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Modification and Construction of Solar Cooker Using Parabolic Reflector

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Abstract: Energy is essential to economic and social development and improved quality of life of human being. A parabolic solar cooker was modified, fabricated and evaluated as a simple device to harness direct sun rays for cooking purposes. This device was constructed on a steel dish which was completely lined with aluminium foil. This reflecting surface was used to concentrate the rays of the sun at a focus which led to production of high temperature for cooking purposes. A cooking pot stand was erected and positioned near the focus. The equipment was tested for temperature (energy concentration) achieved at the bottom of the cooking pot, and by cooking with it. The energy concentration efficiency of the cooker was found to be 53.41%. The average temperature achieved by this cooker during the time of testing was 107.38°C (380.53K) it was also used to cook beans and groundnuts in comparison to other alternatives such as kerosene stove and firewood. It took one hour to cook beans and 18 mins to boil groundnut. On the other hand, it took 33 mins and 40 mins to cook the same quantity of beans using kerosene stove and firewood, respectively while it took 10 mins and 17 mins to cook groundnuts using kerosene stove and firewood, respectively.

Keywords: Energy, Solar, Ray, Parabolic, Fabrication and Cooking

1. Introduction

Solar energy is being seriously considered for satisfying a significant part of energy demand in the world [1, 5, 11]. Solar energy is the energy in form of electromagnetic wave. An accurate knowledge of the solar radiation data at a particular geographical location is of vital importance for the development of solar energy devices and for estimates of their performances. All electromagnetic waves travel through space at the same speed, the velocity of light $c = 2.998\, x\, 10^8\, {}^{m}/_{s}$, and the velocity of light in air is essentially the same as its velocity in space. The power radiated by the sun into space is about $4\, x\, 10^{23}\, kW$. The fraction received by the earth is $2\, x\, 10^{24} kW$. These three principal natural energy sources and their contributors are stated below:

a. Geothermal energy from the earth's interior contributed about 5.2 Q per year.
b. Radiated energy is derived from the sun while its energy contribution is 1.00 Q per year.
c. Tidal energy is the energy derived from the interaction of the earth with the moon and the sun. Its contribution is 0.1Q per year while Q is the unit derived as $2.93\, x 10^4 kW$.

Also, there are two types of solar radiation that reach the earth, one is direct-radiation this come directly without being scattered into space while the other type is diffuse radiation which comes from all direction after being turned back by the atmosphere a number of time. The sum of both type of solar radiations is termed as global radiation. The generation of energy by wind and water mills are typical examples of direct utilization [7]. Principle of operation for parabolic solar cooker; solar energy in form of short electromagnetic wave radiated on the parabolic dish, which allows rays of light on a large surface to be concentrated to a point. With the help of aluminium foil arrangement in the dish, the rays of light were reflected and brought to focus.

1.1. Concentrating Collectors

Concentration of solar radiation is achieved by using a reflecting arrangement of mirrors or a reflecting arrangement of lenses. In order to raise the intensity level received by any one square meter of the absorber, the energy received on a number of square meter, has to be reflected to, or focused on, that one square meter of absorber. This concentrates the energy that is available over a large surface by focusing it on a smaller surface. This is why this type of device is called a concentrating or focusing collector, and why the ratio of the area of intercepted sunlight to target or receiver is called the concentration ratio [8]. There are different types of concentrating collectors such as flat plate collector with plane reflectors, compound parabolic collector, and cylindrical parabolic collector. This keeps the light converging at the focal point of the parabolic section [12].

1.2. Types of Parabolic Reflector

Parabolic reflector is divided into two types

a. Parabolic "Dish"
b. Parabolic "Trough". But with the nature of the project parabolic 'Dish' was selected (Rahul, et al., 2017).

2. Materials and Methods

This study was carried out in the department of Agricultural and Bio-Environmental Engineering Technology, Federal Polytechnic, Bauchi.

