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# Design and Construction of a Thermal Collector of High Temperature

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**Abstract:** This research concerns an experimental study of solar transformation energy into thermal energy by using a follower solar parabolic concentrator using a tracking system of the sun. The experiment was carried out on a concentration prototype of 1m diameter and a copper receiver, 10 cm length, located at a focal plan of the parabola intended to collect solar energy concentrated. The whole of the system is the subject of a numerical simulation in computer.

**Key words:** Solar radiation, parabolic concentrator, reflectors, receiver, focal point

## INTRODUCTION

The development of the solar energy transformation and its applications is becoming a need these days. The principal motivations of such a concern is on the one hand the threats of pollution caused by the use of the traditional sources based on the hydrocarbons or coal combustion and the rise continue price of oil on the other hand, among the techniques of solar transformation photothermic energy conversion is a way promising, cheap and consequently easy to develop.

To work at high temperature, it is necessary to increase incidental optical flow that could be carried out by concentration of the solar radiation. This operation is carried out using sensors called solar concentrators. Among this type of concentrators, there are the parabolic solar concentrators (revolution paraboloid) (Chasseriaux, 1984). These systems in general comprise a reflective surface in parabolic form intended to concentrate solar energy on an absorbing surface, which makes it possible to have a strong increase in heat. The advantage of such a method is to be able to reach high temperatures adapted for the water heating (production of sterilized water (Mehdi, 1976) and water vapour), for the solar kitchens and production of electricity by the stirling engines.

## COMPONENTS OF A PARABOLIC SOLAR CONCENTRATOR

**Reflector:** It consists of a satellite parabola of reception covered out of aluminium paper, which covers the interior surface of the reflectors. The aluminium paper should have its shining side the sun. The parabola rests on a

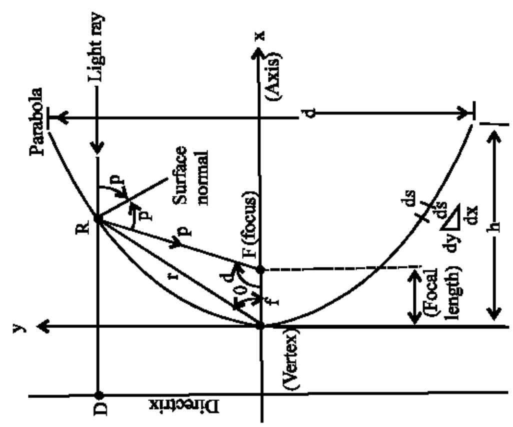


Fig. 1: Paraboloid of revolution

rigid support, attached on the ground. The aluminium coefficient of reflexion is equal to 0.8.

The equation for the paraboloid of revolution (Fig. 1) in Cartesian coordinates with z-axis of symmetry is (Srinivasan and Kulkarni, 1998; Stine and Geyer, 2001):

$$X^2 + Y^2 = 4 \cdot f \cdot Z \tag{1}$$

$$Z = \frac{a^2}{4f} \tag{2}$$

The surface of the paraboloid can be found by integrating the Eq. 2

$$dA_s = 2 \cdot \pi \cdot a\sqrt{dz^2 + da^2} \tag{3}$$

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$$dA_s = 2 \cdot \pi \cdot a \sqrt{\left[\frac{a}{2f}\right]^2 + 1}.\, da \quad (4)$$

The aperture area of the collector of a paraboloid whose focal length is f and diameter d is given by (Stine and Geyrer, 2001):

$$A_s = \int_0^{d/2} dA_s = 8 \cdot \pi \cdot f^2 \left\{ \left[ \left( \frac{d}{4f} \right)^2 + 1 \right]^{3/2} - 1 \right\} \quad (5)$$

By using the equation of the radius parabolic p:

$$P = \frac{2f}{1 + \cos\psi} \quad (6)$$

**Absorber:** The metal of the receiver must have a good conductivity; we chose copper (360W/°K.m²) like absorbing device. It is a tube 10 cm in external diameter and 20 cm length, it is provided with a hole for the filling of water (approximate capacity of 2 liters) and it is closed with a stopper. The absorber covered with a thin coat of black paint to decrease the reflexion of the solar radiation, is located at the focal zone of the parabola.

