

Design and Realization of a Mixed Solar Cooker: Application to the Cooking of the Sorghum Wort

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Abstract: The depletion of fossil energy and his consumption in cooking as the use of firewood are contributing to increase the problem of climate change. It is urgent to find alternative energy sources to take over the situation when the areas are being blessed with higher solar energy potential. The present work concerns design and realization of a mixed solar cooker. It consists of a parabolic reflector of 1m diameter and 0.24m focal point and a box type size of 8.064 dm³. The temperature and irradiance measurements were carried out using a pyranometer and PT 100 sensors. The data were recorded using an acquisition unit (ALMEMO 2390). The design was made by a basic theoretical model developed from the heat transfer equations and simulated using MATLAB software. The tests carried out show that without a sun tracking and without regulating, the temperature inside the cooker rises and reaches the maximum of 95.5°C for a day during which the average irradiance is 690.13 W/m². Without temperature regulation and with manual sun tracking, the temperature is not constant and the maximum value obtained in the cooker is 168°C for an average irradiance of 716.86 W/m². The cooking of 2 litres of sorghum wort was carried out through manual temperature regulation of 80°C for 1 hour and 16 minutes under an average irradiance of 555.52 W/m².

Keywords: Mixed Solar Cooker, Sorghum Wort, Temperature Regulation, Solar Tracker

1. Introduction

The world is in a climate change context. The limitation of greenhouse gases is a paramount necessity, and faced with the threat of depletion of fossil fuels, the current challenge is to find innovative and sustainable sources of energy to meet a need that is as urgent as it is important. From an environmental point of view, a solar cooker can highly decrease the amount of produced carbon dioxide gas (CO₂) per year [1, 2] The report of the African Bank for Development shows that in 2005, over the entire continent of Africa, 50% of energy needs for cooking or heating are met from firewood, charcoal, agricultural waste or animal excrement. Between 2000 and 2005, Africa lost 4 million hectares of forest per year, of which at least half are thought

to be used for fuelwood [3]. However, Africa has tremendous and impressive renewable energy potential. The Far North region of Cameroon is blessed with significant potential in solar energy. Indeed, in Maroua the current solar potential reaches 3490.86 hours or 1933.07 kW.hm⁻² per year [4] and the solar irradiation given by the solar map of Africa is about 5.5 kW.hm⁻² per day [5].

Such potential can help develop technologies such as solar cookers. There are several types of solar cookers among which, box cookers and parabolic cookers. The box cooker can reach high temperatures but not exceeding 150°C [5]. The box type can be equipped with improved system [6–8] This is usually sufficient for many cooking. The cooking time is twice as long as a conventional cooker. Thus cooking in this type of cooker is suitable for all preparations that

require slow and slow cooking over low heat. The parabolic cookers can reach higher temperatures (up to 250°C) [9, 10], which allows the cooking of all foods, with a faster time than the box cookers (the cooking takes place almost as fast as with a medium traditional cooking). But at these high temperatures, the food can burn, so it is necessary to regularly check and stir the contents of the container. The temperature of this type of cooker is therefore controllable, which does not facilitate cooking

In Cameroon, sorghum is usually transformed into a traditional beer called "bili-bili" [11]. The production of traditional and industrial beers includes essential stages including alcoholic fermentation and cooking, which predominantly determine the characteristics of the finished product [12]. In the case of this traditional beer, 52.5% of producers in the city of Maroua have difficulties with the unitary cooking operation. In particular the mastery of the temperatures and the availability of the fuel which is essentially wood: for the long cooking of the beer, it is necessary to burn a lot of wood. It takes between 0.5 and 1 kg of wood to produce 1 litre of sorghum beer. [13].

The general objective of this work is to propose a mixed solar cooker equipped with a system of regulation of temperature. The proposed system is used to cook the wort of sorghum.

2. Material and Methods

2.1. Design and Realization of the Cooker

2.1.1. Design of Parabolic Reflector

To design the reflector, the geometrical study of a parabola is required. The formulae given below are related to Figure 1.