2.1. Functional Design

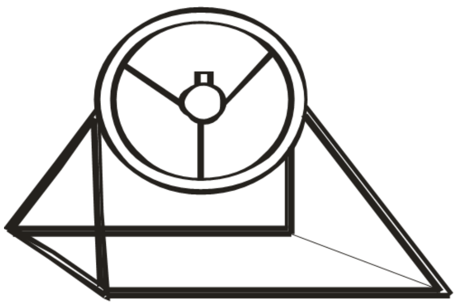

Figure 1. *Schematic diagram of the solar cooker.*

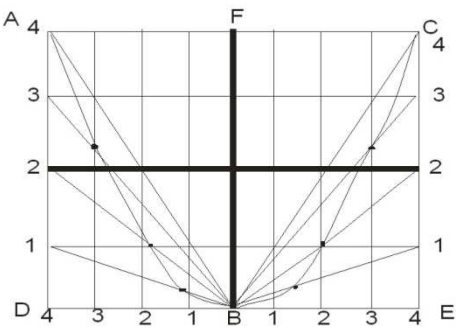

Figure 2. *Conceptual parabola diagram.*

Mathematically, a parabola is a conic section generated by the intersection of a right circular conical surface and a plane parallel to a generating straight line of that surface. A parabola has a single axis of reflective symmetry which passes through its focus and is perpendicular to its directed. The point of intersection of this axis and the parabola is called the vertex. A parabola spun about this axis in three dimension traces out a shape known as a paraboloid of revolution [9].

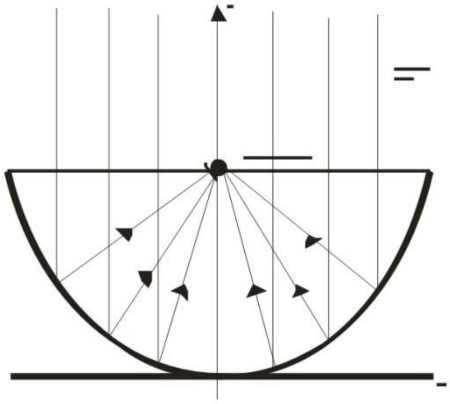

Figure 3. *Paraboloid revolution diagram.*

The depth of the parabola affects the height of the focus, as illustrated below:

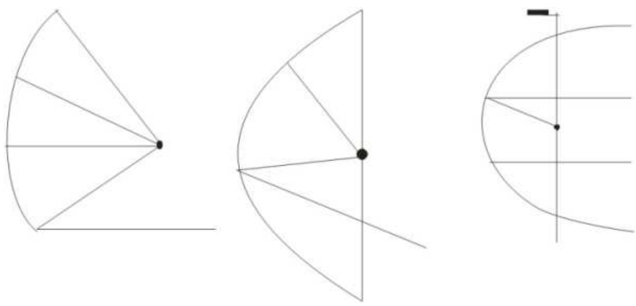

Figure 4. *Effects of parabola depths on the height of the focus.*

2.2. Focus

This is the point where the cooking is carried out on the solar cooker. This can be found by the help of simple calculations or by direct observation. The focus was found by direct observation after the dish was lined with a reflective material. A piece of cardboard was held close to the centre of the dish, and then it was moved up and down towards the sun and back.

2.3. Potholder

The potholder was constructed from structure made from used bike rims which allows the pot to remain level. On this rims the cookware is located and the bottom of the cooking pot was placed a little below focal point for uniform heat distribution. Regardless of the base inclination, the pot can be placed effortlessly in the cooker of solar movement, elevation of the sun, also contributes to asymmetry of the cooker. While the reflector faces the sun, the cookware remains horizontal.

The angle between their axes may be as low as zero [11].

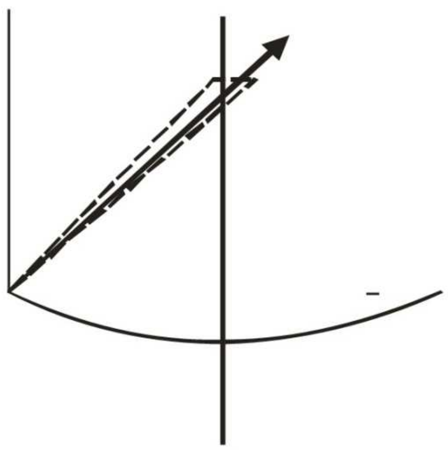

Figure 5. *Diagram showing location of the potholder.*

2.4. Material Requirement of the Solar Cooker

Materials used were locally sourced and were readily available with low cost that can be easily maintained when necessary. Materials used for this project have the following characteristics;

i. Materials are replaceable under degradation.
ii. The material can resist wind damage.
iii. The material is able to resist corrosion from saline water and distilled water.
iv. The material is portable and can be easily dismantled.

2.5. Selection of Reflective Material

During the time of this construction aluminum foil was used after considering many advantages of the material.