- Absorption coefficient of the absorber equal 0.8.
- Mass of the receiver equal 0.6 kg.

The geometrical concentration of this model is

$$C_g = \frac{A_a}{A_r} = \frac{0.899}{0.00783} = 114.$$

## SUN TRACKING SYSTEM

**Functioning:** The orientation of the sensors is a significant problem in the use of the sensors with concentrated radiation. Indeed, the principle even of the concentration supposes that the radiation arrives at reflective surface in a given direction.

Since the apparent sun position compared to a point of collecting is constantly variable on a one day scale, we will thus be obliged to modify the position of the concentrator constantly in order to follow that of the sun by using an automatic tracking system (Fig. 2).

The knowledge of the sun position for a fixed observer is described according to two angles, the angle of incidence of the direct radiation and the angle of azimuth. So that the parabolic concentrator follows the sun it is necessary to have (Braun and Mitchell, 1983) for that we developed a program which makes it possible to calculate instantaneously the solar energy received by the surface of the concentrator.

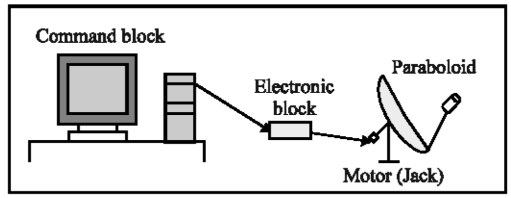


Fig. 2: Tracking system

$$\gamma = \gamma_s \qquad \beta = \theta_z \quad (7)$$

Where:

$$\theta_z = \cos^{-1}(\sin\delta \sin\phi + \cos\delta \cos\phi \cos\omega) \quad (8)$$

$$\gamma_s = \sigma_{ew}\sigma_{ns}\gamma_{so} + \left(\frac{1 - \gamma_{ew}\gamma_{ns}}{2}\right)\sigma_w \; 180^0 \quad (9)$$

**Tracking system realisation:** The tracking system carried out was developed in the laboratory of advanced technology applications to the Mentouri University of Constantine.

The device of orientation consists on a commercial jack uses two axes of rotation to direct the concentrator. It is controlled by a data-processing program. The interface electronic card, the program and all mechanical devices are entirely carried out on this laboratory. This system is composed primarily of two parts.

**Command block:** This part is based on a software command. The program periodically transmits signals starting from the central processing unit towards the electric motor (jack). The duration of the signal makes it possible to activate the engine which directs the concentrator of a rotation angle corresponding to this duration to position it side of the sun.

**Electronic block:** This electronic part rests on systems which allow the reception of the commands sent by the computer, their conversion into electric signals and their transmission with the articulated mechanical system, as well as the activation of the engine (jack). This operation ensures that the solar radiation is always perpendicular to the concentrator.

**Principle of the concentrator working:** The idea to use a parabolic surface comes owing to the fact that it is stigmatic for the points on its axis located ad infinitum.

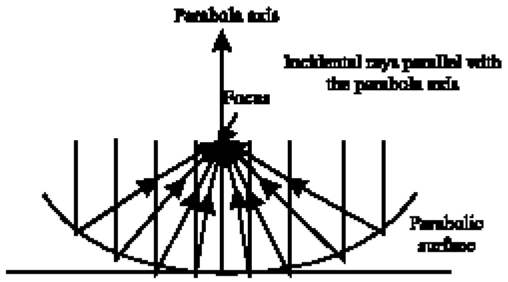


Fig. 3: Optical system of the concentrator

According to the laws of reflexion, any luminous radiation parallel with the parabola axis is reflected by the parabola according to a line passing by the hearth. Therefore, the parabola focuses all the rays reflected in a point called focus (Dye and Wood, 2003) (Fig. 3).