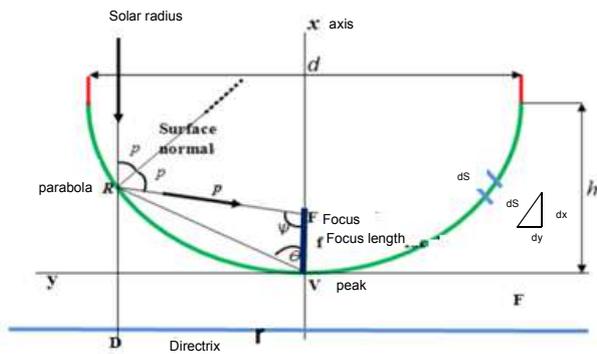


Figure 1. Geometry of the parabola.

If the origin of the reference is taken at the summit (V) and the axis of the parabola, its equation is given by:

$$y^2 = 4 \cdot f. \quad (1)$$

The focal length (f) is the distance from the vertex (V) to the centre. When the origin is shifted towards the focus (f) as is often done in optical studies and the vertex is to the left of the origin, the equation of a parabola becomes [14]:

$$y^2 = 4(x + f) \quad (2)$$

2.1.2. Method of Approximation of the Dish by a Spherical Cap

Let H be the lower part of a circle of radius r and of centre (0, r). We have indeed:

$$H = y = -\sqrt{r^2 - x^2} + r \quad (3)$$

We get by the Taylor formula of order 2:

$$H = H(0) + H'(0)x + H''(0)x^2/2 + \varepsilon^3 \quad (4)$$

$$H y \sim \frac{x^2}{2r}. \quad (5)$$

This equation is well equivalent to that of a parabolic type

$$y = \frac{x^2}{2p} \quad (6)$$

Thus we can approach by rotation symmetry a paraboloid of focal length P/2 by a hemisphere of radius r = p. The parabolic radius P which represents the distance (RF) between the focus f and the curve of the parabola is found in the equation (7)

$$P = \frac{2f}{1 + \cos\varphi} \quad (7)$$

P: parabolic radius, distance (RV), between the curve of the dish and the focus f. φ : angle measured from the line (CF) and the parabolic radius (P)

$$\varphi = 2P \quad (8)$$

Opening angle of the dish [10, 15, 16]

$$\tan\varphi_p = \frac{\left(\frac{f}{d}\right)}{2\left(\frac{f}{d}\right)^2 - \frac{1}{8}} \quad (9)$$

2.1.3. Length of a Dish

We find the arc of the parabola by integrating a differential surface of this curve, and by applying the limits X = h and Y = d/2 as described in figure 1 One finds:

$$s = \left[\frac{d}{2} \sqrt{\left[\frac{4h}{d}\right]^2 + 1} \right] + 2f \ln \left[\frac{4h}{d} + \sqrt{\left[\frac{4h}{d}\right]^2 + 1} \right] \quad [10] \quad (10)$$

The surface of a dish whose focal length is f and the opening diameter is d, is given by:

$$A_s = \int_0^{\frac{d}{2}} dA_s = 8 \cdot \pi \cdot f^2 \left\{ \left[\left(\frac{d}{4f} \right)^2 + 1 \right]^{\frac{3}{2}} - 1 \right\} \quad (11)$$

The opening surface of a paraboloid is given by:

$$A_s = \frac{\pi \cdot d^2}{4} \quad (12)$$

2.1.4. Design of a Cooker Box

The volume of the parallelepiped part is given by the formula

$$v = L \times l \times h \tag{13}$$

L: length, l: width and h: height The slope of the glasses are equal to the latitude of the place where the experiments are carried out.

