IOSR Journal of Engineering (IOSRJEN) **www.iosrjen.org**
ISSN (e): 2250-3021, ISSN (p): 2278-8719
Vol. 05, Issue 01 (January. 2015), ||V3|| PP 56-65

A Solar Parabolic Dish Cooker for Rural African Setting

Manukaji John
Solar Energy Research Centre Federal Polytechnic, Bida Niger State Nigeria

Abstract: - Solar cooking does not involve the use of conventional fuels, which are very expensive to buy, transport, manage and causes a lot of environmental pollution. Solar cooking reduces deforestation, does not generate heat in the kitchen and does not blacken the cooking utensils used during cooking. Its use does not deplete the ozone layer and does not jeopardize future environment.It was therefore desirable to design and construct a solar cooker that uses an alternative source of energy that is renewable.The solar cooker designed and constructed comprises of two parts, the Parabolic dish Reflector and the tracking stand. On testing, it was able to boil 3kg of water contained in an aluminum pot in 20mins using an average solar intensity of 770W/m^2. The cooker was also used to cook a blend of 1.7kg of water and 0.5kg of rice with condiments for an average time of 70mins. This fit comperedfavourably with conventional cookers that use conventional fuels and can act as a supplement. Its size can also be increased as desired.

2. NOMENCLATURE

C_{pa} = Specific heat capacity of absorber
C_{pw} = Specific heat capacity of water
d = diameter of absorber
e = Specular reflectance of mirror
$F_{1\text{-}2}$ = Shape factors of absorber with respect to collector
$F_{1\text{-}3}$= Shape factors of absorber with respect to sky
$F_{2\text{-}g}$ = Shape factor of absorber with respect to ground
$F_{2\text{-}a}$ = Shape factor of absorber with respect to air
Gra = Grashof number of air
H_n = Intensity of solar radiation
h_{1a}, h_{2a} = Average heat transfer coefficient between the surface of the absorber and surrounding air
Ka = Thermal conductivity of air
Kw = Thermal conductivity of water
Pra = Prandtl number for air
α_a= Solar absorbtance of the absorber surface
α= Angle of solar altitude
σ = Stefan-Boltzman constant
ε = Average Emissivity of the absorber surface
ε_a= Average Emissivity of air
ε_g= Average Emissivity of ground
$\square_a$ = Volumetric coefficient of air
$\square_w$ = Volumetric coefficient of water
g = Acceleration due to gravity
$\square_a$ = Kinematics viscosity of air
$\square_w$ = Kinematics viscosity of water

I. INTRODUCTION

Heat in a solar thermal system is guided by five basic principles: heat gain; heat transfer; heat storage; heat transport; and heat insulation.Heat is the measure of the amount of thermal energy an object contains and is determined by the temperature, mass and specific heatof the object.**Canivan, et al 2008.**In solar cooking, the heat generated is a function of the amount of solar radiation the reflector can reflect, its ability to transmit short wave radiation and reflect long wave radiation, the amount of reflected rays the absorber can absorb and its thermal conversion abilities. A parabolic-dish-solar cooker is a device which uses the energy of direct sunlight to heat, cook and fry food. All cooking processes involve a cooking medium which is either water or oil. Heat is therefore transferred to this cooking media either by conduction or convection. When water is heated, kinetic energy is transferred by conduction to water molecules throughout the medium. These molecules spread their thermal energy by conduction and occupy more space than the cold slow moving molecules above them. The distribution of energy from the rising hot water to the sinking cold water contributes to the convection process. Heat is transferred from the absorber pot of the collector to the fluid by conduction. Effective cooking or frying can then be achieved if this constant heat supply is maintained over a period depending on the cooking duration of that type of food, its quantity, the amount of sunshine available at that time, the cooking equipment being used. Also other environmental conditions like wind speed, ambient temperature, the latitude, humidity and the time of day affect the cooking condition and duration.

Since solarcookers use no fuel and cost nothing to operate, its commercialization will be beneficial to many African families. It will help reduce their cooking expenses, air pollution, slow down the deforestation and desertification caused by gathering firewood for cooking,eliminate the danger of accidental fires and the health and environmental consequences of the use of alternativesources of fuel.

Solar cooking involve the use of concentrating reflectors that generate high temperatures and cook quickly like the Parabolic reflector, Fresnel reflectors, Scheffler reflectors. These set of reflectors however require frequent adjustment in order to make sure that all solar rays parallel to the principal axis of the reflector are brought to focus at a point or a region all day. This continuous adjustment of the reflector using a tracking mechanism is to compensate for the seasonal variation in the sun'sdeclination its altitudinal and azimuthal changes

Well designed and constructed concentrating reflectors cookers can attain temperatures above 350°C and can be used to cook and fry all kinds of foods in minutes

Other non-concentrating solar cookers like the box-type solar cooker attain temperatures up to 170°C and can cook other foods

Concentrating Solar cookers are less useful in cloudy weather and near the poles

Some concentrating solar cooker designs are affected by strong winds, which can slow the cooking process, cool the food due to convective losses, and disturb the reflector.

