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Development of a Solar Fresnel Reflector and Its Tracking Stand Using Local Material

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

ABSTRACT
Solar collectors are the engines that drive all solar energy heating systems. Although solar heating collectors have settled upon a few basic designs, they are still manufactured in an array of configurations.Solar collectors are generally classified by the temperatures that can be produced under normal amounts of solar radiation. The collector's end-use application can be determined by their temperature classification such as Low-temperature collectors, Medium-temperature collectors and High-temperature concentrators that track the sun and produces the highest temperatures.Reflectorsthat are axially symmetrical and shaped like a parabola, has the property of bringing parallel rays of light (such as sunlight) to a point*focus and so* any object that is located at its focus receives highly concentrated sunlight, and therefore becomes very hot. This is the basis for the use of this kind of reflector for high solar energy generation. Energy supply for domestic activities had been a major problem faced by both rural and city dwellers for a long time now in Africa. It was therefore desirable to design and construct a solar Fresnel reflector and a tracking stand that can be used to generate heat from the sun for cooking, baking and distillation purposes. The reflector and the tracking stand designed and constructed was able to concentrate solar energy within a regional diameter of 10cm and could be used to raise the temperature of any object placed at its focal region. It was discovered that the heat generated is directly proportional to both the perfection of the collector design, its construction, the quality of the reflectors e.g plain mirror, the area exposed to the sun and the solar intensity of the day.

I. INTRODUCTION

Solar collectors are either non-concentrating or concentrating. In the non-concentrating type, the collector area (i.e., the area that intercepts the solar radiation) is the same as the absorber area (i.e., the area absorbing the radiation). In these types the whole solar panel absorbs light. Concentrating collectors have a bigger interceptor than absorber.**Norton, Brian 2013**

The classification of the collectors by their effective end-use temperatures is a helpful method of differentiation.

Flat plate solar collectors are the most common for heating water and air in the home. The flat plate solar collector is an insulated box with a plastic or glass "lid" on top.

Solar collectors transform solar radiation into heat and then transfer that heat to a medium (water, solar fluid, or air). The term is applied to solar hot water panels, but may also be used to denote more complex installations such as solar parabolic, solar trough and solar towers.

Concentrating solar collectors use mirrored surfaces to concentrate the sun's energy on an absorber called a receiver. Concentrating collectors also achieve high temperatures, but unlike evacuated-tube collectors, they can do so only when direct sunlight is available.

Concentrating reflectors generate high temperatures and cook quickly, but require frequent adjustment. Reflectors that bring rays parallel to its principal axis to point focus can be easily turned to follow both the sun's daily motion and its seasonal one. The cooking pot stays stationary at the focus. If the paraboloidal reflector is axially symmetrical and is made of material of uniform thickness, its centre of mass coincides with its focus if the depth of the reflector, measured along its axis of symmetry from the vertex to the plane of the rim, is 1.8478 times its focal length. The radius of the rim of the reflector is 2.7187 times the focal length. The angular radius of the rim, as seen from the focal point, is 72.68 degrees.

If the reflector is aligned with its focal line horizontal and east-west and is pointed so that its axis of symmetry aims at the sun at noon, it will be tilted up and down as the seasons progress. At the equinoxes, no movement of the reflector is needed during the day to track the sun.

Spherical reflectors operate much like paraboloidal reflectors, such that the axis of symmetry is pointed towards the sun so that light is concentrated to a focus. However, the focus of a spherical reflector will not be a point focus because it suffers from a phenomenon known as spherical aberration.

During the day the sun has different positions. For low concentration systems tracking can be avoided, butfor higher concentrations, however, if the mirrors or lenses do not move, then the focus of the mirrors or lenses changes and so tracking must be carried out from time to time. The tracking system increases the cost and complexity of a collector. With this in mind, different designs can be distinguished in how they concentrate the light and track the position of the sun.

Solar reflectors and collectors use a renewable and non- polluting type of energy source. They reflect and collect an energy that is so decentralized that every home can utilize it as desired. The techniques of construction are simple. It involves only the initial capital cost and does not attract any recurrent cost. Under initial review, it was discovered that on an average sunny day including the periods of cloud cover, the reflectors and collectors, collect enough energy from the sun that are equivalent to the energy supplied by conventional energy sources. Finally, its use will eventually reduce the family energy costs by reducing the amount spent on purchase of conventional fuels. Many solar reflectors have already been developed world wide.

