Modeling of a cylindro-parabolic solar collector and simulation by Matlab software

E. Al Ibrahmi[1]*. S. E Lachhab[1]. F. Hamdaoui[2]. I. El Amrani[1]. A. Achhar[2]and L. Dlimi[1].

[1]Laboratory of Renewable Energies and Environment. University Ibn Tofail. Faculty of Sciences. BP. 133. 14000-Kenitra. Morocco.
[2]Laboratory of Agro-physiology, Biotechnologies, Environment and Quality. Team; Water, Wastewater and Health. University Ibn Tofail. Faculty of Sciences. BP. 133. 14000-Kenitra. Morocco.
*Corresponding Author. E-mail: alibrahmielmehdi@yahoo.fr. (+212669666346)

Abstract— the objective of this study is the use of a cylindro-parabolic solar concentrator in the transformation of solar energy into thermal energy. The reflector and the absorber used have a specific geometrical shape of 2m in length, 2cm in thickness and 6cm in width. A mathematical approach is made by the MATLAB software, of which we simulated a theoretical calculation applied to the dimension proposed to the system studied[12]. The parameters studied in the form of the equations in our simulation are the inlet and outlet temperature in the heat coolant fluid, the absorber and glass temperature, the irradiation flux, and the tilt factor[4].This study also aims at the modeling of the heat transfer of a cylindrical-parabolic solar collector with the values of daily sunshine in Morocco. In addition, we have studied more particularly the solar energy which makes it possible to recover the heat of this solar radiation within a fluid [1-2].The results obtained by this simulation show a good correlation between the experimental curves by the dimensioned system and the theoretical values in the bibliography[8].

Keywords: solar energy, cylindrical-parabolic, simulation of Matlabsoftware, reflector, absorber, irradiation flux.

1 INTRODUCTION

THE world has been experiencing significant economic, industrial and social development for more than a century, leading to strong growth in energy demand.Unfortunately, most of this growth has been covered by fossil energy sources, including CO2 and other greenhouse gases [7].

As an alternative to these concerns, the development and implementation of renewable energies has become necessary. Thermodynamic solar transforms solar energy into heat at high temperature, then converts this heat into electrical energy. This mode of conversion can be done in four technological streams: Cylindro-Parabolic, Fresnel, Central Receiver and Parabola-Stirling [11].

The sensor is a simple absorber of direct and diffuse solar radiation which transforms them into heat. Solar radiation is not only absorbed by the sky, but also by the whole environment [1]. The design of a collector and the effect of concentration involve very complex techniques. The principle of which provides a focusing of incident radiation on a surface absorber that is reduced with respect to the opening surface of the collector in order to increase the concentration of the direct radiation at the absorber levels.

2 THE SOLAR POTENTIAL IN MOROCCO

The solar field is a set of data describing the evolution of solar radiation available over a period of a year. It can be used to simulate the functioning of a solar energy system and to make an exact sizing as possible [6]. Because of its geographical location, Morocco has an enormous solar deposit (fig.1). The acceleration of economic and social development in Morocco has led to a significant increase in demand for energy [9]. To meet these growing energy needs, Morocco has defined a new strategy based on three major axes. These are namely the diversification of energy supply, the development of these energy resources, and the exploitation of energy efficiency potential in key sectors of the national economy[12].

ISSN 2229-5518

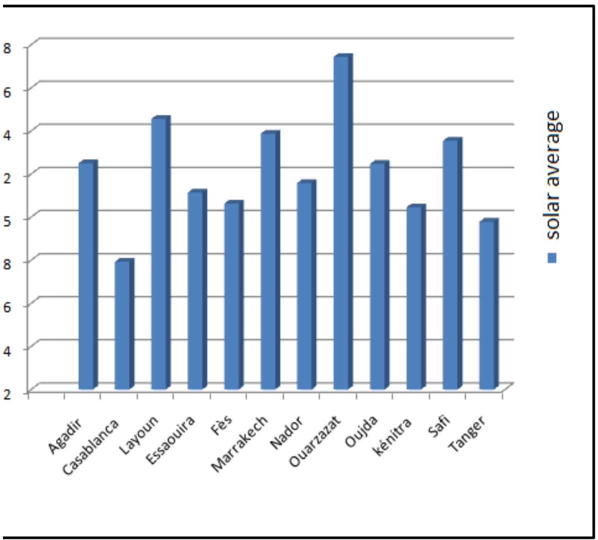

Figure 1: Average global irradiations of some cities in the Kingdom (kWh / m²) (National Meteorology reference source) [2-6].