2.6. Construction of the Solar Cooker

a) Machine process: The solar cooker parts were produced from metal sheets, iron pipe, bicycle rim and aluminum foil. Each part was designed separately with different method and processes. The processes involved were; cutting, shaping, growing, grinding and welding.
b) Parabolic Sheet: The dish was constructed from a metal sheet of a thickness 0.5mm. A metal sheet of 1219.2 x 24384 mm^2 was marked out and cut using a scriber to a diameter of 1730 mm, a square pipe of length 1730 mm was cut and curved to a circular form and conformed to the diameter of the metal sheet. Also a square pipe was cut and curved, and welded to the circular iron pipe in parabolic shape. These also serve as a support to the metal sheet which was cut in segmented layers and welded to the iron square pipe. The whole arrangement was now bolted to the stand made of iron square pipe 1½ square pipe of length 910 mm welded to one another 3/4 square pipe of length 665 mm was arranged inside the dish to hold the potholder at the focal point or parallel to the axis of the symmetry of the dish [3]. The potholder distance to the axis of the symmetry was calculated to be 624 mm.

2.7. Determination of the Focus

Determination of the focus was done using cardboard paper which is a direct observation method. After the dish was lined with reflective material, a piece of cardboard was held close to the centre of the dish, and then it was moved up and down toward the sun and back. A circle of light appeared on the underside of the cardboard, when the circle is smallest, that was the position of the focus.

2.8. General Assembly the of Solar Cooker

The parabolic dish was covered with the reflective material (aluminum foil) using gum. The aluminum foil was arrayed properly to give sharp focal point. Though when the rays of light strikes the surface of the foil some are dispersed away, while the remaining ones converged on the pot, [10] used similar method in his study.

3. Results and Discussions

3.1. Testing

Standard testing procedures were followed and this includes testing of temperature at the focus at various intervals, measuring of the cooking time of the cooker in comparison to other alternatives such as stove and firewood and measuring of the sunshine availability at the time of cooking [4].

3.2. Cooking

Two varieties of food were cooked using the solar cooker, while two other energy sources were used for comparism namely, firewood and kerosene stove. These were used to cook beans and fresh groundnut and their cooking time were obtained as tabulated below, Tables 1 and 2:

Table 1. *Cooking times.*

S/N	Foods	Solar cooker	Kerosene stove	Firewood
1	Beans	1 h	33min	40min
2	Groundnut	18 min	10min	17min

Table 2. *Analysis using method of orthogonal contrast.*

Device	Cooking Time (min)	ti	
Solar cooker	60	18	78
Kerosene stove	33	10	43
Firewood	40	17	57
	T...	178	

$$n = 2, p = 3, N = 6 \ SS_U = \frac{T^2}{np} = \frac{(178)^2}{6} = 5280.67$$

$$SS_t = \sum \frac{Ti^2}{n} - \frac{T^2}{np} = 5591 - 5280.67 = 310.33 \ SS_e = \sum xij^2 - \frac{Ti^2}{n} = 7002 - 5591 = 1411$$

Table 3. *ANOVA results 1.*

Sources of variation	df	SS	Ms	F
Treatment	2	310.33	155.17	0.32
Error	3	1411	470.33	

α, 0.05 = 9.55.

Table 4. *ANOVA results 2.*

Sources of variation	df	SS	Ms	Fcal	Ftab
Contrast 1	1	130.67	130.67	0.28	10.13
Contrast 2	1	24.5	24.5	0.05	10.13
Error	3	1411	470.33		

Since Ftab>Fcal at α =0.05 both contrast will be accepted (Table 3) but contrast 2 will more accepted with the conclusion that there is no significant difference between the cooking time of the solar cooker and other alternatives (Table 4). But in another sense the solar cooker is more at an advantage compared to other alternatives because there is no cost in buying fuel and also there is no harmful effects to the environment in the solar cooker as in other alternatives.

3.3. Temperature Readings

The temperature of the cooker at the focus where the cooking pot is placed was measured at intervals this was done during the time of cooking. The temperatures were from 9am to 4pm, Figure 6:

