

DESIGN AND REALISATION OF A PARABOLIC SOLAR COOKER

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ABSTRACT

The sun's energy is really powerful. Solar energy is renewable and it's free. We can use it to make electricity, to heat buildings and to cook. The field of cooking consumes many fossil fuels such as gas and wood. Million people cannot find enough gas and/or wood to cook, so using solar cookers is a good idea. During this work, we designed, built and studied a parabolic solar cooker. The characteristic equations and the experimental results are given.

Keywords: Solar energy, parabolic cooker, realisation and experimentation.

INTRODUCTION

Solar cooking is a simple and own technology. Nichols [1993] has shown that the concept of solar cooking began over 220 years ago and was used by the French Foreign Legion starting in the 1870's. It makes possible to reduce the costs of cooking and does not employ any raw material expensive or polluting. Moreover it has a slow cooking; the food is not degraded and preserves all their nutritional and gustatory qualities.

All solar cookers work on the principle of concentrating the direct solar rays to raise food or water temperatures to cooking. Cooking temperatures begin at about 65°C although temperatures of 120°C to 200 °C are preferred.

Various designs of the solar cookers were studied in order to optimize their performance. They vary by the geometrical form and the place of the cooking pot. It is well known [Dutta 2003] that an effective solar furnace generally forms part of two categories. One is of type box; the other is with reflectors parabolic focusing.

The guiding principle of a standard box solar cooker is to concentrate heat while letting pass the sunlight through a pane in one limbs closed well-insulated. The light is 'imprisoned' in the box and is transformed into heat when it is absorbed by the pot. The parabolic solar cooker rests on the principle of the concentration of the rays. It is well known [Mark 2004] that the parallel beam of ray of the sun is reflected on the parabolic mirror and the rays converge in the same point, the hearth of the parabola. While running up against a dark container placed in this point, the rays are released their energy in the form of heat. It is obvious that when the parabola is larger, the cooker will be powerful.

HEAT TRANSFER MECHANISMS

Nichols [1993] shown that solar heat is transferred into the food by three mechanisms. First, by direct solar rays, that is sunlight striking the food directly. This is somewhat like a broiler. Second, by convection, that is by the hot air surrounding the food inside the chamber. Third by conduction, heat is transferred from the tray, which the food rests on, to the aliment. If the tray is a heavy metal conductor such as steel or aluminium the sun's rays will heat the tray and conduct the heat under the food like a stove. All these three mechanisms combine to make the food cooking process very efficient.

Nomenclature			
A_{pot}	Area of the cooking pot, m^2	P_a	absorptive radiation power, W
A_{par}	Aperture area of the parabolic concentrator cooker, m^2	P_u	Useful power, W
C	Geometrical concentration	P_e	Thermal losses power, W
C_g	Ideal concentration	R	Radius of the parabola, m
C_w	Specific heat of water, J/kg K	r	Exergy
C_{pot}	Specific heat of the matter of the pot of cooking, J/kg K	T_{wi}	Initial temperature of water, °C
d	the concentrator diameter, m	T_{wf}	Final temperature of water, °C
E	Illumination on the level of The Concentrator, w/m^2	T_a	Ambient temperature, °C
f	Focal distance, m	$\Delta T_{\infty-95}$	temperature difference between the ambient and the boiling temperature, K
F'_{UL}	Factor of losses thermal	η_0	Optical effectiveness
h	Depth of the parabola, m	ρ	the parabola coefficient of reflexion
h_{fg}	Latent heat of vaporization, J/Kg	γ	the absorber coefficient of interception
I_b	Direct radiation intensity, W/m^2	τ	cooking pot Transmittivity
M_w	Mass of water, kg	τ_0	cooling time constant
M_{pot}	Mass of empty pot with lid, Kg	ϕ_0	The opening half angle of the parabola, degree
\dot{m}_{ev}	Mass of evaporated water per unit of time, Kg/s		

DESIGN OF THE PARABOLIC SOLAR COOKER

For better accumulating heat without letting pass the fresh air, we must choose the depth of the parabola. Our parabolic solar cooker is composed of a parabola whose diameter is 180 cm and its depth 26 cm, glazes by rectangular reflective stainless material with a thickness of 1 mm. Figure 1 shows our solar cooker.

The choice of the pot is of primary importance. It must be the darkest possible ideally black. For a good effectiveness, the material of the pot must be a good conductive of heat. In our case we chosen a pot painted in black with a capacity of 2 liters.

We built a support in the form of a circular grid with a diameter of 30 cm attached at the ends of the parabola by two stems. During our tests, the parabola should follow the sun, the time advance of the parabola, as shown by Afifa and Besma [2008], is each 20 min.



