DESIGN, REALISATION AND EXPERIMENTATION OF A SOLAR COOKER FITTED WITH AN ELLIPSOIDAL CONCENTRATOR: PRELIMINARY RESULTANTS OF COOKING TESTS

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Abstract: This article is about the realization and experimentation of an elliptical solar cooker. This prototype has a single focus and a reflective surface made of galvanized sheet. Its opening diameter is 120 cm and focal length is 60 cm. In a first step, Cooking Tests of six eggs in 0.5 L of water were carried out by fixing the maximum cooking time to 2 hours. The first results showed that the cooking of the eggs was partial. Despite adequate illumination, the temperature 82 ^{o} C, at which starts the cooking of certain foods according to «International Solar Cooker", could not be reached. Thus, a glass cubic box was built that served as an envelope for the pan. In 60 minutes with this new configuration, a temperature of 88.23 ^{o} C was reached, which is widely more than the 82 °C required. After 80 minutes of cooking, a temperature of 92.12 ° C was reached. Finally, after 80 minutes of cooking, all six eggs were completely cooked. . In the second step, the reflective surface was coated with mirror. In such configuration, 10 eggs were perfectly cooked after 40 minutes of cooking in 0.5 litres of water. 500 grams of rice were also cooked after 80 minutes of cooking, in 0.625 litres of water.

Keywords: solar cooker, ellipsoidal concentrator, realization, experimentation, glass cubic box.

1. INTRODUCTION

Energy needs for cooking are enormous. In most developing countries, the energy supply for cooking relies so far on conventional sources of energy, such as firewood collected from forest and charcoal. Those energy sources linked to biomass lead to depletion of the forest and therefore to the degradation of the environment. The use of solar energy is one of the alternative solutions which is clean, renewable and sustainable. In Côte d'Ivoire, solar irradiation is important. The daily total radiation varies of course from 3 to 5 Kwh/m², depending on the regions [1]. Solar cookers are therefore promising. The use of solar energy for cooking requires high temperatures. Such temperatures are obtained by means of concentration systems. Some studies have been made about the parabolic concentrator solar cookers. [2-5]. The hot box solar cookers have also been studied [6-7]. Another type is the conical solar cooker, which have been studied by several researchers [8-9]

2. DESIGN AND DESCRIPTION OF THE ELLIPSOIDD CONCENTRATOR

2.1. Design of the concentrator

2.1.1. Co-ordinates x and y calculation for the designed ellipsoidal concentrator

An ellipse is defined as "the set of all points P such that the sum of the distances between P and to distinct fixed points, called the foci, is constant"? The ellipse is represented in Figure 1, with its two focal points F1 and F2 along the Y axis.

For the design of the concentrator, only the focal point F1 was considered. In the x and y co-ordinates system, the ellipse equation is expressed as

$$\frac{x^2}{a^2} + \frac{y^2}{b^2} = 1 \tag{1}$$

a and b are respectively the semi-minor axis and the semi-major axis of the ellipse. On Figure 1, a and b are given by a = OP; b = OV1. The two points V1 and V2 are the vertexes. The ellipse is characterized by the distance c = OF1 = OF2; this distance is expressed as

$$c = \sqrt{b^2 - a^2} \tag{2}$$

As for the focal length f, it is given by

$$f = V_1 F_1 = V_1 O - F_1 O \tag{3}$$

Hence, f is expressed as

$$f = b - c = b - \sqrt{b^2 - a^2} \tag{4}$$

For the design of the concentrator, a truncated ellipsoid is considered. As shown on Figure 1, AB is the opening of the concentrator. Let X0 and Y0 be the coordinates of B. Hence, the opening diameter is d = 2X0. In the design process, we sleeted a so that a =d. Hence, for a given value of d, X was expressed as

