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Performance Evaluation of a Parabolic Solar Cooker

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ABSTRACT

Given the prevalent energy crises across the globe, it is always desired to exploit new and renewable energy sources which are readily available at almost negligible cost. Among these include solar energy with an infinite potential. Solar cookers have come in various forms: parabolic cookers, panel cookers, box cookers, and funnel cookers; each with its own design and performance peculiarities. For efficient utilization of solar energy, focusing type parabolic solar cooker was designed and fabricated, having a focal length of 47.02 cm. The performance evaluation gave a maximum temperature of 90°C at an ambient temperature of 30°C. A black pot which absorbs heat more readily than other materials was used for the performance test. Sensible thermal efficiency was found to be 19 per cent. The solar cooker was found efficient in cooking a variety of food items.

Keywords: *Solar Cooker; Focusing Type Parabolic; Performance Evaluation; Design; Thermal Efficiency*.

1. INTRODUCTION

It is still common to observe that in most underdeveloped countries majority of rural dwellers still use wood as their major source of fuel for cooking. This has resulted in deforestation and fragrance abuse of our natural environment. Desert encroachment and global warming are few among many resultant effects. Most urban dwellers also use kerosene and other petroleum bye products for cooking amidst its attendant environmental hazards. Fossil fuels are not environmentally friendly owing to emissions arising from bye products of combustion which constitute health hazards (George, 1963).

Electric cookers are excellent source of heat energy, unfortunately the high cost of electric energy generation and distribution added to erratic power supply as witnessed in underdeveloped economies constitute obvious drawbacks. Nigeria as well as other countries in the tropics are readily blessed with abundant supply of solar energy which can conveniently be harnessed to fill this gap. In Nigeria for instance, there is hitherto no serious work done to develop a solar cooker that can serve as excellent alternative heat source to fossil fuel-based cookers. There are however some developments elsewhere. In India for instance, a concentrator type solar cooker had been developed consisting of a medium size parabolic disc made of aluminum sheet having 75 per cent reflectivity and with a stand at the focus of the cooking pot (Lura, 1979). In 1875 Muchet made a notable advance in solar collector design using a truncated cone. His design was a able to focus light uniformly along the axis of the cone so that a tube could be used as energy absorbing surface (Blum, 1989). The development of a high concentrating solar cooker that makes use of the high solar radiations in the tropics for heating purposes is a most welcome development, especially among the rural dwellers.

2. PRELIMINARY DESIGN

2.1 Design Concept

Figures 2.1 and 2.2 show the assembly and the orthographic views of the parabolic solar heater, respectively. Table 2.1 shows the component parts of the cooker.

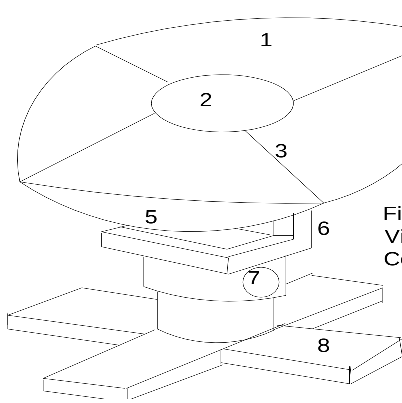

Fig.2.1 Assembly View of the Solar Cooker

Table 2.1 Component Parts of the Parabolic Solar Cooker

S/N	ITEMS	QTY
1	Reflector	7
2	Gyroscopic Pot Stand	1
3	Stand Support	4
4	Parabolic Concentrator	1
5	Wire Mesh	1
6	Concentrator Control Arm	1
7	Adjustment Knob	1
8	Base Stand	1

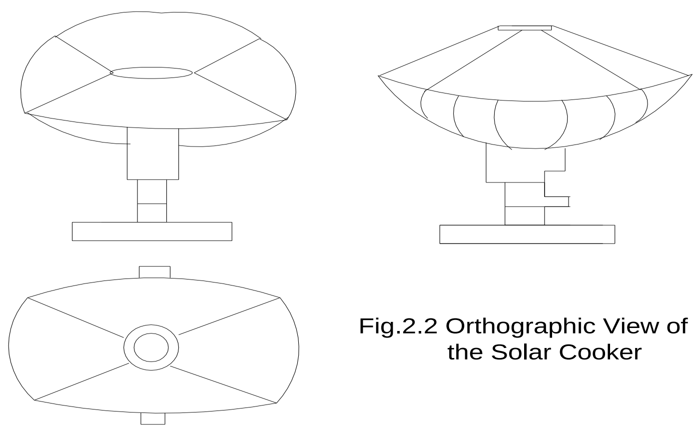

Fig.2.2 Orthographic View of the Solar Cooker

2.2 Description of the Cooker

The parabolic solar cooker is a direct concentrating cooker with a dish type reflector (or concentrator) directing most of the intercepted radiations to a point of focus called the focal point. The cooking vessel (or pot) is positioned at this focal point, thus creating a heating situation very similar to the traditional open fire cooking.