## THE EXPERIENCE

**Adjustment of the concentrator:** At the beginning, the concentrator will be pointed towards the true south. Using a tracking system controlled by the data-processing program, will be initialized and oriented on the sun position since the rising of the day. The sunrays will be reflected to the hearth of the paraboloid and will form the sunspot, which should appear under the absorber.

**The site of the thermocouples:** To determine the temperature reached on surfaces of the receiver, two thermocouples were installed in the external wall of the tube. The first on the receiver opening surface (collecting surface Z = 0) and the second thermocouple on the upper surface (Z = 20 cm) (Fig. 4).

The temperatures were measured using a thermocouple with digital display. The temperature recording is done every 5 min.

**Geometrical characteristics of the reflector:**

| | | |
|---|---|---|
| Diameter | : | d= 1.05 m |
| Size | : | h= 0.08 m |
| Aperture | : | $\psi_p = 30.80°$ |
| Focal length | : | f= 0.894 m |
| Aperture area of the receiver | : | $A_a$ = m 0.899 m² |

**Geometrical characteristics of the absorber**:

| | | |
|---|---|---|
| Diameter | : | $d_t$ = 0.10 m m |
| Length | : | $l_t$ = 0.20 mm |

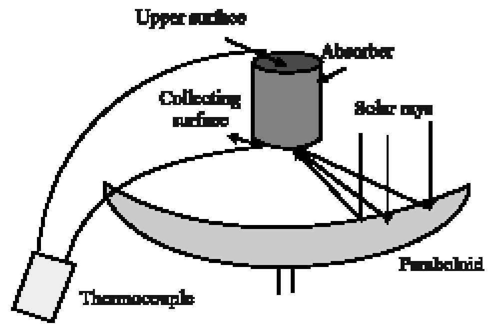


Fig. 4: Position of the thermocouples

Fig. 5: The parabolic concentrator

| | | |
|---|---|---|
| Total surface | : | $S_t$ = 0.0471 m² |
| Collecting surface | : | $A_t$ = 0.00783 m² |

**Temperature evolution of the absorber opening surface according the concentration:** A simplified study will make it possible to estimate the absorber temperature, if $I_b$ is the solar illumination and $A_a$ the surface of the concentrator, the thermal power emitted by the sun and received by the concentrator is (Ari, 1967):

$$Q_a = I_b A_a \tag{10}$$

Considered as independent of the concentration degree, $\eta_{op}$ represents the optical efficiency of the concentrator. The thermal power sent by the concentrator on receiving surface is worth then (Bonned and Laphilippe, 2003):

$$Q_L = \eta_{op} I_b A_a \tag{11}$$

Collecting surface loses a fraction of this power, by natural convection and radiation, if one indicates by T, the average temperature of receiving surface, $T_a$ the

Fig. 6: The sun spot

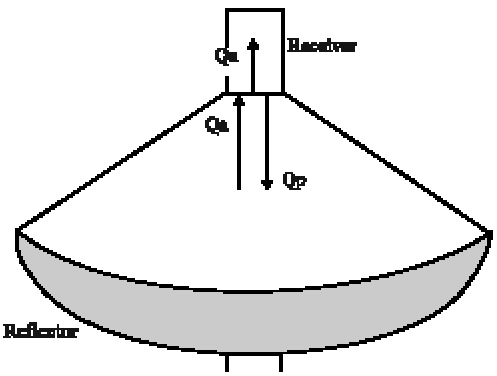


Fig. 7: Energetic sheet balance

ambient temperature and $A_r$ the surface of the receiver (Fig. 5 snd 6). One can write the thermal power absorbed by the receiver (Jorgensen, 1982):

$$Q_u = \eta_{op} \cdot I_b \cdot A_a - K \cdot A_r(T_r - T_a) - \upsilon \cdot \varepsilon \cdot A_r(T_r^4 - T_a^4) \qquad (12)$$

The energy balance of the opening surface of the receiver is given by the following formula (Mehdi, 1976) (Fig. 7):

$$(M_w C_w + M_r C_r)\frac{dT}{dt} = Q_u \qquad (13)$$

$$Q_u = Q_a - Q_p$$

$$Q_u = A_r((\eta_{op}\, I_b \cdot \frac{A_a}{A_r}) - (h_{cv} + h_r)(T_r - T_a)) \qquad (14)$$