$$x_0 = \frac{a}{2} = \frac{d}{2} \tag{5}$$

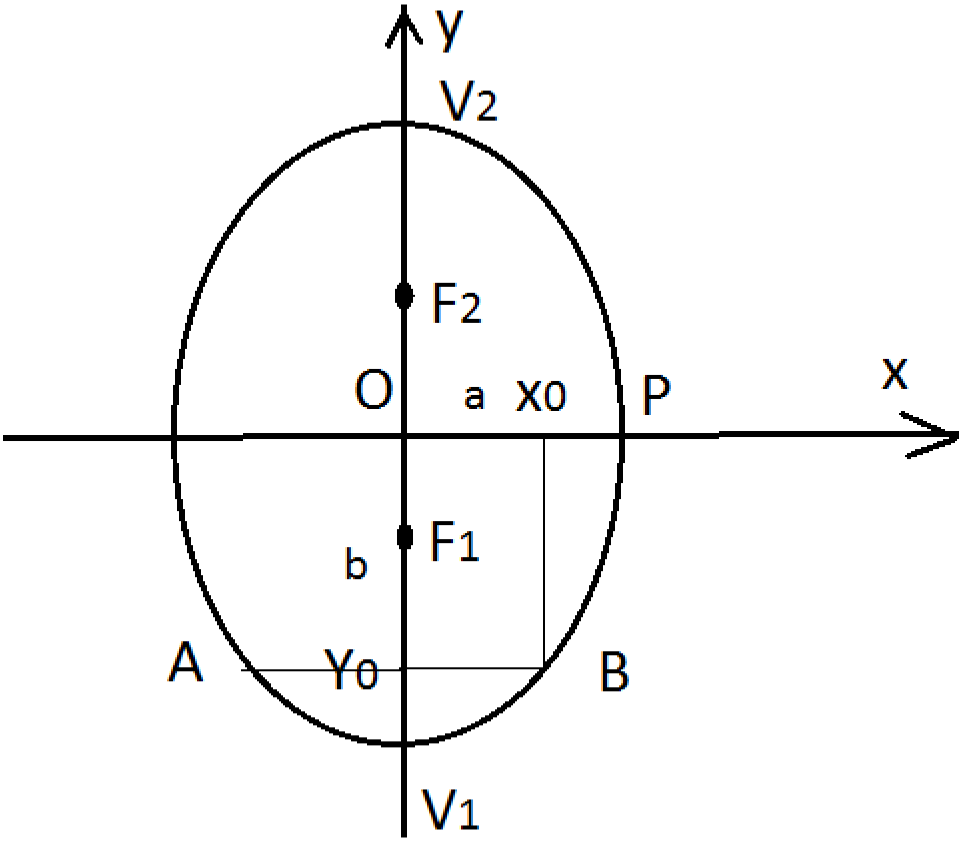

Figure 1. Representation of an ellipse showing its two focal points

As the semi-minor axis a was chosen so that a = d, for a chosen value of d, a is gotten. From equations (1) and (5), one gets