3 Presentation of some possible configurations: Case of a Cylindro-parabolic mirror.

3.1 Mathematical study

In this work we limit ourselves to two dimensions, knowing that the properties of a paraboloid of revolution are the same as those of its generatrix such as a parabola of equation($2py = x^2$). Let an incident ray Ic, parallel to the y-axis, touch the parabola at the point (x, y). By definition, the tangent t at the point (x, y) makes with the x-axis an angle α given by the relation[4]:

$$\tan\alpha = f'(x) = \frac{x}{p}$$

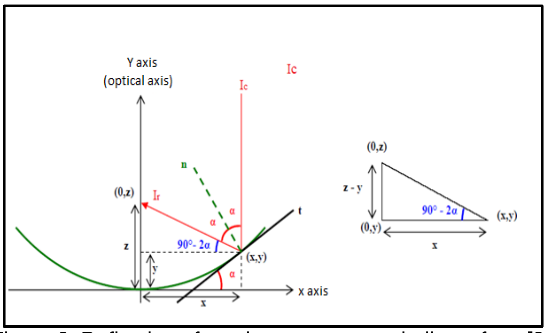

Figure 2: Reflection of a solar ray on a parabolic surface [3-5-7]

Let us draw the normal n, perpendicular to tangential t, passing through (x, y). We have the axis x is perpendicular to Ic and the angle alpha (α) between t and x. this incident (between the normal n and the incident ray Ic) is equal to alpha (α).

Let us now trace the reflected ray Ir which makes an angle α with the normal and which intersects the optical axis at point (0, z). We must now determine z, considering that the reflected rays converge by symmetry on the optical axis of the parabola. The reflected ray forms with the x-axis an (acute) angle of (90 ° -2α). Consider now the right triangle whose vertices are the coordinates (x, y), (0, y) and (0, z).

We have:

$$\tan[(90°-2\alpha)] = \frac{z-y}{x} \Leftrightarrow z - y = \frac{x}{\tan(2\alpha)} = \frac{1-\tan^2(\alpha)}{2\tan(\alpha)}x$$

oùtan $\alpha = \frac{x}{p}$

$$z = y + \frac{1-\left(\frac{x}{p}\right)^2}{2\left(\frac{x}{p}\right)} = y + \frac{p}{2}\left(1 - \frac{x^2}{p^2}\right)$$

With y belongs parabola of equation:

$$2py = x^2 \qquad (1)$$

Now, the luminance of incident ray is written:

$$L_c = \frac{I_c}{ds} \quad (2)$$

The luminance of reflected rays is written:

$$L_r = \frac{I_r}{ds\cos\alpha} \quad (3)$$

According to the law of Lambert one has: $L_r = L_c$

$$I_r = I_c\cos\alpha \qquad (4)$$

3.2 Energy balance in a cylindro-prabolic solar collector

The absorber is the main component in the cylindro-parabolic sensor, which has the function of absorbing the incident solar radiation, converting it into heat and transmitting it to fluid coolant[10-8]. This application allows us to consider the following assumptions:

-The diet is transient.
-The heat transfer fluid is incompressible.
-The shape of the parabola is symmetrical.
-The ambient temperature around the sensor is uniform.
-The flow of the fluid is one-dimensional.
-The temporal variations in the thickness of the absorber and the glass are negligible.

-The exchange by conduction in the absorber and the glass is negligible.
-The effect of the shadow of the absorber on the mirror is negligible.
-The solar flux at the absorber is uniformly distributed.
-The solar radiation is constant.