Finally:

$$Q_u = A_r(P_a - K_{vr}(T_r - T_a)) \qquad (15)$$

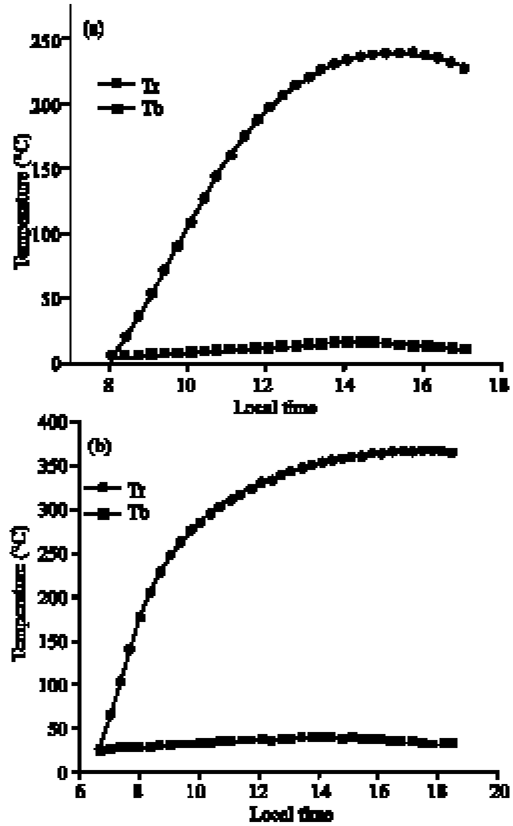


Fig. 8a, b: Receiver temperatures for the days of the 25/01/2006 and 25/07/2006

Where $K_{vr}$ is the combined convection and conduction and radiation coefficient (W/m²K), given by

$$K_{vr} = h_{cv} + h_r \text{ and } P_a = \eta_{op}\, I_b\, C_g$$

The Eq. 17 becomes:

$$M\,C\,dT_r = A_r(P_a - K_{vr}(T_r - T_a))\,dt \qquad (16)$$

After integration from $t_0$ to t, one obtains the temperature according to time (Jorgensen, 1982):

$$T_r(t) = T_a + P_a / K_{vr} - (p_a / K_{vr} - T_r(t_0) + T_a)\exp(-K_{vr} A_r (t - t_0) / MC) \qquad (17)$$

**Efficiency evolution of the concentrator:** This efficiency is defined like the ratio of the thermal absorbed energy by the receiver to the energy received at the concentrator opening (Allain and Gilles, 2002) (Fig. 8-14).