2.2. Description of the Cooker

The mixed cooker to be made consists of a parabolic reflector and a box-type cooker. The reflector is a paraboloid formed of aluminium sheets and flat irons lined with rectangular mirror blade of 10 cm wide. All mounted on a rigid support with two axes of rotation for tracking the sun at altitude and azimuth adjustment. The box cooker is partly made of wood and glass [17]. It is lined inside with aluminium foil (1mm). It slides on a mobile support around a vertical axis. The pot is a stainless steel container painted black. Its volume is two litres. The adjustment is also possible through the movement of the box cooker on the rail.

To apply all the dimensioning relations of the parabola, one must start from the relations giving the transformation of the solar energy of the reflector to the pot [1]. We describe the phenomena occurring in the cooker by making an electrical analogy. For that, we model the transport of heat by the following electrical circuit:

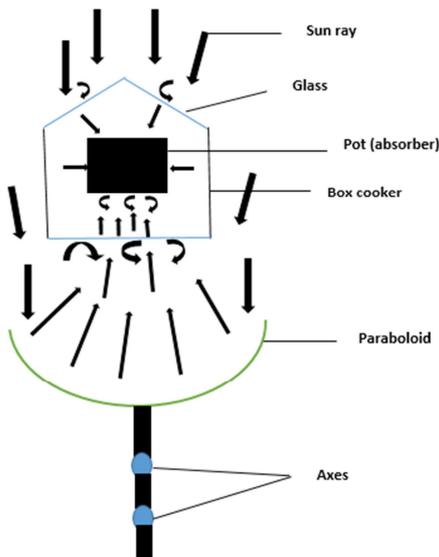


Figure 2. Description of the cooker.

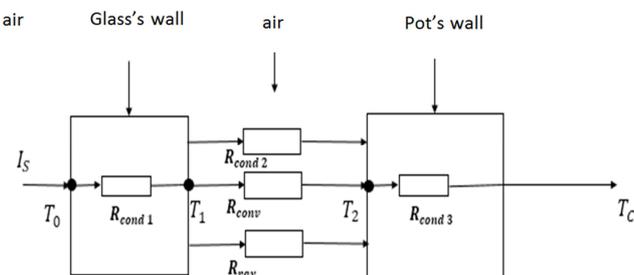


Figure 3. Modelling the transfer of heat flux from the paraboloid to the box cooker.

Simplification makes it possible to have equivalent

thermal resistance R_T
 $R_T \Phi = T_0 - T_C$ and $\Phi = I_s F S_p$. Finally:

$$R_T I_s F (S_p) = T_0 - T_C \tag{14}$$

whereare:

R_T	Equivalent thermal resistance	[K W ⁻¹]
Φ	Thermal flux	[W]
T_0	Temperature of the outer wall of the glass	[K]
T_C	Temperature in the pot	[K]
I_s	Irradiance	[W m ⁻²]
F	Reflection coefficient	
S_p	surface of the dish	[m ²]

The operating tests of the cooker are done with an empty pot. The experimental site position is 10,594° east longitude and 14.29° north latitude. A thermocouple is placed in the kettle, another temperature sensor is placed on the side of the box and a humidity/temperature sensor placed on the outside of the cooker for the environmental data. All these sensors are connected to the ALMEMO data logger. The temperature and irradiance data are recorded every 5 minutes in some cases and every 10 minutes in other cases. It is a question of making measurements of the temperatures of the pot, and of the ambient in the three following cases of following

2.2.1. Without Sun Tracking and Without Temperature Regulation

The data mentioned above are collected by positioning the parabolic reflector at an inclination of 15°, facing south. The box is positioned so as to orient one of the windows inclined full East and the other full West;

2.2.2. With Sun Tracking and Without Regulation

Optimisation of solar cooker equipment

i) Sun Tracking

The parabolic reflector is permanently oriented so that the sun's rays are perpendicular to it. To do this, it is oriented at the beginning according to the height of the sun, then after every hour, it is inclined of 15° following the path of the sun.