Fig. 1. Photograph of the experimental solar cooker

MODELING

To accomplish our simulation we used these different equations:

- The equation giving the focal distance (f) is given by Kalbande [2006]:

$$f = \frac{h^2}{4 * R}$$

- The parabola surface is:

$$A = \frac{8 * \pi * f^2}{3} \left[\left(\left(\frac{d}{4 * f} \right)^2 + 1 \right)^{3/2} - 1 \right]$$

- The half aperture of the parabola is:

$$\tan \phi = \frac{1}{\frac{d}{8h} - \frac{d}{d}}$$

- The heat balance of the solar concentrator with permanent rate is given by Zerelli [2004]:

$$P_a = P_u + P_e$$

- The radiation absorptive power can be calculated by:

$$P_a = E C_g A \rho \gamma \tau \alpha$$

- The coefficient of interception is given by the following equation:

$$\gamma = 1 - \exp \left[-820 \left(0,7 \frac{r}{f} \right)^2 (1 + \cos(\phi_0)) \right]$$

- The power of heating is given as follow:

$$\dot{Q}_{heat} = \frac{M_w C_w \Delta T_{\infty - 95}}{\Delta t}$$

To compare the various cookers in various countries and under various climates, Funk [2000] has shown that the power of radiation is standardize to 700 w/m². The standard power is expressed then by:

$$P_s = \frac{(M_w C_w)(T_{wf} - T_{wi})}{600} * \frac{700}{I_b}$$

“600” represents the time interval of measurement in second.

- The power of evaporation is given by Zerelli [2004]:

$$\dot{Q}_{ev} = \dot{m}_{ev} * h_{fg}$$

- The thermal losses factor is given by the Centre of energy studies [2006]:

$$F' U_L = \frac{(M C)'_w}{A_{pot} \tau_0}$$

$$(MC)'_w = M_{pot} \cdot C_{pot} + M_w \cdot C_w$$

- The optical effectiveness factor is given by the Centre of energy studies [2006] and Kumar [1995]:

$$F' \eta_0 = \frac{(F' U_L) A_{pot} \left[\left(\frac{T_{wf} - T_a}{I_b} \right) - \left(\frac{T_{wi} - T_a}{I_b} \right) e^{-\tau/\tau_0} \right]}{1 - e^{-\tau/\tau_0}}$$

- The output of the cooker is given by Schwarzer [2007] and Kundapur [2006]:

$$\eta = \frac{(M_w * C_w + M_{pot} * C_{pot})(T_{wf} - T_{wi})}{A_{parabole} * \int_0^t I_b dt} * 100$$

- The standard boiling time (in minutes) of the given cooker, which is characterized by F'UL and F' η₀, may be calculated using the following expression for the typical conditions of solar irradiance and ambient air temperature for a location:

$$t_{boiling} = \tau_0 * \ln \left[\frac{1}{\left(1 - \left(\frac{F' U_L}{F' \eta_0} \right) * \left(\frac{A_{pot}}{A_{parabole}} \right) * \left(\frac{100 - T_a}{I_b} \right) \right)} \right]$$

TESTS PROCEDURES

It is presented by the American Society of Agricultural Engineers (ASAE S580) [2006]. It highlights the following experimental procedures:

Procedure for heating test

Heating test is conducted to determine optical efficiency factor ($F'\eta_0$) of the parabolic concentrator solar cooker. For this test, the cooking pot with a predefined amount of the water (as the cooking load) is mounted at the focus of the parabola.

The solar cooker is exposed to unobstructed solar radiation and is adjusted in a manner that the bright spot of the concentrated solar radiation falls on the centre of the bottom of the cooking pot.

The following measurements shall be made at an interval of at least 5 minutes and recorded:

- Intensity of direct solar radiation on the aperture plane of the parabolic concentrator (I_b)
- Diffuse solar radiation on horizontal surface
- Water temperature in the cooking pot (T_w)
- Ambient air temperature (T_a)
- Wind speed at the level of aperture of the parabola (V)
- Temperature of water in the cooking pot shall be monitored continuously till the water temperature reaches 95°C. Tracking shall be done to keep the bright spot onto the centre of the bottom of cooking pot.

Procedure for cooling test

As soon as the water temperature reaches 95°C during heating test, the concentrator shall be shaded by an adequately sized umbrella (with dark color, preferably black) so as to ensure total blockage of solar radiation. It shall be ensured that the shading arrangement causes least interference in the heat loss process from the cooking pot.