The performance of both types hadbeen reported in the literature, but the results of these designs were not based on comparative analysis. The performance of any solar reflector improves if the collector efficiency is increased. Therefore the efficiency of the collector should be maximized if such a step does not significantly increase the reflector and collector cost. The variables affecting reflector and 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 reflectors may be difficult to achieve. Comparatively, literature showed that the parabolic-shaped-collectorgenerated the highest temperature than any other reflector developed in modern times. This is because it produces a point focus while others generated a regional focus. However the production of electroplated parabolic and Fresnel collectors requires a sophisticated and costly fabrication process that is not readily available in most developing countries. This project therefore also aims at developing a collector that has similar performance characteristics like the conventional concentrating reflectors. It will be constructed using local materials and constructional techniques that are affordable by rural African dwellers.

II. 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 smooth optical surface of a reflector or lens can be broken into segments, a trick invented by Fresnel. Optically a Fresnel mirror can approximate a focusing parabola. The effective aperture is obtained by multiplying the total area of the Fresnel mirror by a ground cover factor. Values of the factor between 0.3 and 0.6 are practical for Fresnel reflectors**Duffie and Bechman, 1974**.

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 and Bechman, 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.

CONVECTION: Since the focal point of Fresnel reflectors are located outside the reflectors, placing the absorber in an open sunny location usually exposes it 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 limits the performance, the absorbermay be sheltered on all sides except the top and bottom with a wooden box. This will now reduce the analysis to free convection by the air in the gap between the absorber and casing.

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 2.5 μm. This is called short wave radiation and includes the visible spectrum. **Holman 1963.**

Radiation losses are to the sky and or the environmental. Solar collectors absorb radiation at wavelengths around 0.5μm and emit radiation at wavelengths around 10μm**Holman1963**.

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.

III. 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 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 Fresnel reflector being designed is composed of two major parts
(1) The Fresnel reflector
(2) The tracking stand.

Table1: Materials Used For The Fresnel Reflector

S/No	DESCRIPTION	DIMENTION m	QTY
1	Plywood	1.22x2.44x0.019	2
2	Plywood	1.22x2.44x0.0125	1
3	Galvanized iron sheet	1.22x2.44x.0.00055	2
4	Plain Mirror	0.42x1.22x0.003	4
5	Wood screws	0.04	1pkt
6	Nails	0.0125	0.5kg
7	Evostic		4litres
8	Oxblood paint		4litres

The construction of the Fresnel reflector was made up of five stages.

STAGE 1 PRODUCTION OF THE TEMPLATE

In constructing the Fresnel reflector, a template was produced. The procedure used
in producing the Fresnel template was as follows.

1. A reference base line was drawn on a cardboard paper.
2. A principal axis perpendicular to the base line was drawn
3. A convenient focal distance was chosen along the principal axis (45cm was chosen in this Design)
4. A convenient focal width parallel to the base line at the point of focus was marked A and B.

(10cm was chosen in this design)

5. It was assumed that the first direct ray from the sun passed through the point B, parallel to the principal axis and met the base line at C. That incident ray was marked i_1
6. At point C, a reflected ray r_1 was drawn to pass through the focal width at point A.
7. The angle BCA was bisected and the normal to the incident and reflected rays was drawn to pass it. The normal was n_1.
8. At point C, a line p1 perpendicular to the normal was drawn.
9. A line parallel to r_1 was drawn to pass through point B and meet the perpendicular line from C. This line torched the base line at D.
10. Another assumed incident ray i_2 parallel to the first incident ray i_1 was drawn to meet the base line at D.
11. At D a reflected ray r_2 was drawn to pass through point A on the focal width. The ray r_2 met the perpendicular line from C at E. The point CE was then the length of the mirror segment as well as the slanting height of the Frustum that was to be developed.
12. The angle between i_2 and r_2 was bisected and normal n_2 was drawn to pass through it.
13. A line perpendicular to n_2 was drawn to produce the second segment of the template.
14. Processes 9 to 11 were repeated each time until a template equal in length to the radius of the

circle derived from the collector area calculated was achieved. In this case, the length was 47 cm. The ray diagram described in 1 to 14 above is shown in figure 1 and the template in figure 2.

