DESIGN, CONSTRUCTION OF A SOLAR CONICAL CONCENTRATING COLLECTOR AND ESTIMATION OE ITS PERFORMANCE

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Abstract

The aim of this study is to design, develop and construct a reliable solar conical collector that would be capable of operating at reasonable efficiencies for heating purposes. The cylindrical reflector component of the collector was developed using galvanized iron sheet, coated with aluminum foil, while the absorber is cylinder made of copper sheet and coated with black paint to increase the absorptive. The whole system can be adjusted in two axial directions. The estimation of the efficiency of the solar concentrator indicates the degree of sensitivity of performance to variations in tube radius, ambient temperature, absorptive of the tube coating, and cone half-angle within receiver size and mounting limitations.

Introduction

Many commercial, agricultural and industrial processes required mid temperatures 80 C to 150°C heat energy which at present is being obtained by the use of wood, coal or electricity. Nigeria receives about 5.01 x 10^{12} KWH of energy per day from the sun with more than 2,000 hours-of sunshine per year. The use of solar appliances with 10% efficiency to cover 1% of the country's surface area could generate energy output equivalent to about 10 million barrels of oil per day. This is about 8 times the present level of oil production in Nigeria (Energy Commission of Nigeria, 1995). Thus, solar energy can easily be substituted to supply the required heat energy using concentrating collectors.

This paper presents the design, development/fabrication and estimation of the efficiency of a cylindrical solar collector for steam generation.

The Collector

To reflect the solar radiation on to the absorbing cylinder, fixed along the axis of the cone, the angle of the cone is made to be 45°. The collecting area, the upper circle of the cone is 1.0m'in diameter. The diameter of the lower part of the truncated cone is 20.4cm. The inner surface of the truncated cone is then lined up with mirror strips of proper shape and size. The larger the number of strips the higher will be the concentration ratio of the collector. In this study also, the upper width of the strip and lower width are 64.5cm and 1cm respectively. These parameters formed the basis for calculating other parameters of the concentrator

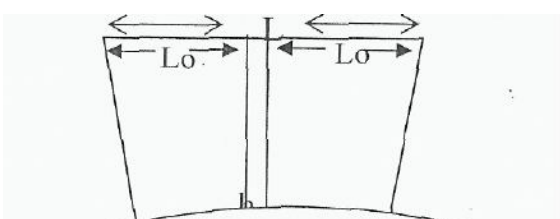


Fig 1.0
The shape of each mirror of the 64 pieces. L is the upper width, L* is the lower width and h is the length of the mirror

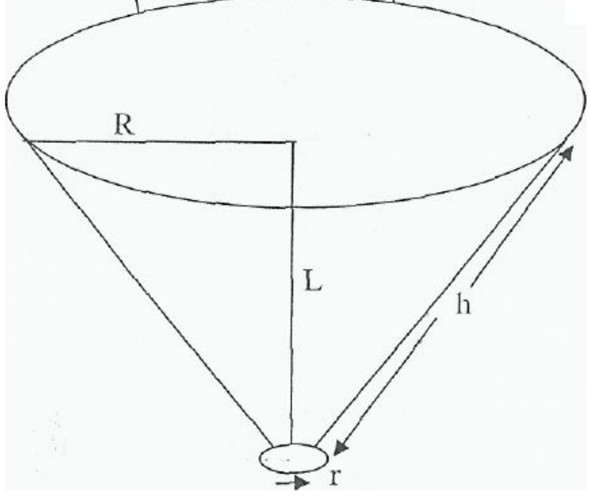


Fig 2.0:
Shape formed by the arrangement of the mirror.

R radius (upper)
r = radius (lower)
L height (vertical)
li slant height
as shown in fig 1.0

Calculation of other **parameters**

Because of the finite width of the mirror strips, the upper and lower parts of the cone will be in form of polygon of 64 sides (fig 2.0).