Measurement and continuous recording of parameters (c) - (d) shall be done at every two minutes interval for the first half an hour and later at five minutes interval until the water temperature reaches a value close to the ambient air temperature.

RESULTS

Cooling test

For each set of the data points, the value of $[\ln(T_w - T_a)]$ shall be calculated, and a plot with this value on Y-axis and time on X-axis shall be drawn, as shown in the adjoining figure. Different

points of the plot shall be fitted to a least square linear regression equation. The slope of the line equals to $(-1/\tau_0)$. In figure 2 we draw a comparison of cooling curve of our unit with SK14.

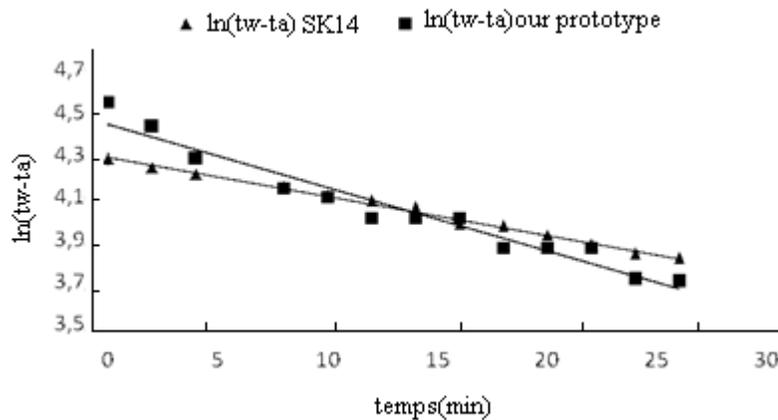


Fig. 2. Comparison of cooling curve of our unit with SK14

The two lines present the same paces, but they haven't the same slope. The various parameters which cause the difference between our experimental results and the SK14 results are the difference between the characteristics of the tow units (dimensions, climatic conditions...). These two curves will be used to determine the thermal losses factor and the optics effectiveness.

Heating test

The optical efficiency factor ($F'\eta_0$) of the parabolic concentrator cooker shall be calculated for each 10-minute interval of the test using Eq. (11). For the first test interval, initial value of the water temperature shall be used for T_{wi} , and the value of water temperature at the end of 10-minute interval for T_{wf} . Subsequently, the value of T_{wf} for the first interval shall be used as T_{wi} for the second interval. This process shall be continued for subsequent test-intervals. A graph showing the time variation of $F'\eta_0$ according to time is shown in figure 3.

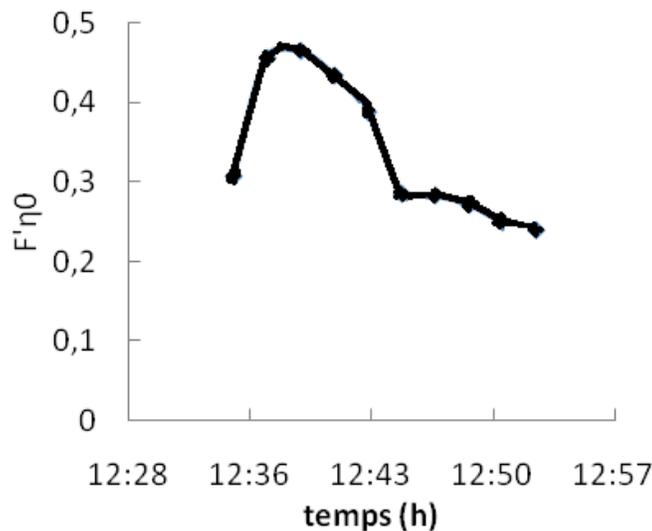


Fig.3. Variation of optical effectiveness factor according to time

The curve takes a no stable form. The optical effectiveness factor increases, reaches a maximum and after that decreases. This is can be explained by the fact that this factor have a variation with the time similar to the solar flux.

Heating and Cooling Tests Conditions

Tests conditions for our unit are:

Solar radiation $500 < I_b < 1000 \text{ W/m}^2$

Ambient temperature is between 20 and 35° C

Wind speed less than 1 m/s

Tests conditions for SK14 unit are:

Solar radiation $> 600 \text{ W/m}^2$

Ambient temperature is between 20 and 40°C

Wind speed Less than 0.5 m/s

Standard Boiling Time and Cooker Characteristic Curve

In order to have a characteristic curve of boiling time, we draw it according to $\frac{100 - T_a}{I_b}$.as shown in figure 4.