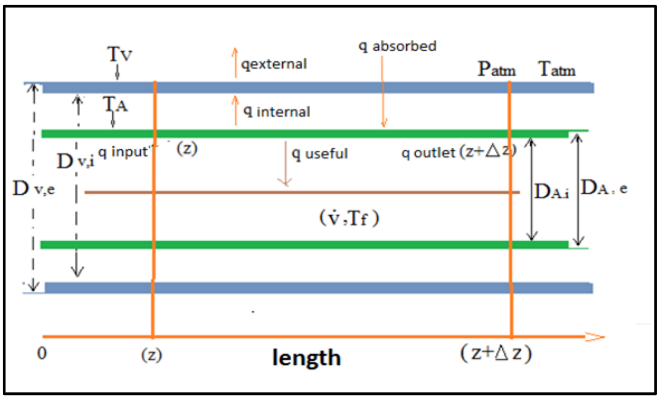

Figure 3: Thermal balance of a collector

3.3 Energy balance in the fluid:

$$\frac{\partial T_F(t)}{\partial t} = A_{Fluid}\, T_{Abs} + B_{Fluid}\, T_{F\ outlet} + C_{Fluid}\ T_F(Z) \quad (5)$$

With

A_{Fluid}, B_{Fluid} et C_{Fluid} : are constants of the fluid equation.

$A_{A,internal}$: Internal surface of the absorber which is expressed by thefollowing relation

$$A_{A,interne} = \pi . D_{A.i}$$

$$\frac{\partial T_{abs}(t)}{\partial t} = A_{abs}\, T_A + C_{abs}\, T_F + B_{abs}\, T_V + cte \qquad (6)$$

3.4 Energy balance in the absorber

Now these A_{abs}, B_{abs} et C_{abs} are constant given by the following relations

σ: Stefan-Boltzmann constant: σ = 5.670 × 10- 8W / m2.K4
εA: Emissivity of the absorber.
εV: Emissivity of the glazing.
ρ: Reflectance factor of the mirror.
τα : Coefficient product transmission of coverage and factor absorption of the receptor.
γ: Optical collector factor

In this section we solved a system of equations from the modification recorded in the energy balance.

3.5 Energy balance in the glass

$$\frac{\partial T_{glass}(t)}{\partial t} = A_V T_A + B_V T_V + cte \ (7)$$

Where: the numbers A_V and B_V are constant that requires to know the following values:

α_v: Absorptivity of the window.
A_v : Surface of the glass
G : Incident global radiation.

We have found a matrix composed of three different temperatures between the heat transfer fluid, the absorber and the glass as a function of the inlet temperature and the number of solar radiation per day. Then, we developed a program with Matlab for the simulation of these equations.

4 Simulation with Matlab software:

4.1 Application to the evolution of solar illuminance

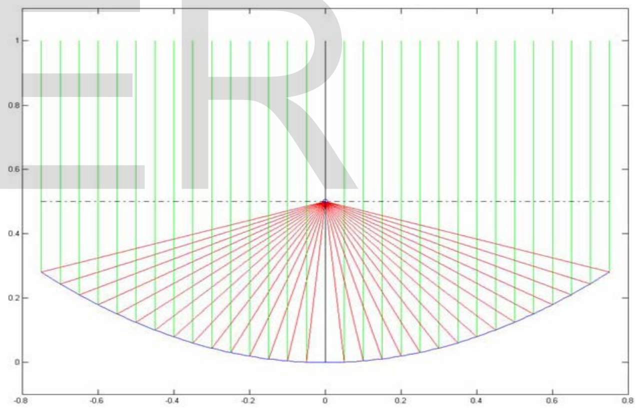

Figure 4: Reflection of rays parallel to the optical axis (the reflected rays converge towards the simulation focus by the Matlab software) [15].

We have developed a program with the Matlab software to focus all the rays reflected by the cylindro-parabolic mirror and to calculate the total number of radiation under a solid angle dΩ.The experimental results were obtained from the tests carried out on the four configurations proposed above.

From Fig. 4, we notice that all the solar rays are focused on the collecting tube. This has won us a great deal of heat. To justify this, we have developed a code with Matlab to describe the evolution of the global irradiation, daily from sunrise to sunset. This code is well verified by relations (8), (9), (10) and

(3).