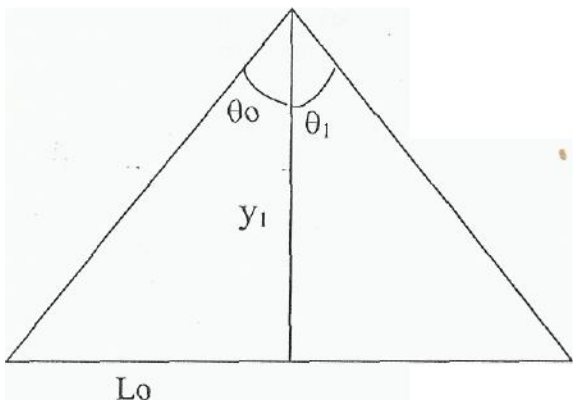
The angle 0 made by each by of (he polygon on it's centre is given by:-

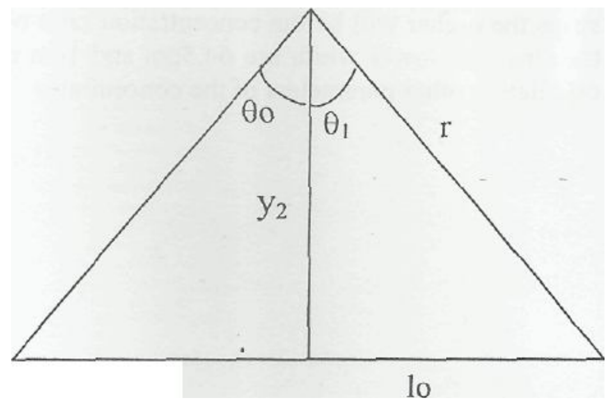
0 $\underline{360°}$ - 5.625°
64

For the upper polygon, length of each strip is 5cm, hence radius R of the upper polygon will be given by Fig. 3.0(a)

The Radius R = 5/2 sin
5.625"
-50.95cm
2

With each length of the polygon sides L = 5cm one can now calculate the total length as they are 64 in number.





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(a) Fig 3.0(a) shows one section of the upper polygon

(b) Fig 3.0(b) shows one section of the lower polygon

Total length = 64 x 5cm = 320cm

To calculate the total upper area of the polygon that forms the frustrum, one starts by calculating for one of the polygon and then multiply by 64.

From Fig 3.0 (a); y, = height of triangle

$y,^2 = R^2$-U =
50.95^2-2.52

y, 50.89cm

Let the area for triangle be a, then

ai = !/2 base c height

}/2 x 5 x 50.89 127.225cm^2 Total upper

Area A_t = 64 x a,

64 x 127.225cm^2 8142.4cm^2

for the lower polygon fig 3.0(b)

Here again e_0 = 2.815° L* = lo + lo =

2 Io= I cm lo — 0.5cm so calculating

the lower r using

Sin 0 - lo___
r

r=Io(sin 2.8125°)"' - 10.19cm

Total length of lower polygon = 64 x 1cm = 64cm

From 3.0(b)

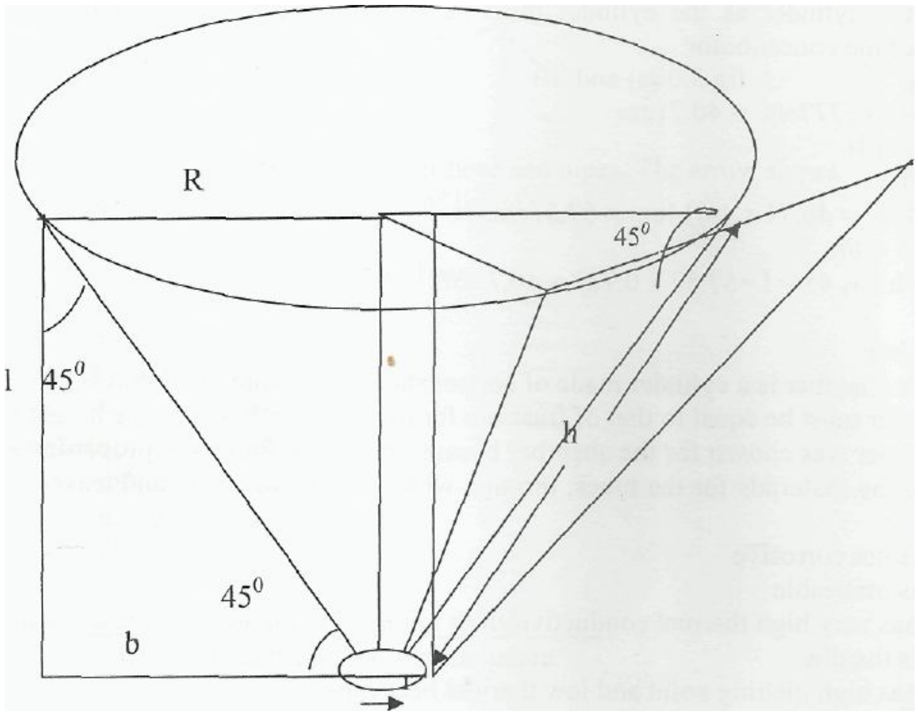
$y^2_2 = r^2 - lo^2$ - 10.19^2-0.52 y_2 = 10.1777cm Area of each triangle is the lower polygon a_2, is given by