$$y_0 = 0.866b \tag{6}$$

As for the depth h of the ellipse, it is expressed as

$$h = b - y_0 \tag{7}$$

Combining equations (6) and (7), one gets

$$h = 0.13397b \tag{8}$$

From equations (2) and (5), one gets

$$c = \sqrt{b^2 - d^2} \tag{9}$$

Hence, the focal length is expressed as

$$f = b - \sqrt{b^2 - d^2} \tag{10}$$

2.1.2. Calculation of the length of the arc of the ellipse

An arc of ellipse is represented on Figure 2

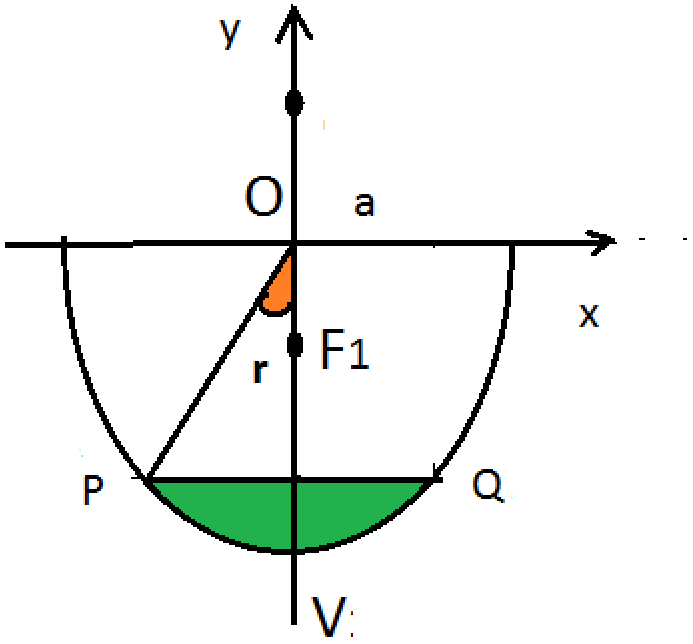

Figure 2. Representation of an arc PQ of h ellipse

Let P be a point of the ellipse and r be the angle between the semi-major axis OV and the line OP . The coordinates of P are expressed as

$$x = asinr$$

$$y = bcosr \tag{11}$$

The length of the arc PV is expressed as [10]

$$s = \int_{r_v}^{r_p} \sqrt{x'^2 + y'^2}\, dr \tag{12}$$

The eccentricity e of the ellipse is expressed as

$$e = \frac{\sqrt{b^2-d^2}}{b} \quad (13)$$

Let L be the whole ellipse length. It is expressed as [10]

$$L = 2\pi b \times [1 - \left(\frac{1}{2}\right)^2 \times \frac{e^2}{1} - \left(\frac{1}{2}\times\frac{3}{4}\right)^2 \times \frac{e^4}{3} - \left(\frac{1}{2}\times\frac{3}{4}\times\frac{5}{6}\right)^2 \times \frac{e^6}{5} - \left(\frac{1}{2}\times\frac{3}{4}\times\frac{5}{6}\times\frac{7}{8}\right)^2 \times \frac{e^8}{7} - \cdots] \quad (14)$$

There are some approximations for the calculation of L. One of them is the Fagnamo approximation which is expressed as [10]

$$L = \pi \times [\frac{3}{2}(a+b) - \sqrt{a \times b}] \quad (15)$$

Another approximation is the following [11]

$$\pi \times (a+b) \leq L \leq \pi \times \sqrt{2 \times (a^2+b^2)} \quad (16)$$

Let the arc- PQ be considered shown on Figure 2. Its length s is calculated from the knowledge of the angle θ between the semi-major axis OV and OP, when PQ is the opening diameter of the concentrator-. The value of s is expressed as

$$s = \frac{2\theta}{2\pi} L \quad (17)$$

where θ is expressed in radian. This angle θ is calculated from the' following relationship.

$$x_0 = a \times sin\theta \quad (18)$$

2.2. Description of the ellipsoidal concentrator experimented

The opening diameter d of the concentrator was chosen to be d = 1.2 m. Therefore, by using equation (5), one gets a = 1.2 m. As for the depth h of the ellipse, it was chosen to be h = 0.20 m. Then from equation (8), one gets b = 1.4928 m. Finally, from equation (10), one gets the focal length f. It is found f = 0.60 m. The concentrator was built using steel rods. It has six facets. Its reflective surface. is made of galvanized steel sheet divided into six facets The base of the black painted pan is held by a collar at a distance l from the focal point, called the back axial distance. This distance l is gotten from the following relationship

$$d_2 = \frac{l.d}{f-h} \quad (19)$$

Where d_2 is the diameter of the pan, f the focal length, h the depth of the ellipsoid and d the opening diameter. The eccentricity calculated from equation (13) is e = 0.594835. The whole length L of the ellipse calculate from equation (14) is L = 8.48m m. As the calculation of L is limited in equation (14), to e^8 , L = 8.4 was considered. From equation (18), one gets θ = 30 °. Then the theoretical value of the length of the arc of the ellipse, calculated from equation (17),is s = 1.36 m. An experimental building of the ellipse's arc was made by plotting the x , y coordinates on a plywood sheet using equation (1). From this plotting, the length s was measured and fond to be s = 1.32 m, which is close to the theoretical value. A photography of the experimental device with the ellipsoidal concentrator is shown on Figure 3.