. The variables affecting collector efficiency fall into several groups.

1. Operating conditions (Insolation, tracking mode, operating temperature, flow rate, wind speed and other general weather conditions)
2. Properties of materials (reflectance, absorbtance, and transmittance)
3. Receiver type (absorber shape, evacuated or non-evacuated) and;
4 Concentrator geometry (concentration ratio and rim angle)

Because operating conditions may vary from installation to installation, relative comparism between existing cookers may be difficult to achieve. Comparatively, literature showed that the parabolic-shaped-collector-cooker generated the highest cooking temperature than any other cooker developed in modern times. This is because it produces a point focus while others generated a regional focus. However the production of electroplated parabolic collector requires a sophisticated and costly fabrication process that is not readily available in most developing countries like Africa. This project therefore aims at developing a collector that has similar performance characteristics like the electroplated parabolic cooker. It will be constructed using local materials and constructional techniques that are affordable by rural African dwellers.

II. GENERAL SOLAR COOKING PRINCIPLES

A solar cooker is a solar energy exchanger designed specifically to deliver heat to foods for the purpose of raising their temperature and causing the chemical changes associated with the process of cooking. In supplying the required energy, the solar cooker supplements and to a greater or less extent replaces conventional fuels.

Although there are almost countless ways of cooking foods, some of the principal methods may be usefully outlined. In boiling and frying, heat is transferred to the solid food from the heated liquid, whereas, in baking and roasting, heat is transferred both by convection from the surrounding hot air and sometimes by radiation from hot surfaces. In all of these processes, the food must first be raised to cooking temperature and then it must be maintained at this temperature for a period sufficient for effecting the softening, drying, decomposing, coagulating, separating, concentrating chemical, physical or other changes required. The quantities of heat necessary for most of these physical and chemical changes involved in cooking are small.

Most foods contain a high proportion of water and heating them to cooking temperature requires nearly 4.18J/kg ^{o}K. The higher the heat input rate to the food and container (and to any additional cooking liquid), the faster will the food be heated to cooking temperature. Where water vaporization is a necessary part of the cooking process as in bread baking, the speed of cooking is practically independent of heat rate. This is possible as long as the temperature is maintained by a heat input rate equal to the thermal losses. It is therefore generally true that differences in the time required for cooking similar quantities of food on cookers having various heat supply capacities are due mainly to the different duration of the heating-up-periods. Thus cookers of low and high heat supply rates may not show large differences in the time required for foods which must be cooked several hours.

The largest of the heat losses in cooking is usually the heat consumed in vaporizing water present in the food or added for cooking. (nearly 2.51kJ/kg). Next in importance are convection losses from utensils and oven walls. If the energy source has limited capacity, control of these losses by use of covers on utensils, insulation on cooking chambers (ovens) and other means becomes important. The great majority of family cooking throughout the world is done either in a utensil heated from below usually by direct fire or in an oven-type enclosure supplied with hot air from a self-contained or separate fuel burning chamber. Actual food temperature required for most cooking do not vary widely because the presence of water in all foods limits their own temperature to about the boiling point of water. The temperature of the heat supply, however depends greatly on the type of food and the mode of cooking. Direct fire involves temperature of a thousand degrees and a very high thermal gradient therefore prevails in the usual surface type of cooking, thus making high heat transfer rates possible. Oven cooking involves air temperature of only 200 to 250^{o}C so that heat transfer rates are lower and longer cooking periods are generally required. In nearly all types of cooking, the maximum temperature of the food does not exceed 100^{o}C. It is necessary therefore to provide a heat source at a considerably higher temperature if satisfactory cooking rates are to be obtained.

The foregoing cooking principles and practices show that a practical solar cooker must be able to deliver to the food an adequate quantity of heat within a reasonable time at temperature ranging from 25^{o}C to about 200^{o}C. To reach the middle and upper temperature ranges solar concentrating devices must be used.

As with all solar energy devices, the performance of solar cookers may be quantitatively evaluated by consideration of energy balance on the system. The energy required for a specific cooking operation is not always well defined. However, it may vary widely with the cooking methods used e.g. whether evaporative losses are controlled by a cover on a cooking vessel. This variability in cooking methods and conditions makes it desirable to base solar cooker evaluation on measurements of net rate of heat delivery to the food or its container, as well as on the time required for cooking a known quantity of food.

The principal requirements for a solar cooker to be successful in a developing country can be summarized as follows:

(a) The unit must cook foods effectively and therefore it must be technologically satisfactory. This requires it to supply sufficient energy rate, at the needed temperature, to the desired quantity of food.

(b) It must be sturdy enough to withstand rough handling and use and to resist damage by natural hazards such as wind etc.

(c) It must be sociologically acceptable and fit in with the cooking and eating habits of the people.

(d) It must be economically affordable and viable.