a_2 - '/$_2$ base x height = >/$_2$ x 1 x 10.1777 = 5.089cm^2 .".

Total lower area of polygon A_2 is given by

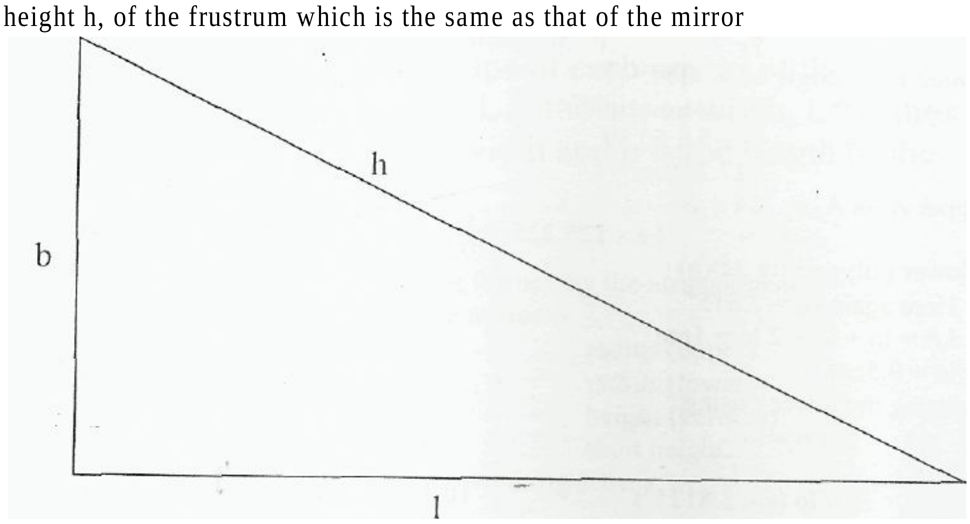
A_2 64 X a_2 = 64 x 5.089 - 325.695cm

One can now calculate for h the height of the mirrors which is the slant height for the cone formec (See fig 3.0 (c)).



(c)

Fig 3.0 (c) shows the vertical height 1 of the frustrum which is the same as that of the the slant height h, of the frustrum which is the same as that of the mirror



With the arrangement of the mirror forming a frustrum, the angle of slope was found to be 45° which is the angle of incidence i.e angle at which the radiation from the sun meets the mirror.

From Fig 3.0 (c) and (d), the slant height of the frustrum as well as the vertical height of the frustrum can be calculated.

Note that the slant height is equal to the height of the mirror and the vertical height is equal to (he height of the cylinder as the cylinder must be of the same height with the cone for maximum efficiency of the concentrator.

$b = y, - y_2$ fig 3.0 (a) and (b)

b = 50.89 -10.1777cm =40.71cm

From fig 3,0 (d)

Sin45 = b/h

h = b (sin 45)-' = 40.71 x 1.414cm = 57.57cm.

Then cos 45 = 1/h

1 = h cos 45 = 1 =57.57 x 0.707 - 40.71cm.