ii) Regulation of temperature

The manual regulation of the temperature consists in adjusting the position of the dish so as to obtain a constant temperature (set temperature or cooking temperature) in the pot. In fact, when the temperature in the pot is lower than that desired, the sun is applied; that is, the parable is oriented perpendicular to the sun's rays, keeping the solar spot under the pot. This has the effect of increasing the temperature in the pot. Once the desired temperature is reached, we stop tracking the sun. However, when the temperature in the kettle is higher than the desired temperature, the kettle is oriented along the axis orthogonal to the sun tracking axis (East/West) so as to remove the solar stain or part of the radiation reflected by the parable of the pot. This has the effect of reducing the temperature in the pot. Once the desired temperature is reached, we stop the movement of the dish. The test was carried out in the city of Maroua from 14h 35 min to 15h 16 min on 18/08/2017.

2.3. Application to Cooking Sorghum Wort

This part is intended for integrating the solar cooker into one of the unit operations of the Sorghum’s beer baking process. After obtaining the sorghum wort, 2 litres were introduced into the pot for cooking. One sensor was introduced into the pot, another into the box outside the pot and a last one out of the cooker to raise the room temperature. With regard to the irradiance prevailing on the day of the test, preheating is performed using the manually controlled solar cooker.

3. Results and Discussion

3.1. Geometric Characteristics of the Cooker

The results obtained on the geometric aspect of the cooker are presented in table 1.

These data will make it possible to highlight the 3D and 2D model.

Table 1. Geometric Parameters of the Parabolic Reflector.

Parameters	Values
d(mm)	1000
P(mm)	2000
f(mm)	430
$\frac{f}{a}$	430
h(m)	145
$A_a(m^2)$	2,545
$\varphi_p(^{\circ})$	60,34
$A_s(m^2)$	0,785
S	1,052

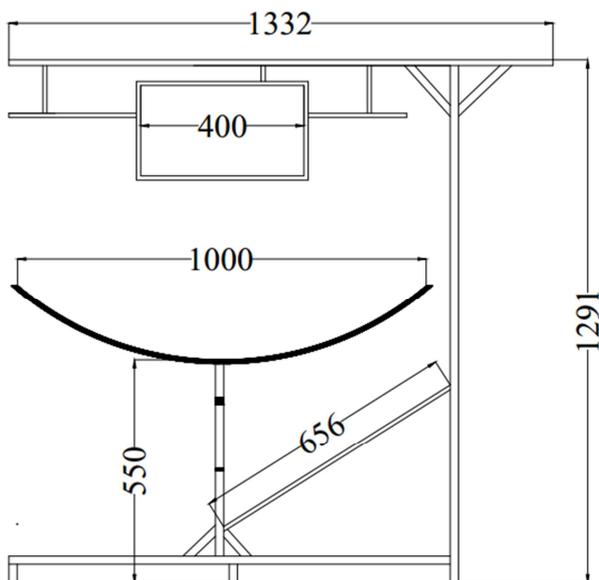


Figure 4. 2D drawing section of the cooker realised (dimensions are in mm).

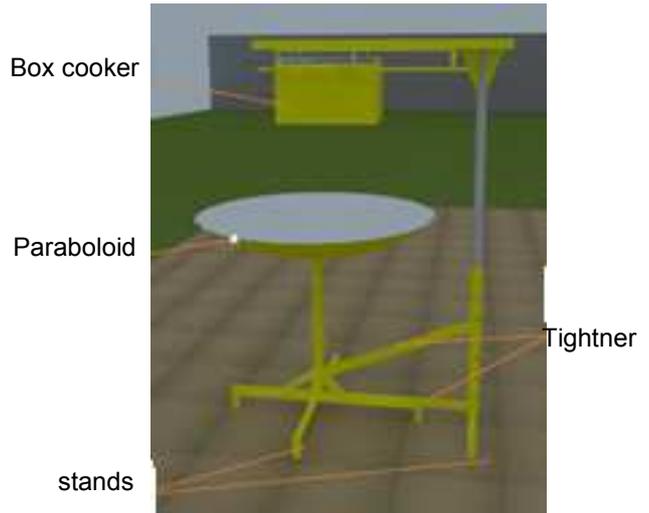


Figure 5. Modelled view of the solar cooker in 3D.