The concentrator is a shallow dish shaped frame mounted firmly on a rotating base which allows the concentrator to be positioned at the desired angle for proper tracking of the incident solar energy. Sheets of wire mesh are riveted on the concentrator frame to support the reflecting materials (reflectors). These reflectors are fixed in several stripes onto the parabolic metal frame to create a continuous reflecting surface which are supported to focus the sun radiation. Across the concentrator are four hollowed rods fixed at each corner. These rods support the gyroscopic pot stand on which the pot is to be placed. The bottom of the pot is painted black for high heat absorption.

2.3 Principle of Operation

The parabolic solar cooker uses sun energy as the heat source for cooking different kinds of food. Three basic phenomena are employed in the design and operation of the cooker. These are:

i. When solar radiation (sunlight) strikes a dark surface, it changes to infra red radiation.

ii. When light falls on a shiny surface, it is reflected and so can be directed to a desired point.

iii. In optics it is known that a concave mirror will reflect a parallel beam of light to a focal point.

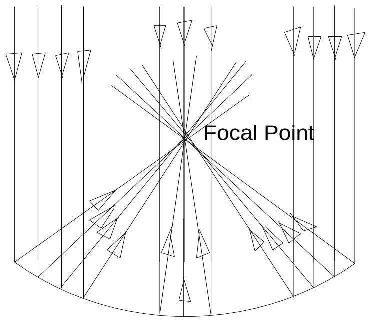

Fig.2.3 Rays of Light Reflection on a Concave Mirror

The cooker uses reflective material which focuses incident sun rays to a specific point, called the focal point. Heat concentrated at this point can be used for cooking. The solar cooker is outdoor operated and works best on bright sunny days. To boil for instance a pot of water, the pot is placed on the gyroscopic pot stand. The parabolic concentrator is turned such that incident sun rays strike the reflective surface. The sun rays are thus reflected through the focal point right at the position of the water pot thereby making the pot scorching hot. The parabolic concentrator is adjusted to track the sun rays and is supervised for safe operation. The water boils within a short period because the parabolic solar cooker can reach temperatures as high as over 120^{o}C and thus can cook faster depending on sun intensity. Before removing the pot, the reflector is rotated to the opposite direction of sunrays, leaving the pot in the shadows.

3. DESIGN ANALYSIS

3.1 Capacity of the Cooker

The capacity is also referred to as the power of the cooker (Gao, 1989).

$P = M_w \times C_w \times \Delta T_w / \delta t$

Where P = Power, Watts

C_w = Specific heat capacity of water, 4200 J/kg.K

$\Delta T_w = (T_2 - T_1)$ = Rise in temperature of water, K

T_1 = Initial temperature of water, T1 = 30^{o}C + 273 = 303 K

T_2 = Final temperature of water, 100^{o}C + 273 = 373 K

Δt = Time required to boil the water at 100^{o}C, sec.

Given that it takes the cooker 5 minutes to boil 1.5 kg of water,

Then, $M_w = 1.5$; $\delta t = 300$ seconds

P = 1.5 x 4200 x (373 – 303) / 300 = 1,470 W

3.2 Total Surface Area of the Parabolic Concentrator

$P = H_{av} \times A \times €$

(Srinivasan, 1979)

Where H_{av} = Average solar insolation, 700 W/m^2

A = Total surface area of the parabolic concentrator, m^2

€ = Emissivity of the reflecting material, 0.95

P = Power of the solar cooker, 1,470 Watts

Thus, $A = P / H_{av} \times €$

A = 1470 / 700 x 0.95 = 2.21 m^2

3.3 Focal Point

The parabola equation is used to determine the focal point such that;

$X^2 = 4FY$ (Habeebullah et al, 1995)

Where X is half the total length, 91.7 cm

F is the focal length, and

Y is the height of the parabola measured from the base, 44.7 cm

$F = 91.7^2 / 4 \times 44.7 = 47.02$ cm

3.4 Heat Gain by Water

$Q_w = M_w \times C_w \times \Delta T_w$

Where M_w = Mass of water, 1.5 kg

C_w = Specific heat capacity of water, 4200 J/kg.K

ΔTw = Temperature rise of water, $T_2 - T_1$

Q_w = 1.5 x 4200 x (373 – 303) =441000 Joules

Q_w = 441 kJ

3.5 Sensible Thermal Efficiency of the Cooker

$\eta = (P / \delta t \times A_c \times H_{av}) \times 100$

(Mullick et al, 1987)

Whereb η = Thermal efficiency

P = Cooking power of solar cooker, 1470 Watts

A_c = Area of concentrator, 2.2 m^2

Δt = Time taking for water to rise to desired (final) temperature, 5 mins

H_{av} = Average solar insolation, 700 W/m^2

$\eta = (1470 / 5 \times 2.2 \times 700) \times 100 = 19.004$ %

4. PERFORMANCE EVALUATION

4.1 Performance Test

The parabolic cooker was tested to obtain its performance characteristics. Measurements were made to determine the maximum temperature of water; the time taken to attain the temperature value, and hence the cooking power of the cooker.