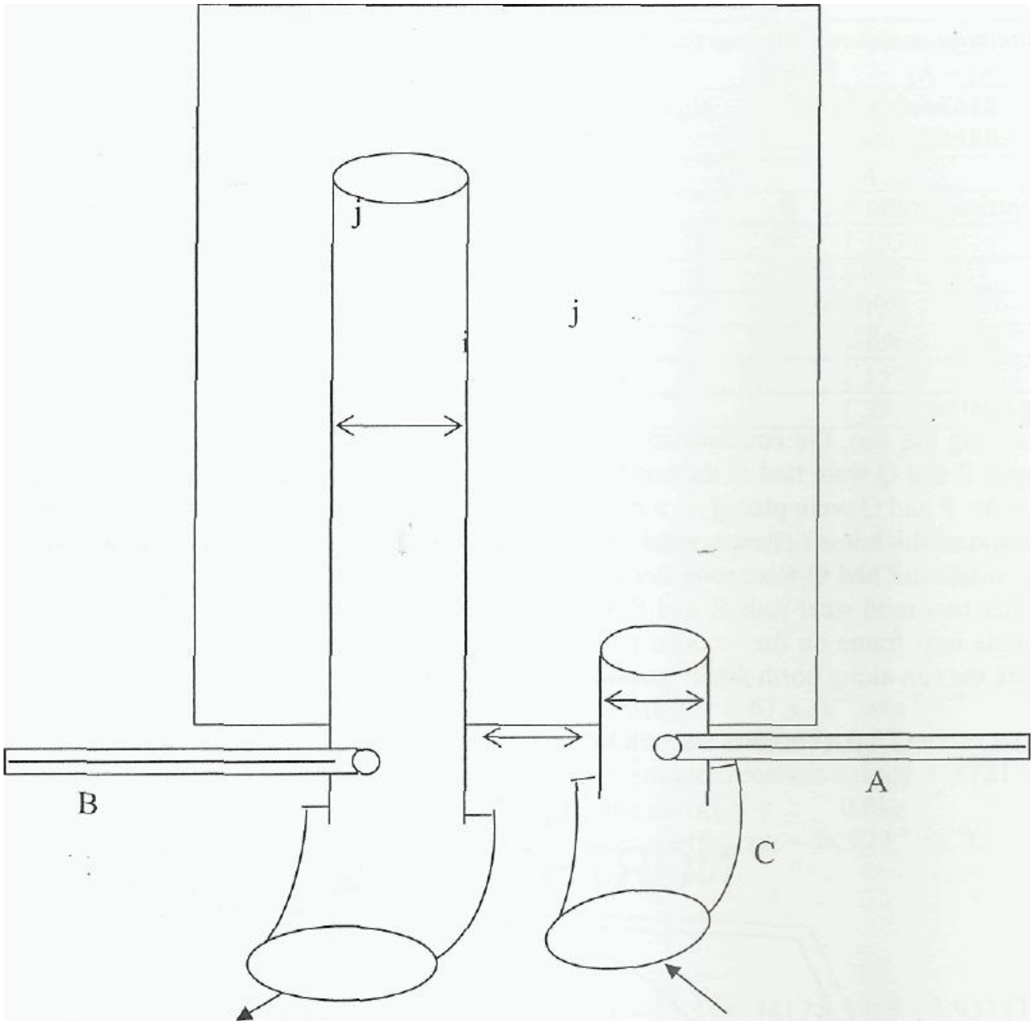
The Absorber

The absorber is a cylinder made of copper sheet and painted with black paint. Since the height of the cylinder must be equal to that of frustrum for maximum efficiency, the height is 40.7cm.

Copper was chosen for the absorber because it has the following properties which also helped in selecting the materials for the tubes, through which the liquid enters and leaves the cylinder. They are:

(i) It is not corrosive
(ii) It is malleable
(iii) It has very high thermal conductivity.
(iv) It is ductile
(v) It has high melting point and low thermal heat caps

Fig 4.0 shows the absorber (cylinder) with the rubber hose and pipes. The arrow shows the direction of



flow of liquid. The stoppers (C) control the flow of liquid.

For the absorber, vertical height of collector = 40.71cm
Radius of cylinder = 3cm
Curved surface area of cylinder Si = 2 Tcrl

51 = 2:tx 3x40.71

- $767.37cm^2$

Area of the upper surface of the cylinder

5_2 nr^2

n $x3^2$ $28.274cm^2$

Concentration ratio = <u>solar radiation intensity at hot spot</u>
Unconcentrated direct solar radiation

Curved area of cylinder Si = 767.37cm' Top area of cylinder 82 = $28.274cm^2$ Total area of collector
Bj = S[+ S_2

= $795.685cm^2$

Area at which energy is received B^ is given by

B_2 A , - A_2

8142.4-325.696

$7816.704cm^2$

Concentration ratio = <u>B_2</u>

B, , .
7816.704
795.658
9.82

The Tracking System

For tracking the sun, the concentrator must be able to rotate about two axes independently. For this, two rods P and Q were tied to the cone of the concentrator along an axis passing through the gravity of the cone. P and Q were placed on a rectangular frame which was free to rotate about an axis RS. The angle iron of thickness 6cm was used for the rectangular frame of length 1.30m, and breadth 1.1 metre. The two rods P and Q were mild steel of lengtrT30cm each and diameter 1.5cm.