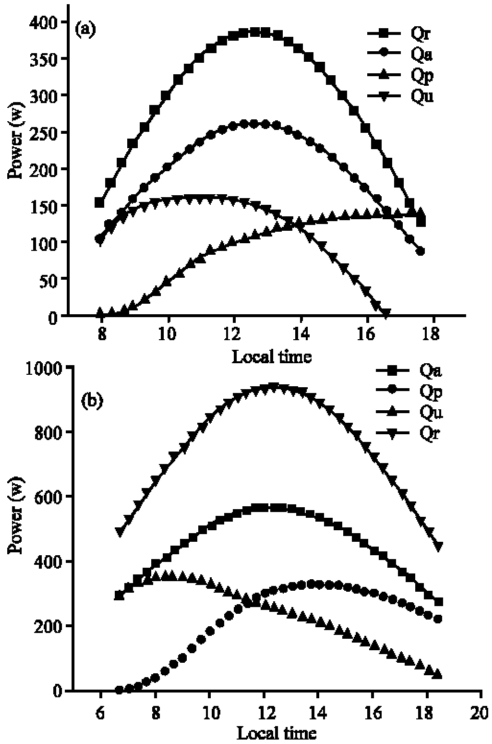


Fig. 9a, b: Thermal power for the days of the 25/01/2006 and 25/07/2006

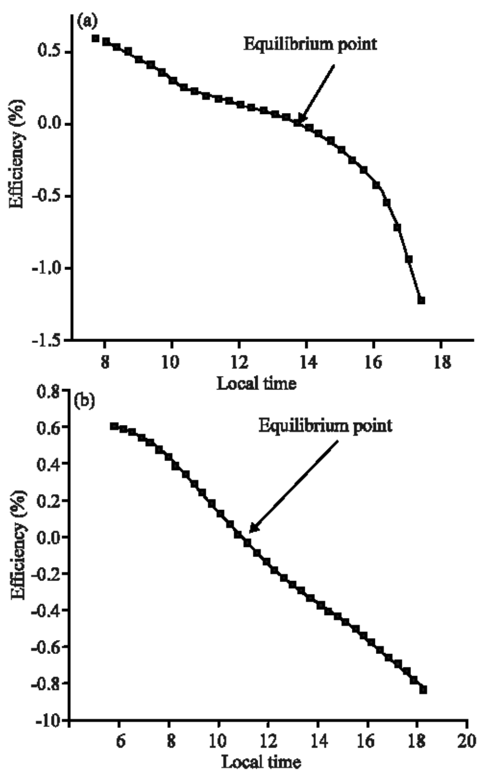


Fig. 10a, b: Efficiency for the days of the 25/01/2006 and 25/07/2006

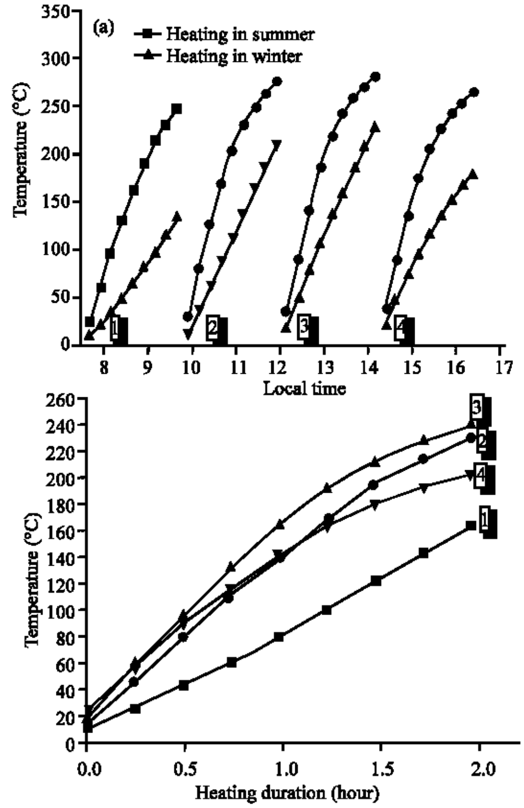


Fig. 11a, b: Temperature of the absorber aperture area every 2 h

$$\eta = \frac{Q_u}{I_a A_a} \tag{18}$$

According to the geometrical concentration:

$$\eta = \eta_{op} - \frac{K_{vr}(T_r - T_a)}{C_g I_a} \tag{19}$$

## RESULTS

The use of this concentrator for the water heating with a stationary fluid on the level of the receiver is not very interesting because of the equilibrium temperature reached in a very short time. The concentrator efficiency becoming null after a certain heating time, it is necessary to carry out the change contents of the receiver; therefore one cannot use this type of model continuously all the day.The working time of this model depends on nature on the application which one wants to carry out.