Figure 6. Photo of the cooker realized.

3.2. Evolution of the Temperature and Irradiance

3.2.1. Measurement Without sun Tracking and Without Temperature Control

Figure 7 shows the variations of temperature and irradiance during a test between 9:01am and 3:31am. Overall, there are significant fluctuations in temperatures in the pot that would be due to the intermittency of irradiance including cloudy blankets in the sky frequently observed during the test. It is also noted that the pot temperature could not reach 100°C throughout the test period. The maximum temperature reached is 95.5°C. Although having irradiance values reaching 993 W/m².

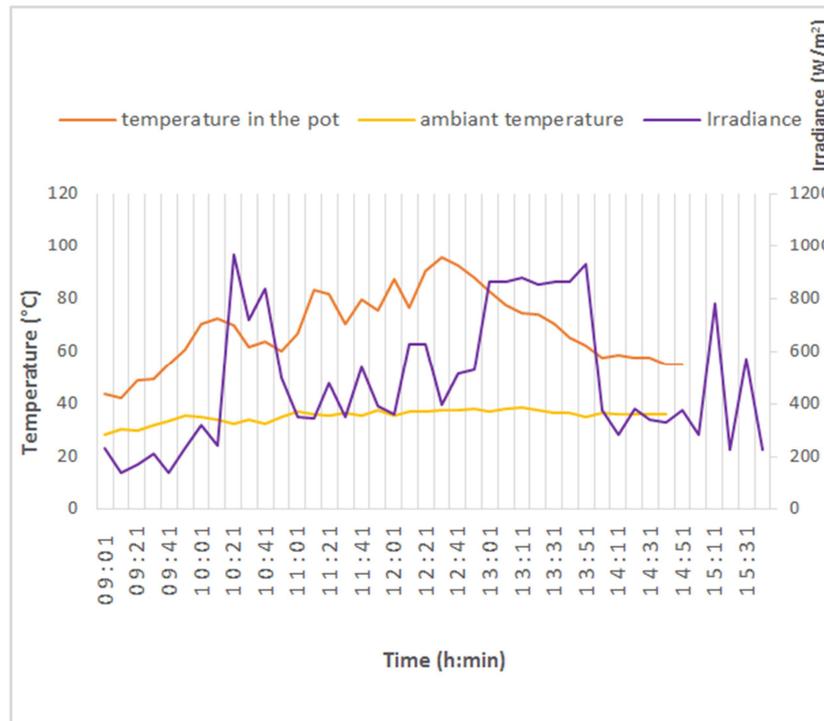


Figure 7. Evolution of the measured temperatures without continuation of the sun and without regulation of the temperature (no-load test of 12/08/2017,

3.2.2. Measurement with Sun Tracking and Without Temperature Control

The test performed, whose temperature and irradiance variations are shown in Figure 8 indicates that without regulation and with sun tracking. The irradiance values of the second day of testing are generally higher than those of the first day for the same periods. This phenomenon explains consequently higher temperatures this day compared to those measured the first day. The maximum temperature reached for this period is 168°C. under an average irradiance of 716.86 W/m².

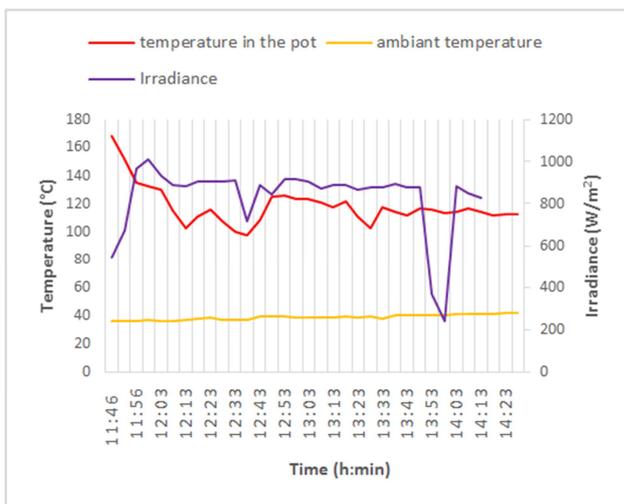


Figure 8. Evolution of the temperatures measured with sun tracking and without temperature control (no-load test 08/08/2017).