Temperature values were measured on hourly basis at different time of the day. The following apparatus were used to determine the efficiency of the cooker:

- mercury – in – glass thermometer
- black pot, and
- the parabolic solar cooker

The concentrator was positioned to track the incident solar radiations of the sun. The thermometer was placed inside the pot containing 1.5 kg of water. Different temperature values were measured at hourly intervals between 9am and 4pm.

4.2 Results and Analysis

Figures 4.1, 4.2, and 4.3 shows the temperature variations of the water measured at hourly intervals on Day1, Day2, and Day3, respectively.

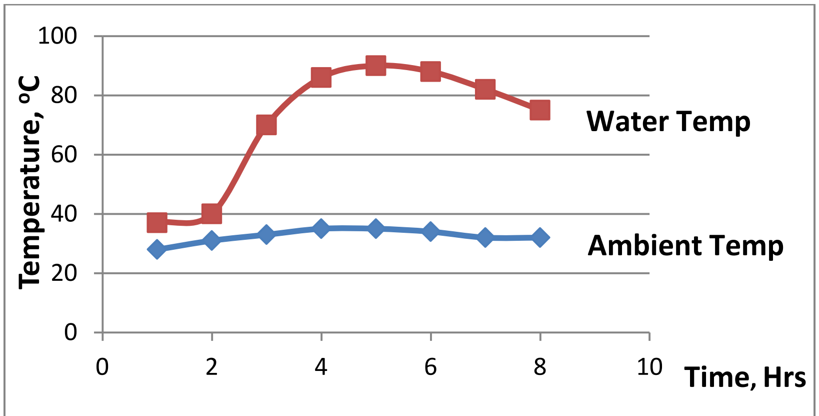

Fig. 4.1 Temperature Vs Time for Day-1

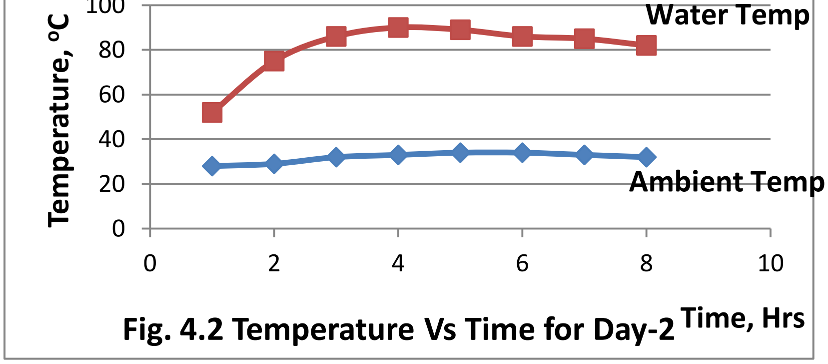

Fig. 4.2 Temperature Vs Time for Day-2

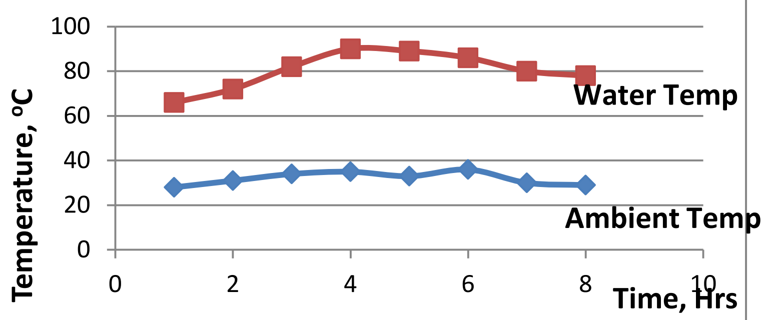

Fig.4.3 Temperature Vs Time for Day-3

4.3 Observations

From the above results, we observe that the highest temperature attained by the parabolic solar cooker was 90^{o}C within the time range between the hours of 12 noon and 2 pm.

5. CONCLUSION

The maximum temperature attained by the parabolic solar cooker was 90^{o}C between the hours of 12 noon and 2pm which basically represents the ideal time to use the cooker.

6. RECOMMENDATIONS

There may be the need to develop an automated tracking device that will automatically adjust the position of the parabolic cooker with respect to the sun radiations. It may also be possible to incorporate in the design an auxiliary device to up heat energy from the sun during sunny hours and which can be utilized in periods of low sun intensity.

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