To make this prototype completely autonomous and more powerful, it would be judicious to make it function by using NaCl like coolant fluid and

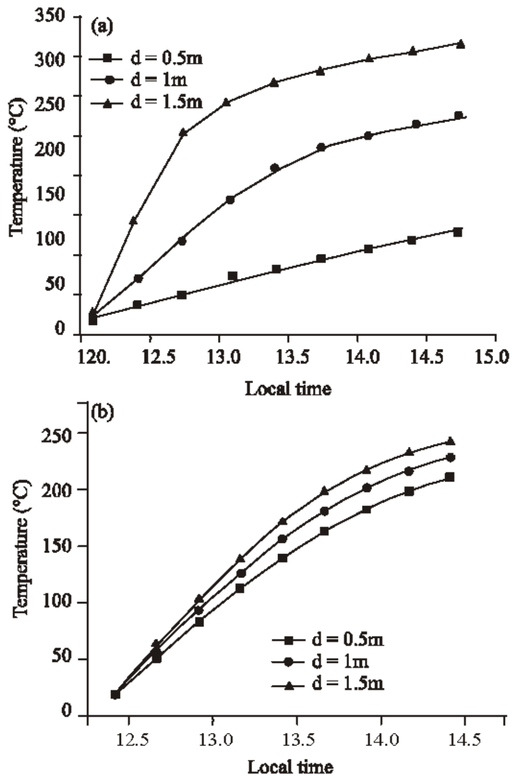


Fig. 12a, b: Reflector diameter and wind speed influence

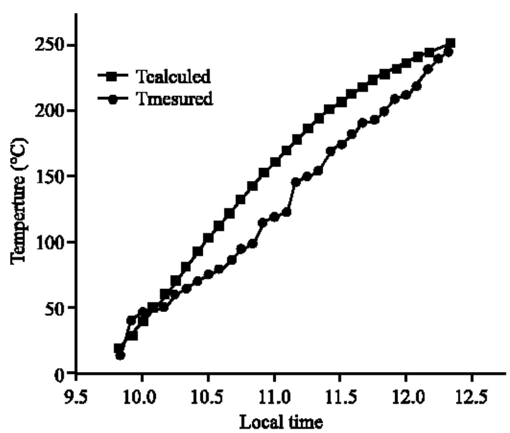


Fig. 13: Measured and calculed temperature of the absorber

transmit this heat by means of a moving water exchanger.

The second possible application of this system is for the sterilization of medical instruments or solar kitchen device.

Our concentrator containing satellite receiver gave convincing results with regard to the rise in the temperature which can reach 350°C in summer, makes it

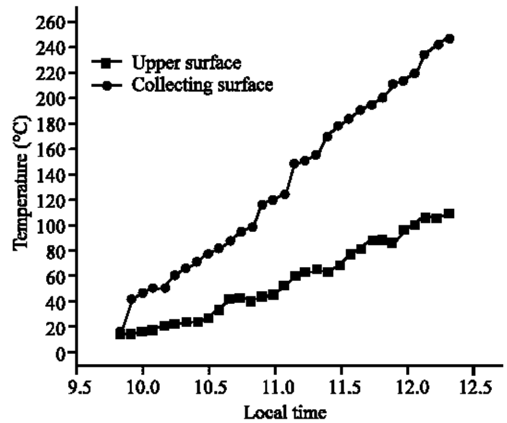


Fig. 14: Measured temperature

possible to use a small absorber, while avoiding the thermal losses, therefore a better efficiency.

## NOMENCLATURE

$A_s$ : Aperture area of the collector [m²]
$A_a$ : Aperture area of the receiver [m²]
f : Focal length (focus) [m]
d : Diameter of parabola [m]
$\psi_p$ : Rim angle of parabola [degree]
$C_g$ : Geometric concentration ratio
$\theta_z$ : Zenith angle [degree]
$\gamma_s$ : Azimuth angle [degree]
$\gamma$ : Surface azimuth angle [degree]
$\beta$ : Slope of the parabola [degree]
$Q_a$ : Solar irradiance entering the parabola [W]
$Q_L$ : Energy incident on absorber [W]
$Q_u$ : Rate of (useful) energy output [W]
$T_r$ : Temperature of receiver [K]
$T_a$ : Ambient air temperature K]
$h_{cv}$ : Average overall convective heat transfer coefficient (W/m²K)
$h_r$ : Average overall radiation heat transfer coefficient (W/m²K)
$\eta_{op}$ : Optical efficiency
$\eta$ : Collector efficiency

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