III. DESIGN ANALYSIS

Many potential applications of solar heat require higher temperature than those achievable by the best flat plate collectors.

A concentrating collector comprises a receiver where the radiation is absorbed and converted to some other energy forms. A concentrator is the optical system that directs beam radiation onto the receiver. Therefore it is usually necessary to continually move the concentrator so that it faces the solar beam.

The aperture of the system A_a is the projected area of the concentrator, facing the beam. The concentration ratio is the ratio of the area of aperture to the area of the receiver.

$CR = A_a/A_r$

The individual plane or curved segments are each designed to reflect radiation to the receiver. The advantage of the system is in its lack of appreciable dimension in the direction normal to the radiation which may permit easy fabrication. A disadvantage lies in the lost area between the segments near the rim of the assembly**Duffie andBechman, 1974**

CONDUCTION: For the non-uniform flux distribution of the radiation on the absorber's surface, substantial temperature gradients may exist across the absorber's surface and due to high surface temperature of the absorber, the conduction losses through the support structure may also be significant . To reduce the conduction losses the terminal edge of the wire gauze on which the pot is placed is screwed to wooden frames.

Since the bottom and the sides of the pot is the part receiving most of the concentrated radiation, it is the part that will be heated most. Therefore, there will be a temperature gradient in the liquid as it gets heated from the hot pot by conduction. Therefore the maximum temperature of the water cannot exceed that of the hot pot. (In practice, the water at the bottom and sides of the pot will be hotter than that at the top, but for simplicity of the analysis we neglected it)

CONVECTION: The focal point of the parabolic reflector,places the pot in an open sunny location where it is usually exposed to cooling breeze: This increases the convective losses through forced convection by wind. The analysis of this loss will be complex since the wind speed changes from time to time. To reduce loss of heat from the absorber by forced convection from wind which severely limit the performance, the focal point of all parabolic reflectors should be designed to be located inside the dish. This will now reduce the analysis to free convection by the air in the gap between the pot and parabolic dish.

RADIATION: Solar radiation arrives on the earth's surface at a maximum flux density of about 1 kW/m^2 in a wave length band between 0.3 and 2.5μ m. This is called short wave radiation and includes the visble spectrum**Twidell .and Weir Anthony 1986**.

Radiation losses is to the sky and or the environmental. Solar collectors absorbs radiation at wavelengths around 0.5μ m and emit radiation at wavelengths around 10μ m**TwidellJohn and Weir Anthony 1986.**

The rate of radiation heat transfer between two surfaces also depends upon their geometric configuration and relationships. The influence of geometry in radiation heat transfer can be expressed in terms of the radiation shape factor between any two surfaces 1 and 2.

IV. THERMAL ANALYSIS

For simplicity, the following assumptions are made:

(1) The absorber temperature is uniform

(2) Air surrounding the absorber and mirror elements is at ambient temperature.
For such conditions, the energy balance equation may be written as

$Q_u = Q_{ab} - Q_c - Q_R$ .... (1)

Where Q_{ab} is the total energy reflected onto the absorber surface in one second, Qc and Q_R are the convection and radiation losses per second from the absorber surface and $Q_u$is the energy utilized in one second for heating the liquid and the absorber.

The expressions for Q_{ab}, Q_c and Q_R are given by

$Q_{ab} = H_n . A_3 .e.\square_a + H_n . A_2\square\ \square_a$ ....(2)

$Q_c = (h_{1a}. A_1 + h_{2a}. A_2) (T_s - T_a)$ ....(3)

and

$Q_R = \frac{\varepsilon}{1 - \varepsilon}\{A_1 (\sigma T_s^4 - J_\square) + A_2 (\sigma T_s^4 + J_2)\}$ .... (4)

Where J_1 and J_2 are given by (**Sparrow 1973** and **Bahadori 1976**) as

$J_1 = (1 -\varepsilon) \{\varepsilon_g F_{1-2} + \varepsilon_a F_{1-3}\}\sigma\ T^4_a$ ....(5)

and $J_2 = (1 -\varepsilon)\{ \varepsilon_g F_{2-g} + \varepsilon_a F_{2-a}\} \sigma\ T^4_a$ ....(6)

The energy Q_u is utilized in heating the absorber and the liquid in the absorber. An increase in the temperature □ T of the two in time □ t is given by

$Q_u\square\ t = M_a. C_{pa}.\square\ T + M_w. C_{Pw..}\square\ T$..(7)

where the heat transfer coefficient h_{1a} and h_{2a} depend on the wind velocity V_o, and are given by **Kreith 1981and karlekar 1977** as

$h_{1a} = 0.174\frac{ka(Vod}{d\square}\ \text{Cos}\alpha)^{0.618}$ .... (8)

$h_{2a} = 0.664 \frac{Ka}{0.88d}Rea^{1/2}Pra^{1/3}$...(9)

When the wind velocity is reduced to zero by shielding the pot with a plywood frame,
the heat transfer from the absorber to the air will be by free convection and the heat

transfer coefficients in that case are given by

$h_{1a} = \frac{0.53ka}{d} (GraPra\ \text{Cos}\square)^{1/4}$ ....(10)

and $h_{2a} = \frac{0.53ka}{0.88\ d} (Gra.Pra)^{1/4}$ .... (11)

V. DESIGN SPECIFICATIONS

All foods start cooking with boiling water or oil. The preparation of different foods therefore depend strictly on the duration of boiling or frying i.e some foods cook under one hour while others cook at more than one hour duration of consistent boiling or frying.

