv}\tau_g GP\rho_R^{n}d\left[1+\left(\frac{\rho_{pv}\rho_g\rho_R^{2\bar{n}}}{C}\right)\right]\left(1-\eta_{pv}\right)=}$$
$$\mathrm{h_{cpg}\frac{A_{ct}}{A_c}\left(T_p-T_g\right)+h_{rpb}\frac{A_{cb}}{A_c}\left(T_p-T_b\right)+}$$
$$\mathrm{h_{cpf}\frac{A_{ct}}{A_c}\eta_p\left(T_p-T_f\right)+h_{rpb}\frac{A_{cb}}{A_c}\left(T_p-T_b\right)}\ldots\ldots\ (2)$$

Where d is a correction of gap loss [6].

$\varphi_p$is the total efficiency of the absorber plate [15]

$$\varphi_p=\frac{A_c+A_{fin}\eta_f}{A_{cb}}\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

Where $\eta_p$is the fin efficiency?

$$\eta_f=\frac{\tanh\,(mH_f)}{\lambda_f\delta_f},\ m=(\frac{2h_f}{\lambda_f\delta_f})^{1/2}\ldots\ldots\ldots\ldots\ldots\ldots(4)$$

The solar cell efficiency depends on the cell temperature as given by reference. [13], [5]

$$\mathrm{\eta_{pv}=\eta_{ref}[1-0.0054(T_P-298.15)]}\ldots\ldots\ldots\ldots\ (5)$$

Where $\eta_{ref}$is a reference efficiency of solar cell at solar irradiance 1000 W/m2 and temperature Tref=25°C. In this work η_{ref} is taken as 10% [8].

- Energy balance of Cooling air

$$\mathrm{\frac{mC_f dT_f}{wdx}=h_{cpf}\frac{A_{cb}}{A_c}\eta_p\left(T_p-T_f\right)+h_{cpf}\left(T_p-T_f\right)}\ldots\ldots(6)$$

- Energy balance of Absorber

$$\mathrm{h_{rpb}\frac{A_{cb}}{A_c}\left(T_p-T_b\right)+h_{cpf}\left(T_p-T_f\right)=U_b(T_b-T_a)}\ldots\ldots\ (7)$$

IV. HEAT TRANSFER COEFFICIENTS

In the above equations, Radiative and convective heat transfer coefficients are calculated using the relations reported in refs. [10], [5],[11].

- Radiative heat transfer between the glass cover to sky

$$h_{rgs}=\frac{\varepsilon_g\delta[({T_g}^4-{T_s}^4)]}{T_g-T_a}\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(8)$$

Where the equivalent sky temperature is evaluated as [2],[11].

$$\mathrm{T_s}=0.0552T_a^{1.5},\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(9)$$

- Radiative heat transfer between the glass cover to absorber plate [2],[9].

$$h_{rpg}=\delta(T_p+T_g)(T_p^2+T_g^2)/((1/\varepsilon_p)+(1/\varepsilon_g)-1)..(10)$$

- Convective heat transfer between the glass cover to an ambient [3],[10].

$$h_{cgw}=2.8+3V_w\ldots\ldots\ldots\ldots\ldots\ldots(11).$$

- Convective heat transfer between the solar cells and glass cover [4].

$$h_{cpg}=\left(\frac{l}{H_{pg}}\right)\left\{1+1.44\left[1-\frac{1708}{RaCos\beta}\right]^{+}\times\left[1-\right.\right.$$
$$\left.\left.sin(1.8\beta)^{1.6}/\frac{1708}{RaCos\beta}\right]+[\left(\frac{RaCos\beta}{5830}\right)^{(1/3)}-1]^{+}\right\}\ldots\ldots\ldots\ldots(12)$$

- The forced convective heat transfer coefficient of cooling air [3],[11].

$$\mathrm{h_{cpf}=h_{cbf}\left(\frac{l}{D}\right)[0.0158Re^{0.8}+.(0.00181Re+}$$
$$\mathrm{2.92)exp^{\left(-\frac{0.03795X}{D}\right)}}\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(13)$$

Where D is the hydraulic diameter of the channels; Re is the Reynolds number; x is the distance from the entrance.