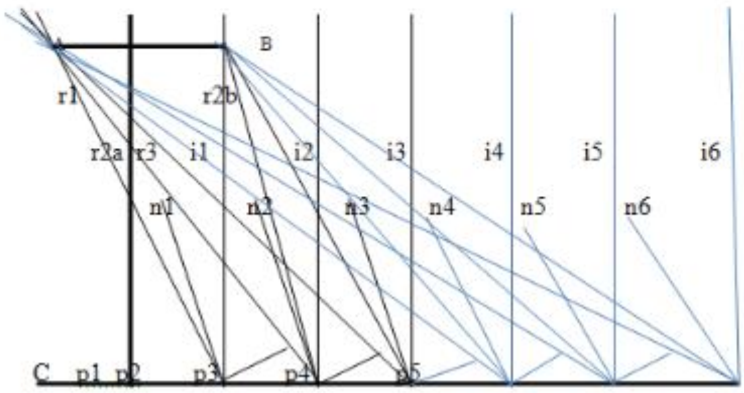


Figure 1 Ray diagram used for the development of template

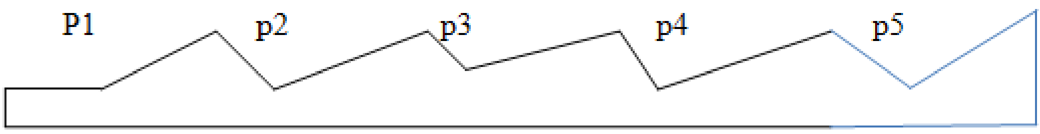


Figure 2 the developed template.

The diagram in fig 2 was cut out from the cardboard and transferred to the 21 mm thick plywood. Twenty four of these shapes were produced.

STAGE TWO: DEVELOPMENT AND PRODUCTION OF THE FRUSTUM RINGS.

1. The vertical and horizontal components of each template segment with reference to the base line and the principal axis were determined. These points were indicated as shown in fig 3.

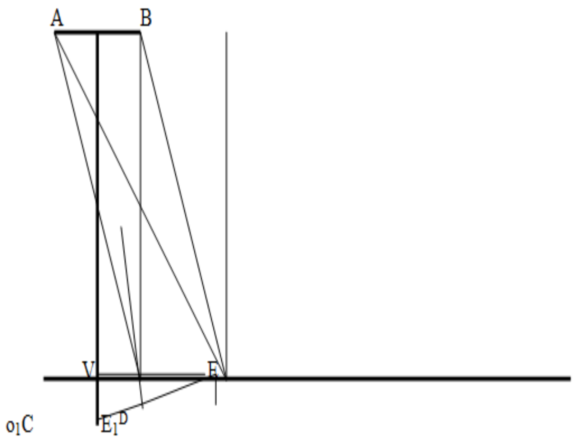


Fig 3 Ray diagram for the development of the Frustum ring.

VE was d_2
Oc was a_1
O_1V was A_1
O_1C was b_1
O_1E was B_1
CE was d_1
The completed image of fig 3 is shown in fig 4

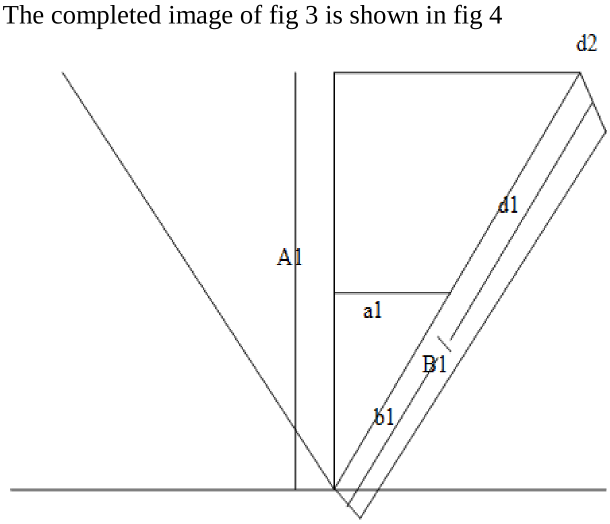


Fig 4. Complete image of Fig 3

Note that
d_2 = radius of the big cone
a_1 = radius of the small cone
B_1 = Slant height of the big cone
b_1 = slant height of the small cone
d_1 = slant height of the Frustum

The Frustum ring was developed by performing the following operation.

(1) Half of the drawing in fig 4 was produced
(2) With d_2 as radius and V as centre, an arc was constructed from point E to meet the extended line O_1V at F.

(3) With F as centre and same radius, the previous arc was cut at G.
(4) With E as centre and same radius the previous arc was cut at H.
(5) With centre O_1, and radius B_1 an arc was produced starting from E to point J
(6) With O_1, as centre and b_1 as radius another arc was produced starting from C to point k
(7) With FG as length 13 points were marked off on the EJ arc.
(8) The points O_1L and O_1J were joined.