Figure 3. Experimental device with the ellipsoidal concentrator

3. EXPERIMENAL STUDY OF THE ELLIPSOIDAL CONCENTRATOR SOLAR COOKER

Several cooking tests of eggs and rice were carried out. For the first experiment, the tests were made with 0.5 litres of water and six eggs in the pan. During the tests, temperature measurements were performed by using platinum resistance thermometers. Temperature data were recorded at a time interval of 10 minutes. The measured temperatures were the ambient temperature Ta, the temperature Tbas at the bottom of the pan and the cooking temperature Tcuisson. An Eppley –type pyranometers was used to record global solar radiation, at time interval of 10minutes. Every 20 minutes, the ellipsoidal concentrator was oriented in front of the sun by means of a manual tracking system. Two configurations were studied. In the first configuration, cooking tests performed without any glass cubic box around the pan. The maximum cooking duration was 2 hours, from 11:00 to 13:00; the maximum cooking temperature reached was 74.39 °C, which is lower than 82 °C. According to "Solar Cooker International", foods star to cook between 82 ° and 91 °C. Figure 4 shows the evolution of temperatures and solar radiation E with time, for the experiment without glass cubic box. The cooking of the six eggs was not perfect. This experiment showed that thermal losses of the pan, by radiation and convection, were very important. Consequently, in the second configuration, a glass cubic box as been installed, that served as a wrapper for the pan. The aim was to reduce the thermal losses. Figure 5 shows the evolution of temperatures with time in that second configuration. After 60 minutes the cooking temperature was 82.23 °C. After 80 minutes of cooking, the cooking temperature reached 92.12 °C and the six eggs were completely cooked. Farther experiments were made to improve this result. For that the reflective surface was coated with mirror, in order to increase its reflection coefficient. The mirror was cut in square pieces whose dimensions are 0.05 x 0.05 m². In that configuration, 10 eggs were perfectly cooked in 0.5 litres of water after 40 minutes of cooking. The cooing temperature reached was 91.47 °CC, while Tbas, the pan's bottom temperature reached was 117.75°C. Moreover, after coating the reflective surface with mirror, cooking tests of rice were carried out. 500 grams of rice in 0.625 litres of water were cooked after 80 minutes of cooking. The maximum cooking temperature reached for the rice was 102.75 °C, while the maximum Tbas (the pan's bottom temperature) reached was 131.99 °C