V. NUMERICAL PROCEDURE

When substitute the equations. (1), (2) and (6) into equation (7), we can eliminate variables T_g, T_p and T_b from equation (3), and give the following first-order linear differential equation.

$$\frac{dT_f(x)}{dx} + pT_f(x) = q \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots..(14)$$

Where p and q are the constants obtained through algebraic manipulations.

The boundary condition is $T_f(x) = T_i,\ \text{at}\ x = 0$

$T_f(x) = T_o, \text{at}\ x = l$

Solving eq. (14) yields the air temperature in x-direction

$$T_f(x) = \frac{q}{p} + \left(T_i - \frac{q}{p}\right) e^{-px} \dots\dots\dots\dots\dots\dots\dots\dots\dots...(15)$$

And the outlet air temperature

$$T_0 = \frac{q}{p} + \left(T_i - \frac{q}{p}\right) e^{-pl} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots... (16)$$

The numerical calculations are based, an iterative procedure winch is adopted to incorporate the effect of the temperature dependence of various heat transfer coefficients .the temperature, is first calculated by using Gauss –Seidel methods. The equations are solved by assuming the heat transfer coefficients constant and then new solutions are used to generate all the heat transfer coefficients again till the values converge. The region of concentrating PV/T system is divided into 50 units (n =55) with each of 0.20 m, to start calculation, T_g, T_p (T_p=T_{pv}) and Tb are guessed for all the units respectively. The inlet temperature of the airflow at x=0 is equal to the ambient temperature ($T_{i,1}$=T_a). With these temperatures, the heat transfer coefficients and electrical efficiency of solar cell are evaluated for the first unit, and then new temperatures can be obtained by solving the energy equations. The iteration process is continued with the latest updated variables until all the temperature values converge. Thus the outlet temperature of the airflow for the first unit can be determined. Applying it as the inlet one to the next unit, the outlet temperature for the second unit can be similarly calculated. With Repeat this step, all temperatures for different components can it be determined.

VI. PERFORMANCE PARAMETERS

Some main performance parameters of the hybrid PV/T are defined and calculated as follows. The useful thermal energy gained by airflow through the PV/T system is

$$Q_u = \sum_{j=1}^{n} Q_{u,j} = \sum_{j=1}^{n} mC_f\left(T_{o,j} - T_{i,j}\right) \dots ...(17)$$

The thermal efficiency of the concentrating PV/T system is [1],[8].

$$\eta_t = \frac{Q_u}{GC} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots ....(18)$$

The power energy generated by the concentrating PV/T system is

$$E_{pv} = \sum_{j=1}^{n} E_{pv,j} = \sum_{j=1}^{n} \tau_g \alpha_{pv} G P \rho_R^{\bar{n}}\, d \left[1 + \left(\frac{\rho_{pv}\rho_g\rho_R^{2\bar{n}}}{C}\right)\right] \rho_{pv,j} \text{ ....(19)}$$

The combined photovoltaic-thermal efficiency of the system is the sum of photovoltaic and thermal efficiencies of the system [2] as

$$\eta_{pvt} = \frac{Q_u + E_{pv}}{CG} = \eta_{pv} + \eta_t \dots\dots\dots\dots\dots\dots\dots\dots\dots ....(20)$$

The energy efficiency of the combined photovoltaic- thermal system is [3]

$$\eta_{energy} = \eta_{pv} + \eta_t \left[1 - \frac{298}{298 + (T_{o,air} - T_{a})}\right] \dots\dots\dots ....(21)$$

TABLE I

Thermo-physical parameters of the PV/T system

Parameter	value	Parameter	value
α_p	0.95	α_p	0.95
τ_g	0.90	ρ_R	0.94
ρ_a	0.05	ε_g	0.86
ρ_g	0.06	ε_p	0.95
α_{pv}	0.90	λ	203.6
c_f	1008	ε_R	0.94
d	*0.95*	ε_b	0.95
H_{pg}	0.191	α_g	0.04
$\bar{n}$	0.61	Ta	298
P	*0.52*	C	2.00

VII. RESULTS AND DISCUSSIONS

Some main thermo-physical used in the calculation are in table 1. The system dimensions are 0.636m*11m (W*L).