The solar cooker being designed will be used to boil water. Detailed parameters of water and other materials used are as follows

Mass of water M_w = 3 kg
Mass of Aluminum pot Ma = 0.5kg
Assumed time of boiling t = 1800s
Temperature of boiling water T_{Fw} = 100°C or 373°K
Temperature of hot aluminum pot T_{fa} = 200°C or 473°K
Diameter of aluminum pot d = 0. 2 m
Height of aluminum pot h = 0.1 m
Solar intensity for BidaH_n = 770W/m^2
Initial temperature of aluminum pot T_{1a} = 20°C or 293°K
Initial temperature of water T_{1w} = 20°C or 293°K

Other values used in the calculation were derived from the general heat transfer and solar energy books (references 1,3, 4, 8, 9, 10)

The areas A_3 of the collectors derived was 0.696m^2. Multiplying this area with a factor of safety of2 in order to take care of other thermodynamic and heat transfer factors that were mistakenly overlooked, the
New area is now 1.392m^2

VI. DESIGN SPECIFICATION AND CONSTRUCTIONAL DETAILS

MATERIAL SELECTION

The selection of materials for engineering design and construction, varies directly, with the type of design, the aims and objectives of the design, the function of each material and varies inversely with the cost of the material, availability of the material, processing of the material and maintenance.

Some of these factors have direct bearing with the dimensions of the material, and the various ways of joining the elements of the system. Others affect the configuration of the total system and its usage.

The nature of the constructional problems, its economics, the facilities and equipment available and working methods play a key role in selection exercises.

The solar cooker being designed is composed of two major parts

(1) The Parabolic Dish reflector
(2) The tracking stand.

Table 1**MATERIALS USED FOR THE PARABOLIC DISH REFLECTOR**

S/No	DESCRIPTION	DIMENTION m	QTY
1	Plywood	1.22x2.44x0.019	1
2	Plywood	1.22x2.44x0.0125	2
3	Ceiling board sheet	1.22x2.44x.0.0055	3
4	Plain Mirror	0.42x1.22x0.003	3
5	Wood screws	0.04	1pkt
6	Nails	0.0125	0.5kg
7	Evostic		4litres
8	Oxblood paint		4litres
9	Black paint		4litres

The construction of the Parabolic Dish reflector was made up of five stages.

1. The drawing of the parabolic shape with a determined focal point was made on a big card board paper, using all the engineering principles
2. The drawn parabola was divided into two equal parts along the principal axis
3. Each half of the parabola is placed on a ½ inch plywood and the shape cut out with the aid of a band saw fig. 1
4. A circular plate of a predetermined diameter was cut out of ¾ inch plywood Figure 2
5. Ten ofthe half parabolic shapes cut out of the plywood are places at predetermined positions on the circular disc with the aid of a screw
6. Triangular shapes are cut out of a ceiling board and square mirrors are cut out of plain mirrors figure 3
7. The triangular shaped ceiling boards are placed between the parabolic shapes and lined with square plain mirrors to form the parabolic dish