The above construction was drawn to scale and when it was exploded gave the first Frustum ring of the first segment of the template. The diagrams produced are in fig 4 and fig5. The other Frustum rings for the other segments of the template were produced following the same steps.

Fig 5 Frustum ring

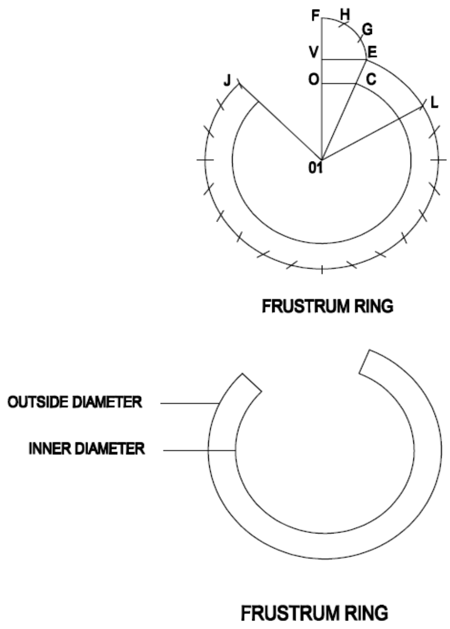


Figure 5

The full scale dimension of the Frustum ring was now cut out from the 0.55 mm thick

galvanized iron sheet.

STAGE THREE: PRODUCTION OF THE TRAPEZOIDAL SHAPED MIRROR TABLETS.

The circumference of the outer edges of the first Frustum is $C_1 = 2\pi d_2$
The circumference of the inner edges of the first Frustum is $C_2 = 2\pi a_1$

C_1 was divided into twenty four equal parts and C_2 was divided into twenty four equal parts and the two divisions formed the two parallel sides of the trapezoidal mirror tablets. The height of the mirror tablet was B_1 - b_1 each. The other Frustums were also developed. The first two Frustums were divided into 24 each to form the dimension of the mirror tables while the other three Frustums were divided into 48 each to form the dimensions of the mirror tablets.

The mirror tablets are shown below in fig 6

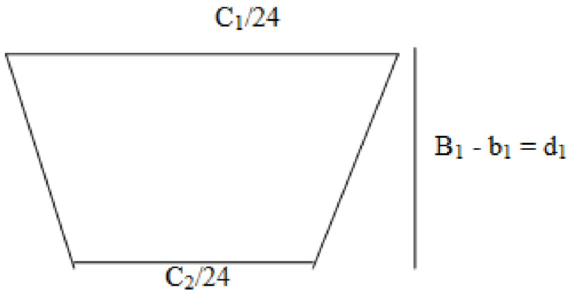


Fig 6 mirror tablets

STAGE FOUR: PRODUCTION OF THE BASE PLATE

A circular disc with a diameter equal to the diameter of the circular area calculated was cut out from the 21 mm thick plywood.

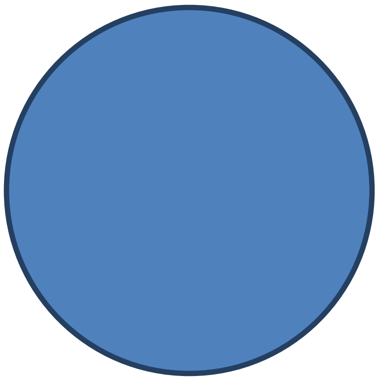
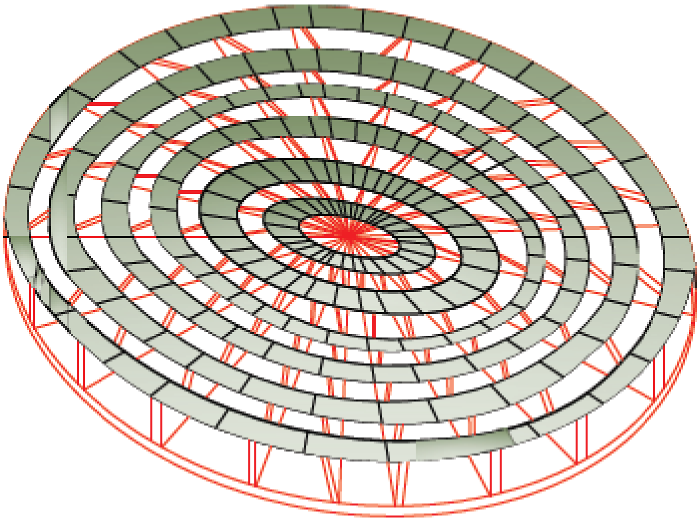