The fin dimensions are 0.0015m*0.025m*11m (δ *H*L).

Number of the fins is 200.

The operating conditions for the calculated PV/T system are: the wind velocity is 3 m/s, and the range of solar radiation intensity is 200-1200 W/m^2.

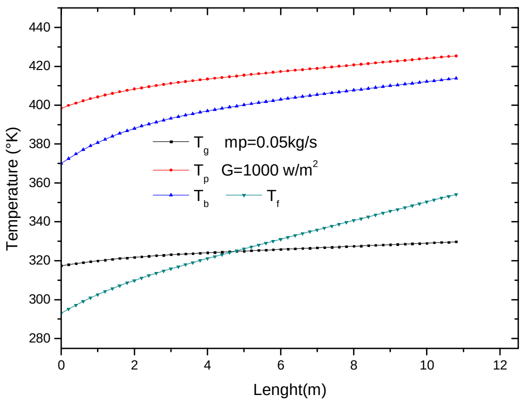

Fig.1 Variation of temperature of collector

[M=0.05kg/s, G=1000 w/m2]

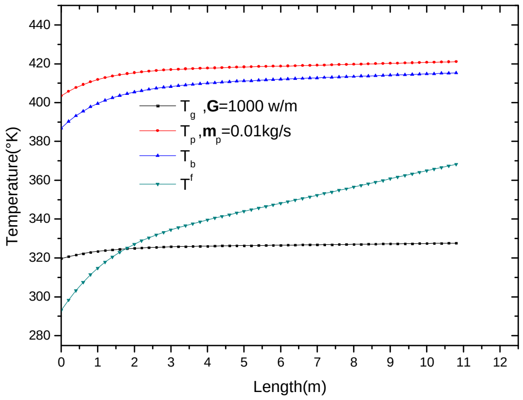

Fig.2 Variation of temperature of collector

[M=0.01kg/s, G=1000 w/m2]

Figure 1and 2 illustrate the temperature variations of the components along the length of the system with and without CPC concentrator in m. the case of G=1000 W/m2, M=0.01 kg/s, the temperatures increase along the length of the system, and the solar cell temperature is higher.

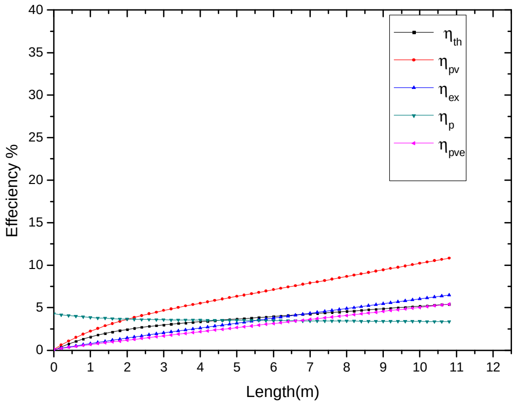

Fig.3 Variation of efficiency of solar PV/T

[M=0.01kk/s, G=1000 w/m2]

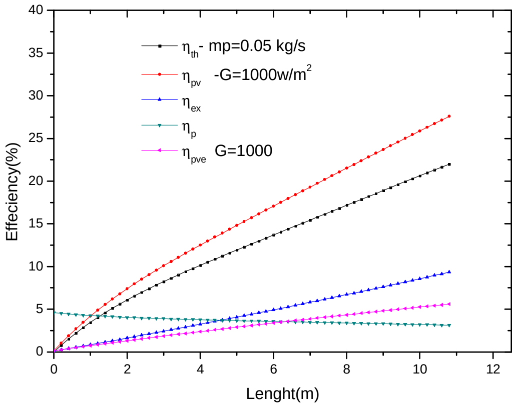

Fig.4 Variation of efficiency of solar PV/T

[M=0.05kk/s, G=1000 w/m2]

Figure 3 and 4 presents the variations of the electrical, thermal, exergy and system efficiencies of the system with CPC in the length direction. It can be seen that the thermal, exergy and system efficiencies increase along the length direction, but the electrical efficiency decreases.