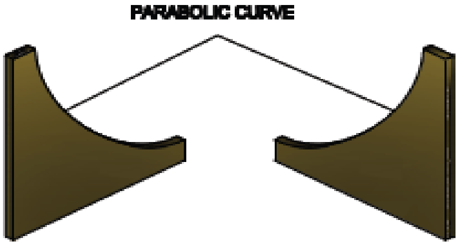


Figure 1

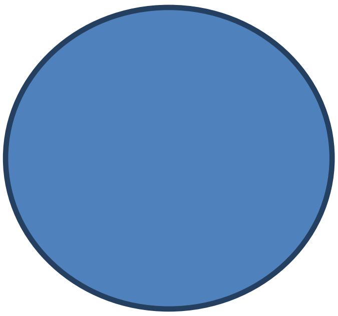


Figure 2

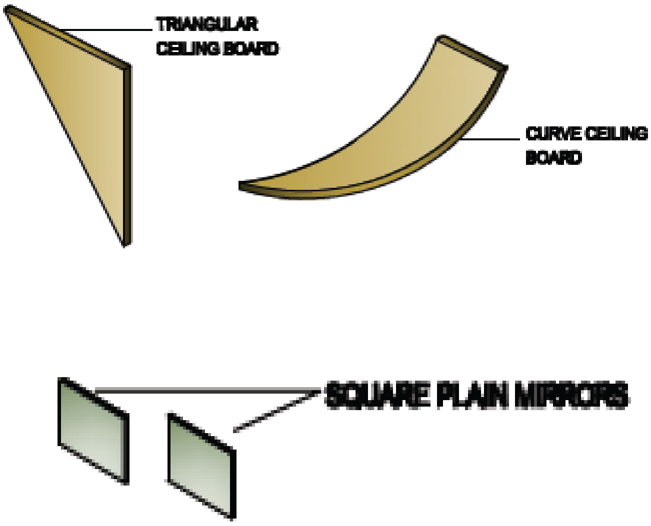


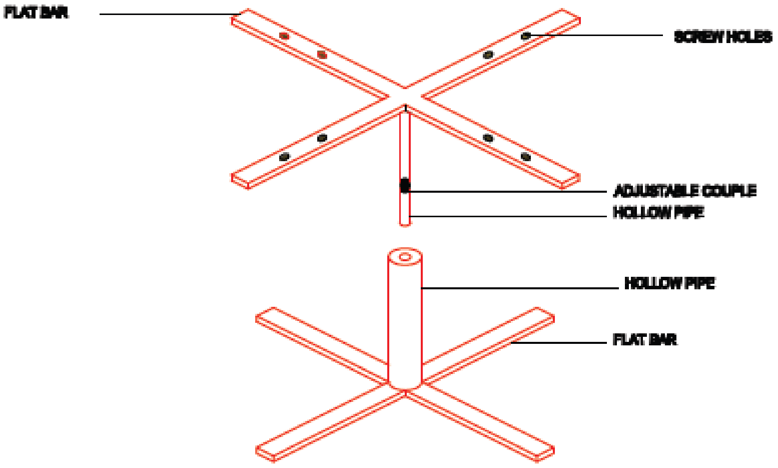
Figure 3

VII. THE TRACKING STAND

Table .2 MATERIALS USED FOR THE TRACKING STAND

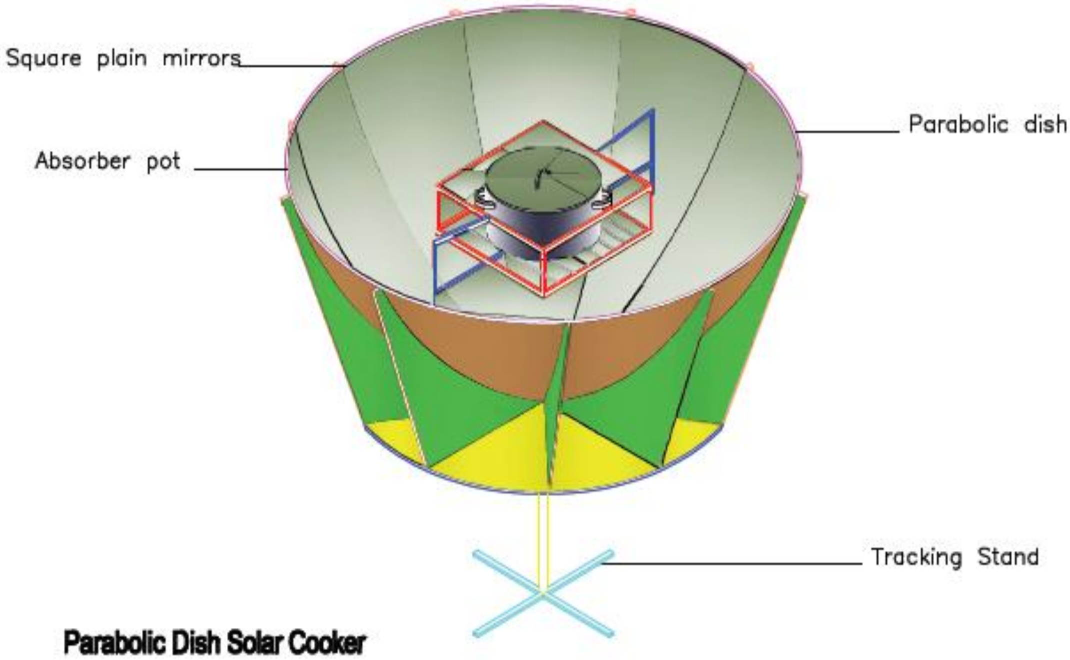
S/No	DESCRIPTION	DIMENTION M	QTY
1	Galvanized hollow pipe	0 0.05x 3.66	1
2	Galvanized hollow pipe	0 0.45 x 3.66	1
3	Bolts and nuts	0 0.01 x 0.04	8
4	Mild steel flat bar	0.005 x 0.05 x 3.66	1
5	Mild steel angle iron	0.002 x 0.025 x 3.66	1
6	Welding electrode		1pkt
7	Wire mesh	0.35 x 0.35 x 0.002	1
8	Couple		1

The pipes and flat bars were cut into appropriate dimensions and were joined together to produce the structure in fig 4



TRACKING STAND

The assembly drawing of the Parabolic collector with the tracking stand is in fig 5.