Figure 7

STAGE FIVE: ASSEMBLING

The twenty four templates were fixed round the surface of the circular disc with the aid of the 40 mm wood screws. Each Frustum ring was nailed into position at the right template segment with the aid of the 15 mm nails. The mirror tablets were glued onto the surface of the Frustum rings with the aid of evostic as shown below



FRESNEL REFLECTOR

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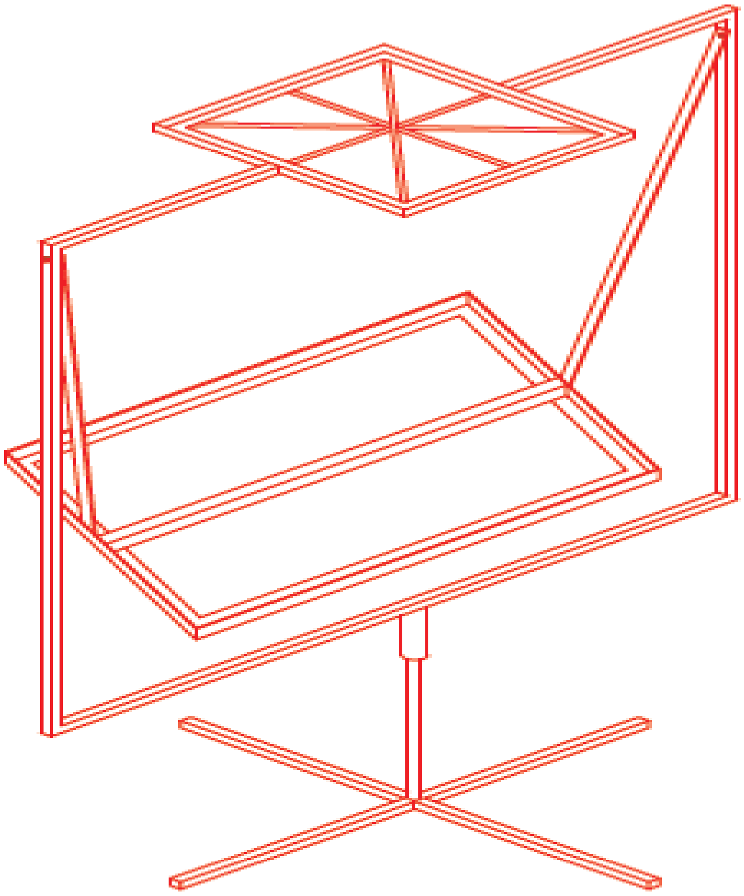
Figure 8

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

The pipes and flat bars were cut into appropriate dimensions and were joined together to produce the structure in fig 9.



TRACKING STAND

Figure 9

The assembly drawing of the FRESNEL collector with the tracking stand is in fig10.