The combined efficiency of the system with CPC is al-most 35% which is close to the value obta [1] the energy efficiency of 12.6% of the system with CPC is higher due to the increasing of temperature.

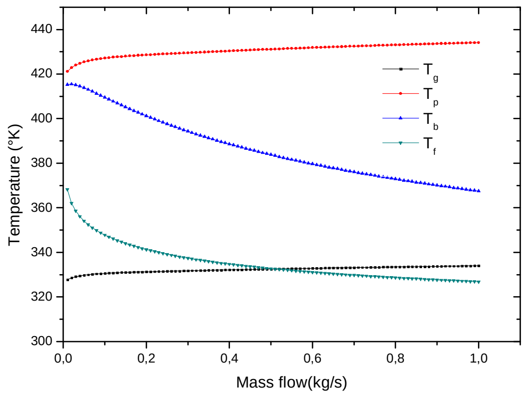

Fig.5 Effect of mass flow of the fluid on the local temperature of system

Figure 5 present de effect of mass of the fluid on the local temperature of element of collector, we remark the temperature of fluid decrease when the mass flow increase, the same remark that the temperature of absorber, but the temperature of cell increase when the mass flow of fluid increase

VIII. CONCLUSION

The simulation of the system PV / T with CPC hub has the following results.

Temperatures on the cover glass plate, on the surface of the cell and on the insulating rear face are an increasing function of the distance x measured in the direction of fluid flow. If one comported the temperatures of any point on the direction of the flow that of cell and absorber are higher than those of the glass. Moreover, the study confirms that the effect of the hub increases the temperatures of all components of the system in comparison with a system without concentration. The concentration is a very effective method to reduce the cost and weight of material the CPC system would compare with the system without concentration.

The study shows that the yields of electric current, developed by the cell, and the exergy thermal efficiency of the system increases with the distance x measured in the direction of flow.

The study of the outputs shows that the electric current developed by the cell, the output of exergy and thermals of the system increases according to distance X measured in the direction of the flow.

The effectiveness of cell decreases in the same conditions the increase in mass flow of the fluid, allows improving the photovoltaic and thermics effectiveness of the hybrid system by decreasing the fluid and the insulating wall and explained good heat exchange between the fluid and the plate of the solar cells.

The electric current developed by the cells, the exergy and the electric and thermal effectiveness are better with than without CPC.

The temperature of fluid increases exponentially at the beginning of this one to reach a balance far from his departure. The difference between the temperatures of the cells, and the fluid decreases when X increases.

With a constant radiation, the increase in the flow of exchanged fluid increases the thermal effectiveness and decreases the electric effectiveness.

All the temperatures of the system decreases when the flow increases, thus reduce the losses of heat with the environment, follows then the improve of the system effectiveness, but the ventilation increases.

IX. NOMENCLATURE

Ai	Area	m2
Cf	Specific heat	J/Kg .k-1
G	Solar irradiation	W/m2
T	Temperature	K
L	Length of collector	m
W	Width of collector	m
U	Heat loss coefficient	(W.m-2.K-1)
M	Mass flux	(kg.s-1)
V	Wind velocity	(m.s-1)
P	Area of absorber covered by cells	m2
Q	Heat	W
E	Electrical energy	W
h	heat transfer coefficient	W.m-2.K-1

Creek letters	
α	Absorptivity
ρ	Reflectivity
τ	Transitivity
θ	Acceptance angle
λ	Thermal conductivity$W.m^{-1}.K^{-1}$
δ	Thickness m
Subscripts	
a	Ambient
b	Back pate
c	Convective
f	Fin
p	Absorber plate

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