VIII. PERFORMANCE TEST

The Parabolic reflector cooker was positioned outside in the north-south direction to facilitate an east-west tracking of the sun: The reflector was adjusted by adjusting the coupling at 15 minutes time intervals for altitudinal changes in the sun's position. The azimuthal changes were compensated for by rotating the stand. The black painted aluminum pot of 0.5 kg was filled with 3 kg of water for the boiling test and placed at the focal point. Thermocouple wires were attached at the pot and inside the water. The lid of the pot was kept in place and a Comark digital thermometer was used for the readout. The temperature readings were carried out every ten minutes. The readings were plotted against time and shown in figs 6, 7, 8, 9, 10.

The cooker with the same aluminum pot was used to cook a mixture of 0.5 kg of rice, 1.7 kg of water, 4 table spoonful of oil, 2 cubes of maggi, 0.15 kg of dry fish and salt to taste. It was discovered that the cooking time averaged 70 minutes in all the five tests.

IX. DISCUSSION

A critical analysis of the results derived with the aluminum pot showed that the cooker was able to raise the temperature of the pot to an average temperature of 200^oC. It was also able to boil water within an average time of 20 minutes for tests carried out between 9.00 am and 11.00 am. For tests carried out between 12 pm and 3 pm an average water boiling time of 15-18 minutes were recorded. The difference in the boiling time could be traced to the fact that solar intensity is normally higher during the afternoons than in the mornings.

The result obtained was traced to

1. the nature of the metal alloy used in casting the pot
2. the thickness of the pot
3. the mass of the pot
4. the specific and thermal conductivity of the pot materials
5. the purity of the metal alloys used in manufacturing the pot.

X. RECOMMENDATION FOR FURTHER WORKS

The current cost of the cooker is N15750 including the cost of labour. A cheaper cooker that can achieve better results and affordable to rural villagers should be designed. Since the performance of the cooker is strictly connected to the weather condition of the day, more efficient reflectors that can produce faster cooking should be developed and used. The fragile mirrors used as reflectors should be replaced with developed flat sheets electroplated with shinning surfaces. Automatic tracking mechanism should also be developed and incorporated to make the cooking less labour intensive.

XI. CONCLUSION

From the results obtained when the aluminum pot was used, the cooker performed satisfactorily and did not deviate much from the initial assumption made during the designing stage. The cooker usesthe free renewable energy of the sun. its use zero pollution and reduce "global warming." The food it cooks tastes better and does not destroy the valuable vitamins and nutrients in the food. Solar cookers cannot burn food that is cooked in them.You never have to stir the food as you do on a conventional cookers. Unlike conventional cookers, solar cooking does not heat the kitchen. Since its performance compared favourably with the performance of conventional cookers, its use should be recommended for most African rural and city dwellers.

REFERENCES

[1] Bahadori K.N.(1976), Design of Solar Autoclave, Solar Energy Volume 18 no 6,
[2] Duffie J.A. and Bechman, W.A(1974), Solar energy thermal processes, John Wiley and Sons New York.
[3] Canivan, John, JC Solarhomes,(2008)Five Solar Thermal Principles
[4] Halacy Beth and Dan (1978): The Solar Cookery Book, Everything under the sun. n Peace Press Holman J.P,(1963). Heat transfer seventh Edition McGraw-Hill publishing company
[5] Howel, Banneret, Vliet (1985), Solar thermal Energy systems Analysis and Design. McGraw Hill
[6] Karlekar B.V. and Desmond R.M,(1977) Engineering Heat Transfer, West Publishing Company
[7] Kreider Jan F and KreithFrank(1975) Solar heating and cooling. Engineering practical design and Economics. First Edition McGraw-Hill Book Company.
[8] Kreider Jan F. and Kreith Frank: (1981) Solar Energy hand-book McGraw-Hill book company,
[9] Kreider Jan F. and Kreith Frank, (1977) Solar Heating and Cooling, Active and Passive Design. 2nd Edition. McGraw Hill.
[10] Musa U., Sambo A.S. and Bala E.J.(1991): Design construction and performance test of A parabolic concentrator cooker. Nigerian Journal of Solar Energy Volume 10.
[11] Oyetunji S.O., Sawhney R.L and Aro T.O.(1985): Design, construction and estimation of performance of a composite conical concentrator, Paper presented at conference of Solar Energy Society of Nigeria.
[12] Pita Edward G.(1981): Air Conditioning principles and systems, An Energy Approach. John Wiley &Sons ,
[13] Reddy T. Agami: (1897)The design and sizing of active solar thermal systems
[14] oxford science publication
[15] Simonson J.R. (1984): Computing methods in Solar heating Design. Macmillan Press Ltd
[16] Sparrow M.(1973), Radiant Interchange between surfaces separated by non-absorbing and non-emitting media, handbook of heat transfer, McGraw-Hill
[17] Twidell John W. and Weir Anthony D (1986), Renewable. Energy Resources. The University press Cambridge,
[18] United Nations: Proceedings of the United Nations conference on new sources of energy
[19] solar energy, wind power and geothermal energy. Rome, 21 - 31 August 1961, Volume 6
[20] VezirogluT.Nejat(1978) Solar energy and conservation. Volume 2 Pergamon press,
[21] Welford W.T. and Winston R.,(1978) The optus of non-imaging concentrators: light and solar Energy. Academic press.
[22] Williams J.Richard,(1977) Solar energy Technology and Applications. Revised Edition.Ann Arbor science publishers Inc.