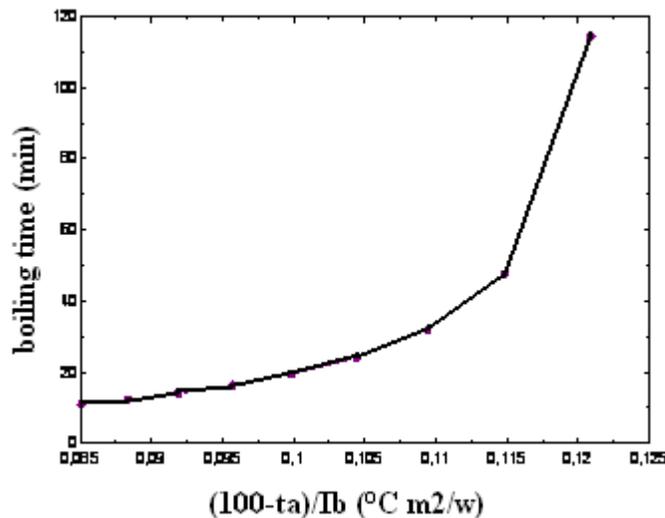


Fig.4. Heating curve of water

The characteristic curve of heating represents an increasing pace. At the maximum solar flux, the time of boiling is 10 min, and when the solar flux decreases this time increases gradually.

Cooking tests

It was found that the warming-up time of water of 40°C until 80°C is 12 min. The maximum temperature by using oil is 130°C. The temperature without sunning goes down from 100°C until 80°C during 45 min, and if the lid is removed, the same fall is reached during 8 min.

In the following test, we tried to boil two liters of water successively from 9h: 45. This test is carried out at 10-05-08. These results are represented in fig. 5. For each time and when the quantity of water reaches the boiling point, then we take a new quantity and we make it boil.

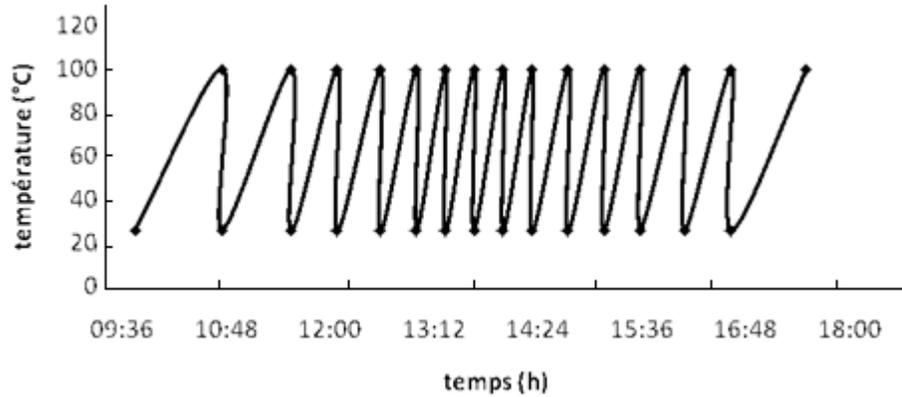


Fig.5. Variation of the time of boiling of two liters water according to time

Two liters of water take almost an hour to boil with the first tests between 9:45 and 10:45h. This time decreases about midday with the increase of the direct solar flux; this is proven by the peaks which become increasingly acute. This test of water heating can inform us finally over the most favorable period of cooking. For a quantity of water which borders the standard capacity of the cooker (according to standard ASAE S580 JAN03), the necessary period of heating to reach boiling is on average one hour and half according to climatic conditions.

To validate our cooker, we tried to cook some food. The following table summarizes the tests of cooking carried out.

Table 1
Cooking tests

Prepared meal	ingredients	Time of cooking	Solar flow (W/m^2)
Soup with meat	1.5l water + 300g meat + 500g passels	1h 10min	750
 Cake	egg + 100ml oil + 100g sugar + 300g flour + 100ml milk + vanilla + yeast	40 min	600
Tee	200ml water+10g tee +sugar	8 min	700

CONCLUSION

A parabolic solar cooker has been designed, built and tested. The experimental results showed that the favorable conditions of cooking are:

- The best hour of cooking is between 13h: 30 – 14h: 30.
- The cooker is more effective if the solar tracking is correctly.

Test procedures for heating and cooling are used. They shall be conducted to evaluate characteristic performance parameters of the parabolic solar cooker under testing. These parameters are:

- Heat Loss Factor ($F'UL$)
- Optical Efficiency Factor ($F'\eta_0$)

The cooker presents encouraging results while being compared to the SK14 and when it was used to cook some food. The difficulty appeared at the time of advance of the parabola because of its great dimensions and weight.

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