3.2.3. Measurement with the Regulation of Temperature

Figure 9 describes the evolution of the temperature of the pot and the ambient temperature during manual temperature regulation at 80°C. This was made possible by adjusting the paraboloid. We can notice that though the irradiance varies considerably, when adjusting the paraboloid the temperature is maintained around 80°C from 8:59 am to 2:01 pm.

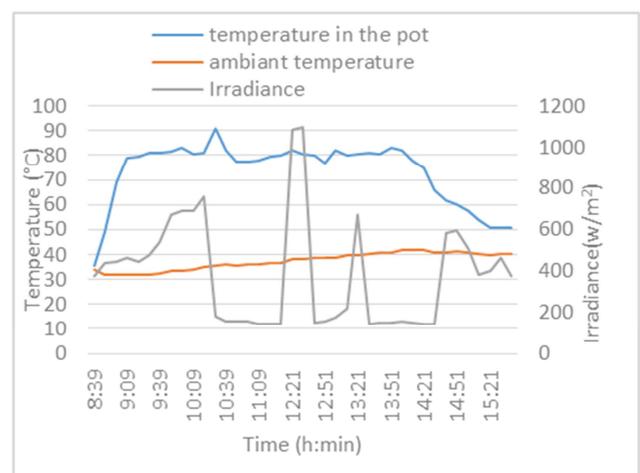


Figure 9. Evolution of the temperature of the pot and the ambient temperature during manual regulation.

3.2.4. Measurement with the Regulation of Temperature Applied to the Cooking of Sorghum Wort

The test whose measurements are presented in Figure 10 was carried out between 8:43 am and 12:31 am. It consisted of leather 2 litres of sorghum wort at a temperature of 80°C. We notice a rise in temperature between 8:43 and 11:05 am.

The value of the temperature tends to stabilize at 80°C between 11: 05 and 12: 31 am. This last period corresponds to the cooking time at almost constant temperature of the must of sorghum which was 1 hour 21 minutes

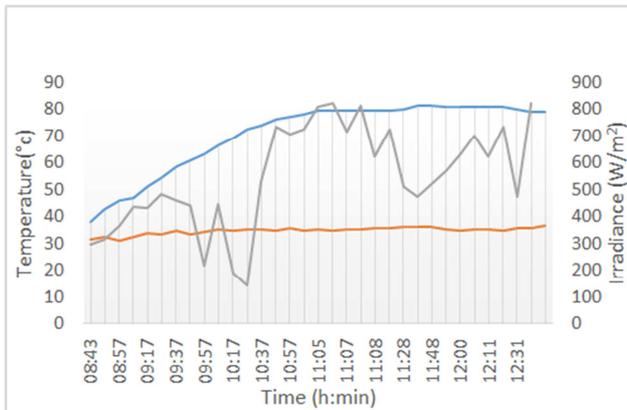


Figure 10. Evolution of the temperature of the pot and the ambient temperature during manual regulation during cooking (test of 18/08/2017, cooker loaded with sorghum wort).

4. Conclusion

The work we were doing was aimed at proposing a new type of solar cooker for cooking sorghum must. To achieve our goal, we designed and built a solar cooker with manual regulation. The tests carried out over several days show that although this system is manual, it makes it possible to have high temperatures favourable for cooking sorghum must. Finally, we performed a test of cooking sorghum must at a temperature of 80°C. It was noted, among other things, that the temperatures in the cooker depended on the irradiance. In perspective, we plan to: evaluate all the thermal performance of the cooker in particular; cooking tests of several types of food; we intend to improve this prototype by integrating automatic sun tracking and automatic temperature control devices.

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