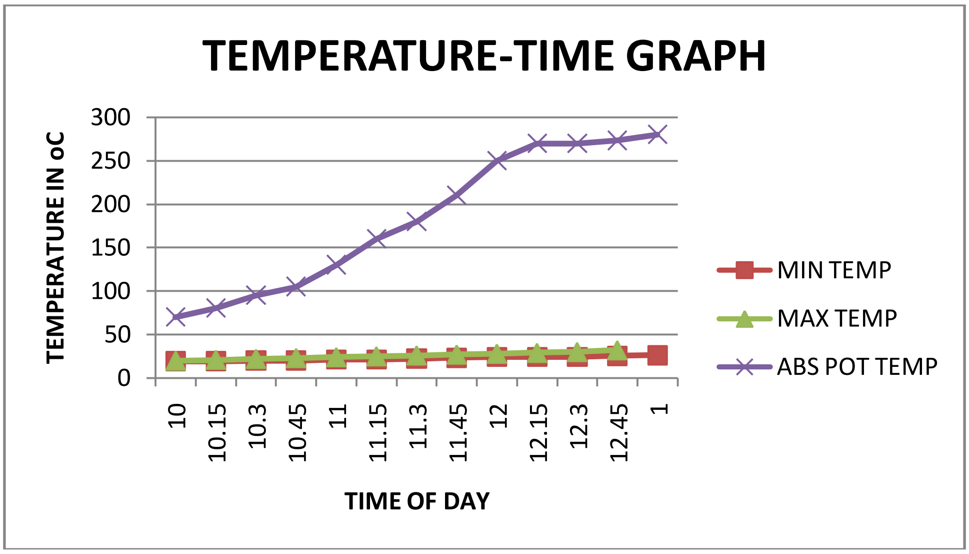


FIGURE 6

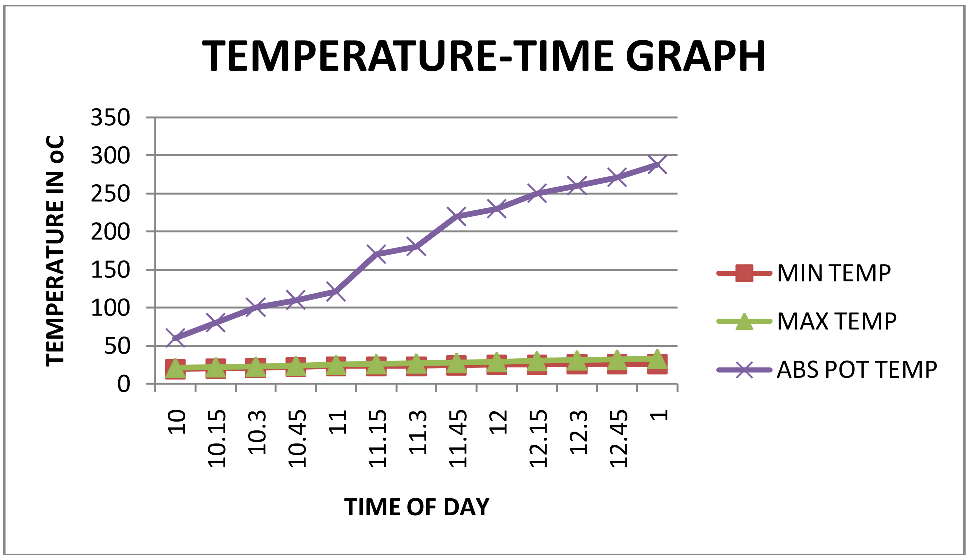


FIGURE 7

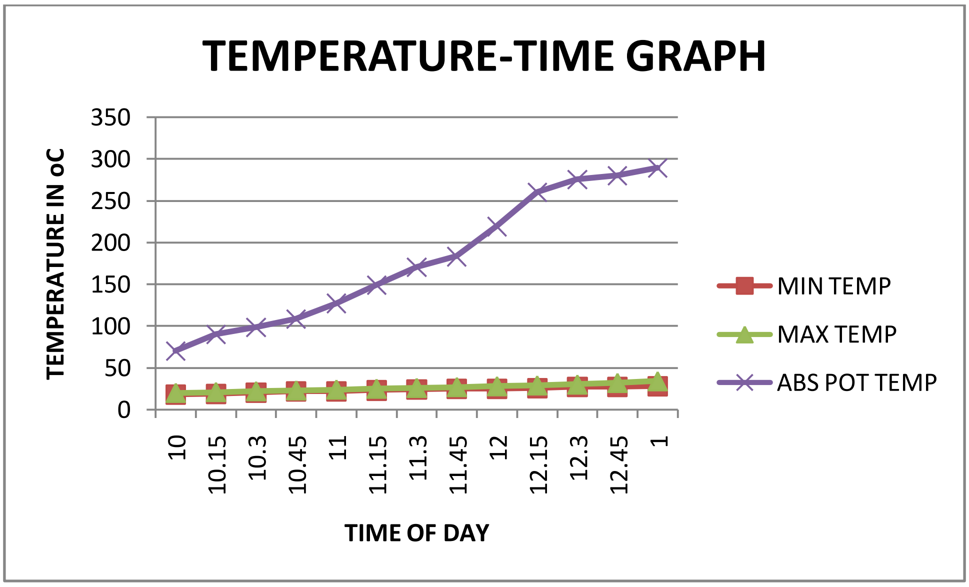