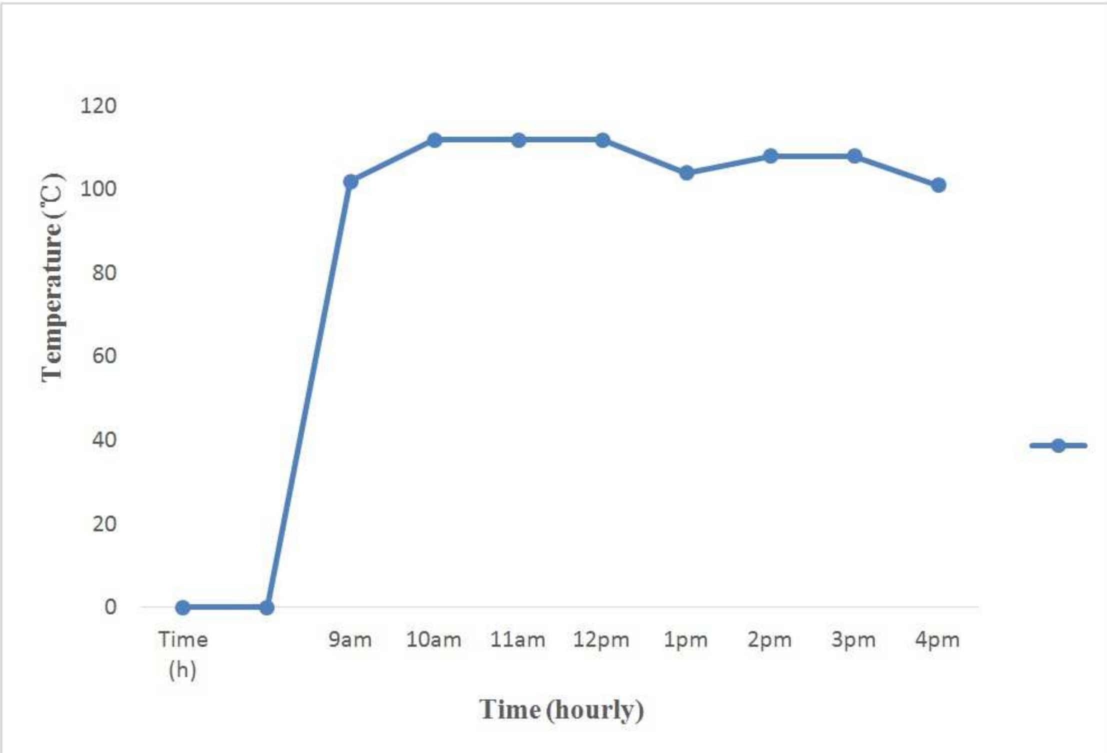

Figure 6. *Temperature readings from 9am to 4pm.*

The average temperature obtained was 107.38°C. The temperature was measured using a glass bulb thermometer due to the non-availability of the digital thermometer.

3.4. Sunshine Availability

The sunshine availability for the day this testing was carried out and was measured using the sunshine record. The readings obtained hourly were as follows (Table 5):

Table 5. *Time and readings.*

Time	Reading
08 - 0900	0.9
09 - 1000	1.0
10 - 1100	1.0
11 - 1200	1.0
12 - 0100	0.8
01 - 0200	1.0
02 - 0300	1.0
03 – 0400	0.9

Total Sunshine 7.6 h.
Note: 0.0 – No Sunshine, 1.0 – continuous sunshine.

The sunshine recorder is an instrument use to measure the intensity of the sun. It has a sunshine card which is placed under the glass ball graduate hourly. When the sun is high and intensive enough it burns the card the level of burning is read from the card [2].

3.5. Efficiency of the Solar Cooker

The thermal efficiency of this cooker is calculated by the formulae equation (1):

$$Thermal\ Energy = \frac{Focus\ Enenrgy}{Energy\ received\ at\ the\ dish} \quad (1)$$

It is assumed that:

Focused energy = Energy available at the potholder

Energy received = Total amount of energy radiated by the sun which strike the dish.

This was calculated using equation (2)

$$E = A\delta T^4 \quad (2)$$

$$E = Total\ amount\ of\ energy\ radiated\ {}^{W}/_{m^2}$$

$$\delta = Stefan\ constant\ with\ value\ 5.7\ x\ 10^{-8}\ {}^{W}/_{m^2K^4}$$

$$T\ =\ Temperature\ of\ the\ surface\ K$$

$$A\ =\ Area\ of\ the\ dish\ \left({}^{2}/_{3}\right)$$

$$A\ =\ Area\ of\ the\ potholder(\pi r^2)$$

(a) **(b)**

Figures 7. *(a) and (b): Solar Parabolic Cookers (a) sketch and (b) constructed.*

The efficiency of this cooker was found to be 53.41%. Certainly there are losses of energy due to radiation and incomplete reflection of this ray to the focus due to inaccurate curvature. But nevertheless since the cooker was designed for cooking. The only thing that affects the efficiency of this cooker is when the intensity of the sun is low and there are clouds in the sky.

4. Conclusion

In conclusion the solar cooker with efficiency of 53.41% was fabricated and tested to cook some food items. The solar cooker is an efficient device which can be used to cook some foods depending on some factors such as correct production process and the sun intensity available in the area where it is been used [6].

5. Recommendations

The following recommendations were made:

1. Anyone who wishes to improve on this project should think of a possible way to measure the energy to be used in cooking at the focus.
2. Find a possible curvature that can trap and reflect all the sun radiation to the focus.
3. It is important that one wears a dark protective sun glasses during cooking.

Conflict of Interest Statement

There is no conflict of interest.

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