The other two mild steel rods R and S were of length 30cm and diameter 2.5cm. These two rods rest the angle iron frame on the wooden plank U and V of length 1.50m each. This enabled the collector to track the sun along north-south motion throughout the year.

DIAGRAM SHOWING TRACKING SYSTEM

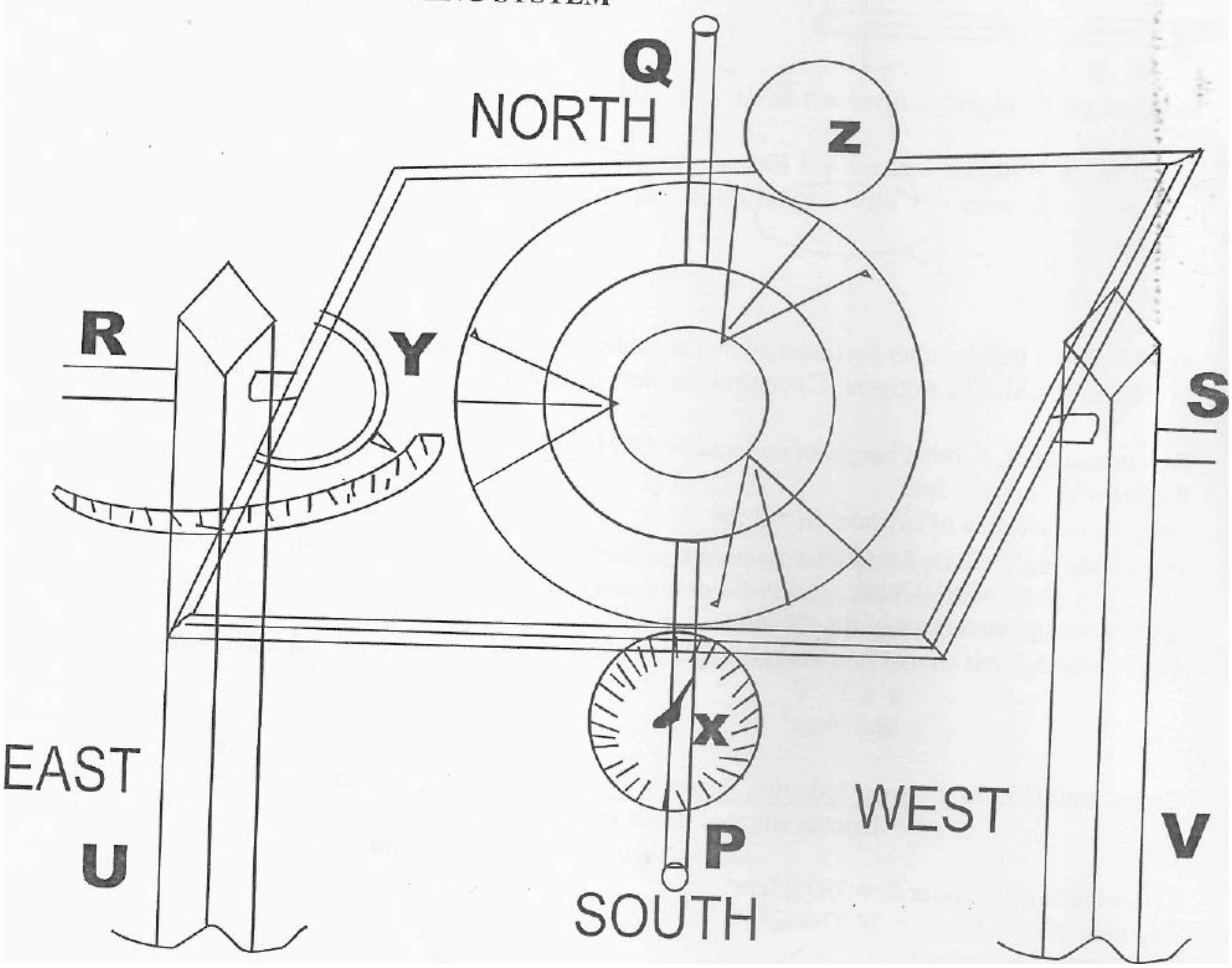


table 1:

Estimation of Maximum Temperature using the Hourly Temperature Variation and the Zenith Angle for 29th **of July** 2006 **in Ilorin**

Time T<Hr)	Hourly temp. T_0°C	Zenith angle 02	Values of estimated temp.
9.00am	21.5	45.028	42.3
! 0.00am	23.9	31.345	121.5
1 1.00am	25.8	18.802	153.0
12.00	26.8	10.680	178.6
1.00pm	27.4	18.802	159.7
2;00pm	27.6	31.345	156.5
3.00pm	27.6	25.028	157.9
4.00pm	27.9	59.015	39.9

Latitude of Ilorin is 8°30' - 0_0°

Solar constant 1000w/m^2

The formula below is used is estimating the maximum temperature T| for the different hours 1000 cot

0_2 x C.R x t x B_2 « o-E (T, ${}^4T_0{}^4$)x t x B_2 + h (T, - T_0) x t x B_2 + M (Tj - T_0) cot Go

Where	E	=	Emissivity of the absorber = 0.95
	<j	=	Stefan Botzmann's constant = *5.67* x $10^{"8}$ $wm^{"2}$ $K^{"4}$
	C.R	=	Concentration ratio of the concentrator = 9.82
	B_2	=	Area at which the concentrator receives energy = 0.7817m^2
	M	=	mass of the liquid in the absorber = 0.8kg
	h	=	convective heat transfer coefficient = 78.927 ^{w}/m C

For 9.00am, and on substitution of the above values, we have

1000 fcot 45.0280 Tx 9.82 x 9 x 0.7817 ^{L}

Cot 8.5° ^{J}

= 5.67x 10^8 x.95 (T,^{4} - 21.5^4)x 9 x.7817+ 78.927(1!-21.5} x.7817 x 9 0.8 x 1.932 (T,-215) ^>

3.7895 x $10^{'7}$ T,^{4} + 2101.017 = 88896.332

In the above equation, the value before Ti^4 is small, so one can divide the term on the right hand of the equation by the value before TI so as to obtain the range of TV On dividing, the value of T, was found to be 42.1°C, on substitution, it was found to be too low, and higher value was tired i.e 43°, it was very high on substitution, so one assume T, to be between 43°C and 42.1°C ie 43 > T > 42.1 on trying many values between the range, 43.3 was found to be the closet value with some negligible values.

On substituting 42.3 into the above equation to see how close, we have 3.7895

x $10^{'7}$ x 42.34 + 2101.017 x 42.2 - 88896.332

1.21 +8873.019-88896.322

88874.229 = 88896.322

Other values of T were calculated similarly except that T takes the calculated value of T while To is varied.

Efficiency of the Solar Concentrating Collector

The efficiency of a solar collector

= <u>heat gained by liquid in a specified time ______________</u>

Useful insolation incident on the collector in the same time

^in

The value of Q depends on the flow rate of liquid, S_{in} = solar insolation.

The heat gained by the working fluid is

$Q = MC(T_{out}-T_{in})$------------- (1)

Where M = Mass of the liquid

C = specific heat capacity of liquid

T_0ut $^=$ final temperature of liquid .

Ti_n - Initial temperature of liquid

The incident insulations can be estimated.

In many parts of the world, both sunshine and cloud cover, have been used as parameters for estimating solar radiation.

(Fadakin, 2000) for West Africa, (Richard 1977) gave an Amgstron type equation which is expressed in the form

$B = B_0(a+b^s/_{So})$ ------------ (2)

Where Bo = maximum possible solar radiation

S = measured sunshine hours

So = maximum sunshine hours

a and b are constants.

For West Africa, around June-July, a = 0.611 and b = 0.194 The efficiency of the collector can therefore be estimated from equations (1) and (2) above.