FIGURE 8

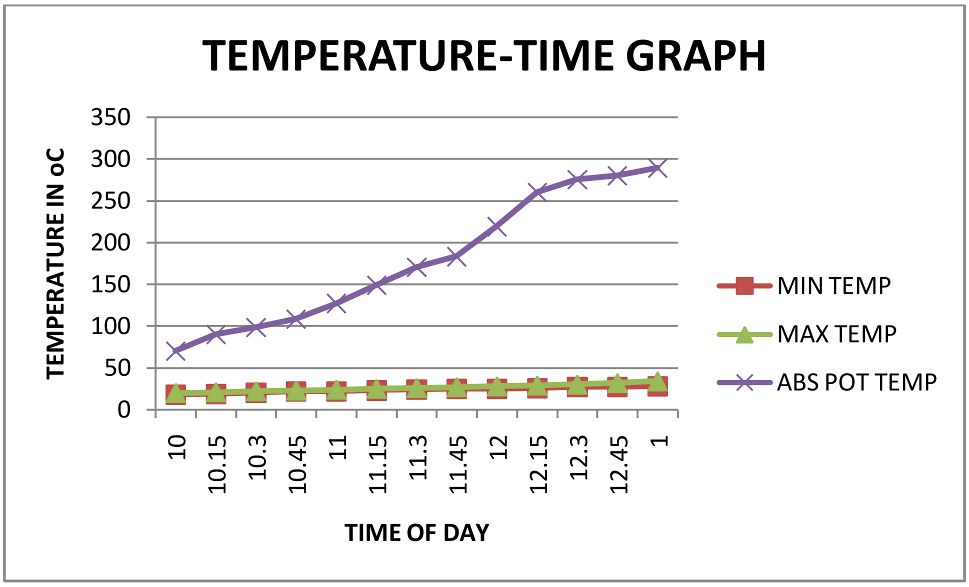


FIGURE 9

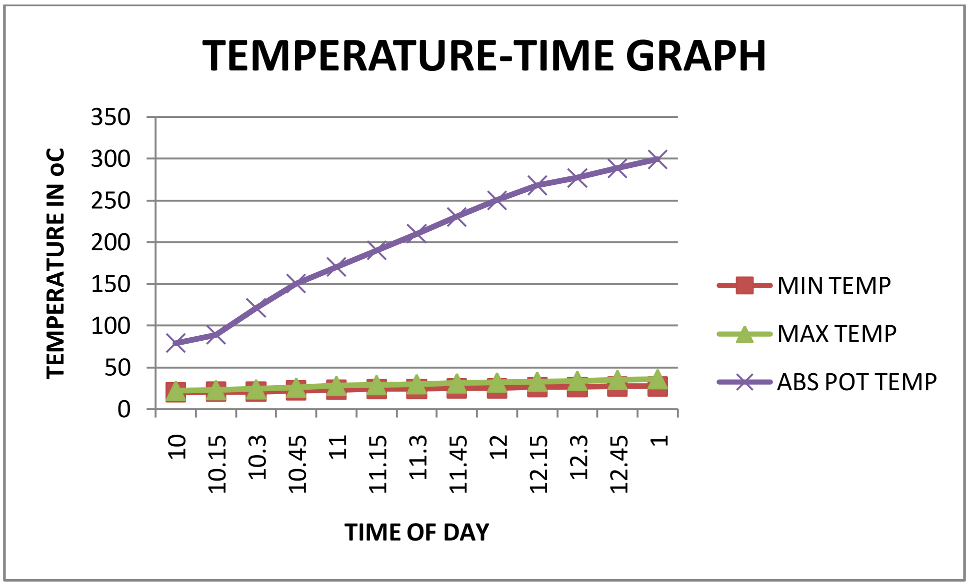


FIGURE 10