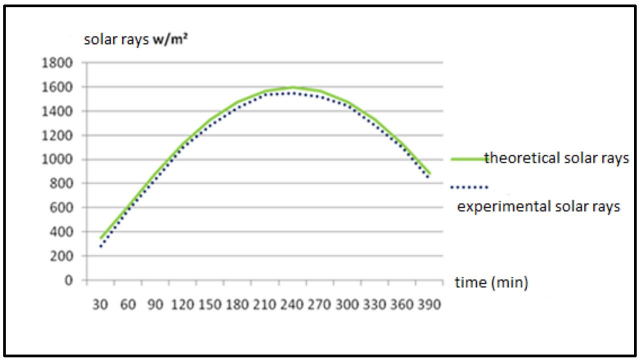

Figure 5: Theoretical and experimental solar rays

This figure shows a good agreement between theoretical and experimental radiation. In the same conditions, this figure represents the evolution of the experimental and theoretical radiations at the inlet and the outlet of the solar collector for the same flow rate of coolant.Indeed, the number of radiations increases in continuity to a maximum, as much as the solar flux increases.

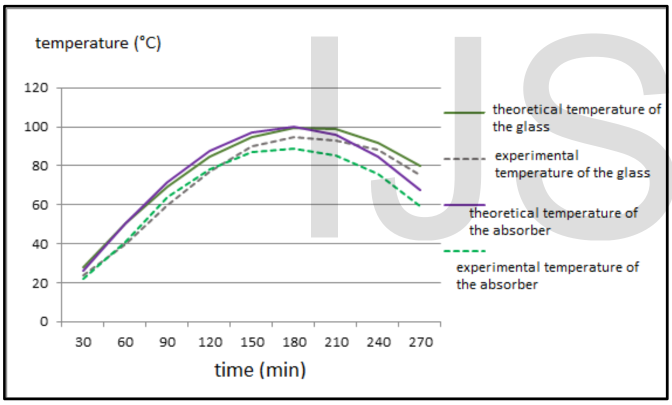

FIG. 6: Evolution of the experimental and theoretical temperatures of glass and absorber

This figure represents the variations of experimental and theoretical glass and absorber temperature. In addition, it shows the temperature difference between the two curves at a given instant. It also informs us indirectly about the evolution of the instantaneous temperature of the sensor which is directly proportional to this difference.

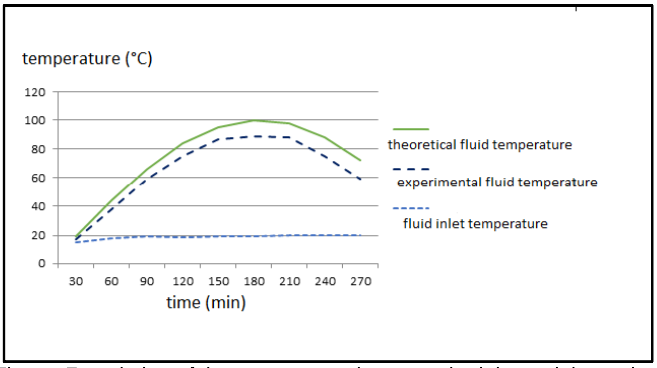

Figure. 7: variation of the temperature between the inlet and the outlet of heat transfer fluid and the mean theoretical temperature

Figure. 7 shows the variation of the inlet and outlet temperatures of the heat transfer fluid, as well as the variation in the calculated mean (theoretical) temperature. We note that the theoretical curve representing the average temperature of the fluid is similar to the two experimental curves of the inlet and outlet temperatures of the heat transfer fluid. This allows us to say that we have achieved very satisfactory results.

5 Conclusion

In this work, we have been able to demonstrate a thermo-solar energy balance. In this sense, we carried out a theoretical and simulated study of a solar collector of cylindro-parabolic type.A mathematical modeling has been well developed and we have studied the different equations of the temperature variation in the fluid, in the glass and also in the absorber [5 -14].For this we have developed a calculation code from MATLAB software that we used.The results obtained show the influence of the angle of inclination of the solar collector on the rate of the solar radiation absorbed by this device.This is clearly explained by the fact that there is a very good correlation between the theoretical and the simulated values.

These results also give an indirect indication of the evolution of the instantaneous temperature of the sensor, which is directly proportional to the difference between the curves.The technology of cylindro-parabolic sensors is currently the most proven solar concentration techniques (theoretical-simulation)[13].The heat energy received is collected and absorbed and then used to heat the heat transfer fluid at high temperature.

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