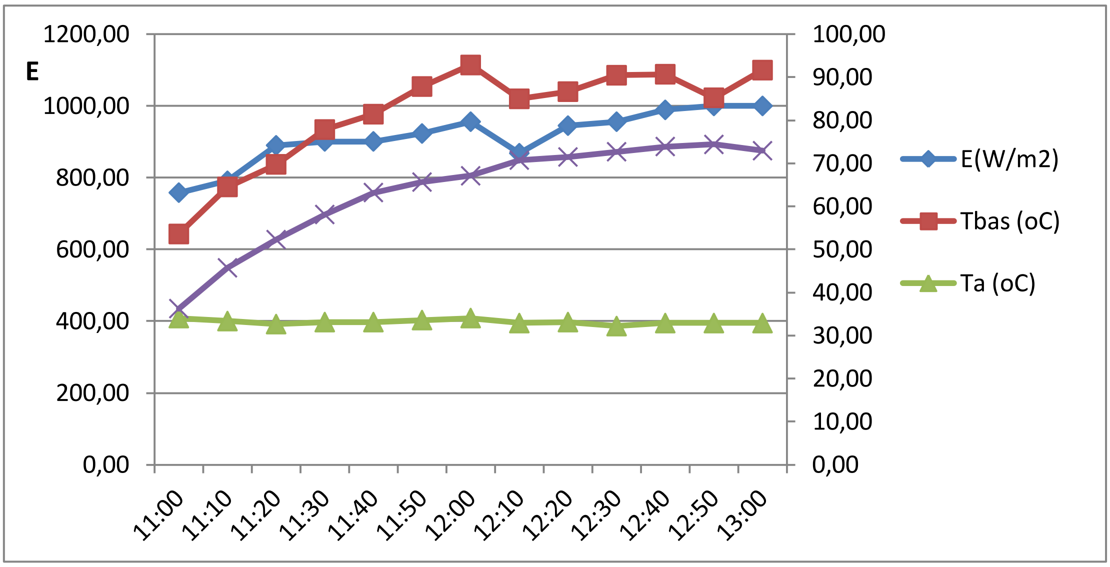

Figure 4. Temperatures and solar radiation evolutions for cooking without glass cubic box

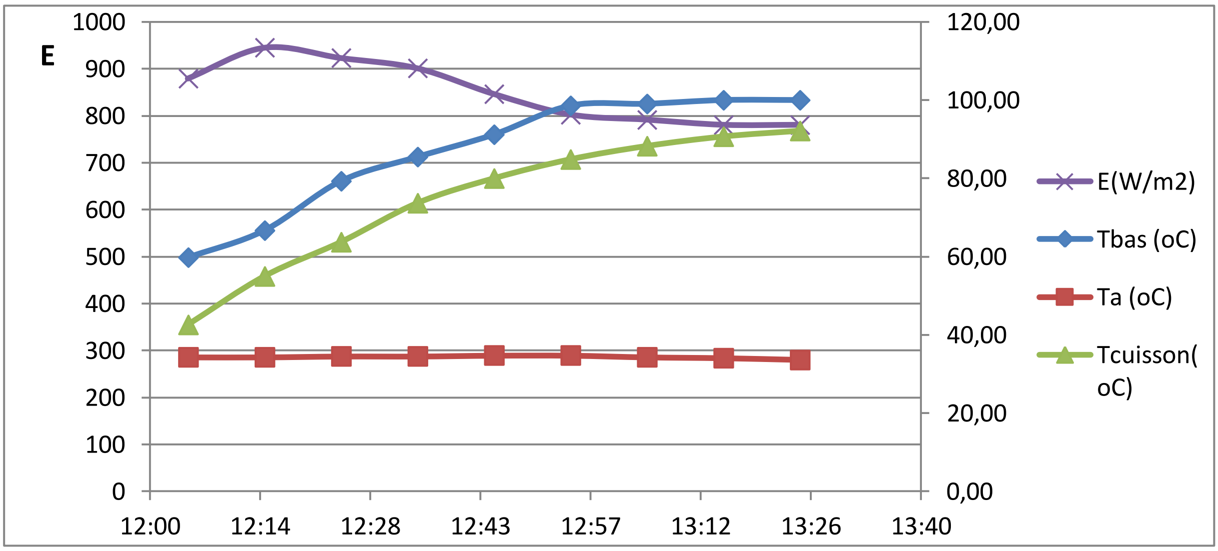

Figure 4. Temperatures and solar radiation evolutions for cooking with glass cubic box

3. CONCLUSION

A solar cooker has been designed with an ellipsoidal concentrator, by using one the two focal point of the ellipse. In a first step, the reflective surface was a galvanized steel sheet..In the experimental study, two configurations were tested: experimentation with and without glass cubic box. In the configuration with glass cubic box, six (6) eggs were completely cooked after 80 minutes of cooking. In the second step, the reflective surface was coated with mirror. In such configuration, 10 eggs were perfectly cooked after 40 minutes of cooking in 0.5 litre. 500 grams of rice were also cooked after 80 minutes of cooking, in 0.625 litre of water. The study showed that the ellipsoidal concentrator is efficient and well suitable for solar cooking.

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