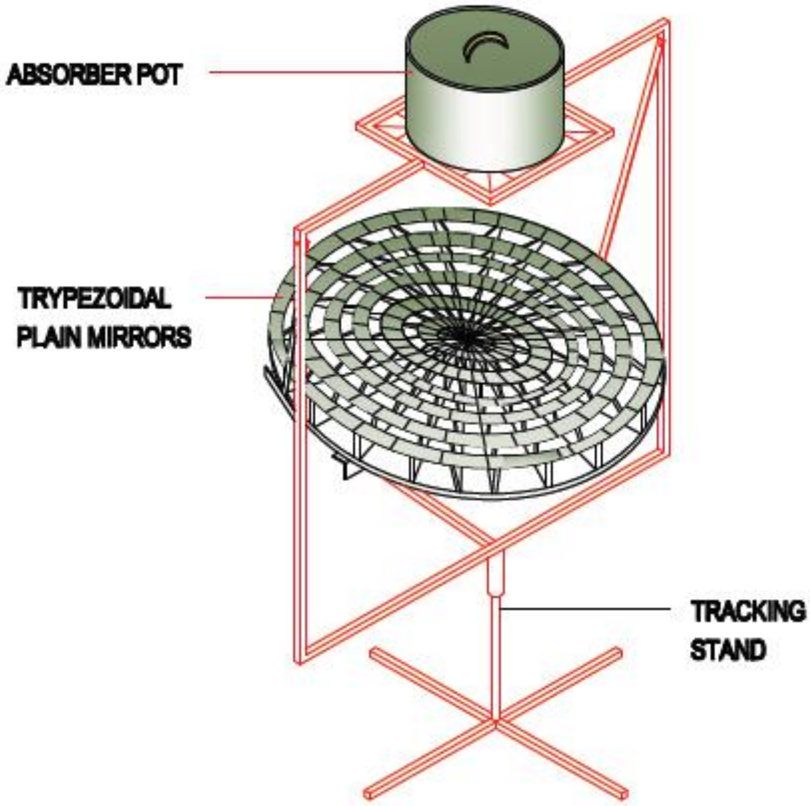


Figure 10

IV. PERFORMANCE TEST

The Fresnel reflector mounted on its tracking stand was positioned outside in the north-south direction to facilitate an east-west tracking of the sun: The reflector was adjusted by changing the position of the chain at 15 minutes time intervals for altitudinal changes in the sun's position. The azimuthal changes were compensated for by rotating the stand. A black painted aluminumdisc15cm in diameter and 1cm thickness was placed at the focal point. Thermocouple wires were attached to the Aluminum disc.AComark digital thermometer was used for the readout. The reflector was able to raise the temperature of the aluminum disc to an average of 300^{o}C

V. DISCUSSION

A critical analysis of the results derived with the aluminum disc showed that the reflector was able to raise the temperature of the disc to an average temperature of 300^{o}C. It was also able to boil 3kg of water within an average time of 30 minutes for tests carried out between 10.00 am and 1.00 pm. For tests carried out between 12 pm and 3 pm an average water boiling time of 24-28 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. This therefore shows that the temperature generated with the Fresnel reflector is directly related to the weather condition of the time and day of testing.

VI. RECOMMENDATION FOR FURTHER WORKS

Since the performance of the reflector is strictly connected to the weather more efficient reflectors that can produce higher temperature 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 tracking less labour intensive.

VII. CONCLUSION

From the results obtained when the reflector was used, it performed satisfactorily and did not deviate much from the initial assumption made during the designing stage. The reflector uses an energy that has been generally accepted as the most promising, renewable and non-polluting type of energy. The reflector can also be produced using local materials and does not involve complex constructional techniques. The energy it uses is so decentralized that any user can use it without having to transport it to the sight of use. The energy it uses is also free. Since its performance isfavourable, it should be used for cooking in Africa.

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.] Halacy, D. S.; Halacy, Beth (1992). *Cooking with the sun*. La Fayette, CA: Morning Sun Press.

[4.] Halacy Beth and Dan (1978): The Solar Cookery Book, Everything under the sun. Peace Press

[5.] Holman J.P,(1963). Heat transfer seventh Edition McGraw-Hill publishing company

[6.] Howel, Banneret, Vliet (1985), Solar thermal Energy systems Analysis and Design. McGraw Hill

[7.] Karlekar B.V. and Desmond R.M,(1977) Engineering Heat Transfer, West Publishing Company

[8.] Kreider Jan F and Kreith Frank(1975) Solar heating and cooling. Engineering practical design and Economics. First Edition McGraw-Hill Book Company.

[9.] Kreider Jan F. and Kreith Frank: (1981) Solar Energy hand-book McGraw-Hill book company,

[10.] Kreider Jan F. and Kreith Frank, (1977) Solar Heating and Cooling, Active and Passive Design.2nd Edition.McGraw Hill.

[11.] 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.

[12.] Norton, Brian (2013). *Harnessing Solar Heat*. Springer.

[13.] 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.

[14.] Pita Edward G.(1981): Air Conditioning principles and systems, An Energy Approach. John Wiley & Sons,

[15.] Reddy T. Agami: (1897)The design and sizing of active solar thermal systems oxford science publication

[16.] Simonson J.R. (1984): Computing methods in Solar heating Design. Macmillan Press Ltd

[17.] Sparrow M.(1973), Radiant Interchange between surfaces separated by non-absorbing and non-emitting media, handbook of heat transfer, McGraw-Hill

[18.] Twidell John W. and Weir Anthony D (1986)., Renewable. EnergyResources. The University press Cambridge

[19.] United Nations: Proceedings of the United Nations conference on new sources of energy solar energy, wind power and geothermal energy. Rome, 21 - 31 August 1961, Volume 6

[20.] VeziroglluT.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.