Estimation of the efficiency of the solar concentrator

The insolation incident on the collector, Sj,, is fist estimated.

The sun set on the hour angle, w, either side of noon. It is given by

Cos D Cos W Cos L - -Sin D Sin L

i.e Cos W - -tan D tan L----------- (3)

At the equinoxes, W is zero, so that the sun rises and sets exactly on the east-west line. The solar declination at other times of the year is best obtained from tables, though for most purposes, a rough calculation is permissible (Brinkworth, 1972).

Since, we are in similar solstice, the days (d) that the readings are taking from summer solstice, ie June 22'" can be calculated. This gives

D =23/2 Sin 2rcd degrees.

365

d = July 28 -June 22 = 36

D = 0.256°

The latitude, L, for Ilorin = 8°30'

Substituting into (3) gives

Cos w = tan 0.254 tan 8.5 =6.58x1 O^^{4}

.-.w = 89.96°

but w = 2rct, where w - hour angle

~^A~

t = 24w = 24 x 89.96

180 .180

- 11.995

= 12hrs

This implies that sunrise and sun set occur 6.00hrs before and after noon respectively.

Therefore maximum possible sunshine hours

So= 12hrs

lo = solar constant = $1000^w/m^2$ For

Ihr bright sunshine, S = 1 .'. S_{in} lo (a + b (So)

x B_2

Where B2 = $0.7817m^2$ = the area at which the sunshine is received. .-. S_{ir}, =

1000(0.611 + 0.194 (12)_x_p.7817 - 2297.42 $^w/m^2$

1 Heat Q gained by the

fluid in a specific time is given by

$Q = mc(T_{final} - T_{initial})$

As said earlier the efficiency r| is given by $_{n}$ = Q

= Mc (T_{final}-$T_{initial}$)

"^in ^in

Substituting the values of T^ (i.e T estimated), and $Ti_{n}m_{a}i$ (hourly temperature) in table 1 the hourly efficiencies are thus obtained as shown in Table 2

Table 2: Hourly Efficiencies Obtained by using the Hourly Temperature of Variation for 29th of July 2006 in florin

Time (t)	Temperature	Efficiency % З
9.00	42.3	12.99%
10.00	131.5	60
11.00	153.0	14.46
12.00	178.6	17.22
1.00	159.5	- ve
2.00	157.9	- ve
3.00	39.9	0.94
4.00		-ve

The efficiency for the day 27"' July 2006 was calculated by finding the average and its value s

ri_{av} = 13.32%

Comments on Result and Conclusion

From Tables 1 and 2 one would observe that the maximum estimated temperature of the working fluid used in the concentrator was above that of the boiling point of water though the parameters used were recorded on a day when the intensity of the sun was low.

It is also observed that the efficiency was low since the estimated temperatures were very low. The reason for the low temperature is the effect of the weather at the period. That is, the effect of cloud and that of the cool wind blowing around the period.

It is the hope of the researcher that the efficiency of the concentrator be compared with others around the area of study when the maximum temperature is obtained at a period when the sun will be very bright.

References

Brinkworth BJ (1972): *Solar energy for man.* Compton Press G. Britain

Carolyn R. (2000): Concentrating solar collector: Washington state university solar engineering spring; Extension energy Programme.

Energy Commission of Nigeria (1995): ECN annual report

Fadakin W. (2004): Applied solar energy for heating system. A seminar paper presented at the annual conference of the Nigerian Institute of Plumbing.

Gobo, A.E (2004): *Meterology and man 's environment,* Ibadan African -Link books.

http://lhefraserdomain.typad.com/cnergy/solatherama/index-htmil 10/03/2009

National Research Council (NCR), (2002): National science education standards. Washington DC. National academy press.

Rice M.P.; Modest, M.F.; Borton, D.N. & Rogers, W.E, (1979): Heat transfer analysis of receivers for a solar concentrating collector. American Society of Mechanical Engineers, Winter Annual Meeting New York, N.Y; 5P

Richard J. (1977): Solar energy technology and application. Ann Arbar science Michigan, 48106. Solar news links; the energy Biog's Solar Thermal page.

Telkes M. (1974): Solar energy storage. Association of Hampton Roads Aluimni extension journal pp 38-44

CONSTRUCTION OF A CONICAL CONCENTRATING COLLECTOR

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