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Development of a Compound Parabolic Solar Concentrator to Increase Solar Intensity and Duration of Effective Temperature

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Abstract

For efficient drying of product through indirect drying method, a compound parabolic concentrator (CPC) was installed. Six numbers of semi-cylindrical parabolic concentrators were interpolated on a receiver plate for direct conversion of solar energy to thermal energy by trapping the maximum incident rays into metallic tubes which were placed on focus lines of the parabolas. Experiments were carried to study the comparative performance of a solar flat plate collector and compound parabolic concentrator of same size. Average temperature rise of 9.5^0 C was observed during the period. A manual solar tracking was facilitated along the two axes up to 4.68^0 vertical and 11.54^0 horizontal. Average temperature increase of 11.2^0 C could be achieved over the ambient. Solar radiation trapping time at a constant temperature level was increased by 1.5 hours in comparison to fixed CPC.

Keywords: solar, concentrator, compound, parabolic, energy, temperature, tracking.

1. Introduction

Sun-drying method may be an efficient and cheap process but has disadvantages such as contamination by dirt, insects and bacteria and loss due to wetting by rain squalls. These are usually accepted as an inherent part of the method of processing. In order to protect the products from above mentioned disadvantages, to reduce drying time of the products, to have control over final moisture and to reduce wastage through bacterial action, different types of solar dryers can be used (Exell 1980, Fohr and Figueredo 1987, Ghazanfari and Sokhansanj 2002, Janjaia*et al.* 2008, Khalil *et al.* 2007, Roa and Macedo 1976, Ting and Shore 1983, Yaldyz and Ertekyn 2001).

An example of such design is the semi cylindrical parabolic solar concentrator. A semi-cylindrical parabolic solar concentrator is based upon the direct conversion of solar energy to thermal energy by heating, reaching temperatures above 300 ºC, depending on the efficiency of the concentrator. It is for this reason that parabolic solar concentrators are suitable for use in a wide variety of industrial processes which use thermal energy, such as dairy, processed waste, electricity, etc., replacing in this way the use of fossil fuels (Romero *et al.*).

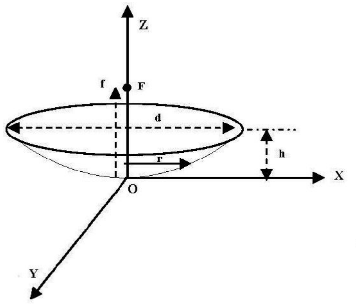
The main basis of the prototype solar concentrator is a parabolic reflective surface, which takes advantage of every ray of light coming from the infinite is concentrated at the focus. At focus, a metal tube is placed which serves to transform solar energy to thermal energy (Romero *et al*).These collectors are mounted with their surfaces facing towards the equator and the tilt angle is set approximately equal to latitude (Jamil *et al.*).

It is necessary to calculate the optimum tilt angle which maximizes the amount of collected energy. The best way to collect the maximum solar energy is by using solar tracking systems to follow the sun as it moves each day, and thus to maximize the collected beam radiation. It is possible to collect 40% more solar energy by using a two-axis tracking system (Markvart *et al.*).

In general solar concentrating systems comprise a reflective surface in the shape of paraboloid of revolution intended to concentrate solar energy on an absorbing surface, which makes it possible to reach a high temperature.

2. Materials and Method

Solar energy capture increase can be achieved by using larger curved reflectors to intercept larger areas of sunshine and redirect that solar energy to a smaller ‘focus’. At the focus, a smaller more intense ‘image’ of the Sun is formed (Fig.1).



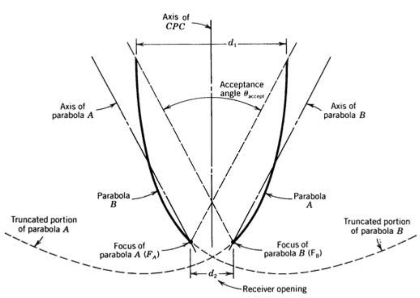


Figure 1: Parabolic disc (Ouederni et al.) **Figure 2**: Compound Parabolic Concentrator (Hinterberger *et al.*)

A more sophisticated parabolic collector trough was designed, that avoided the need to track the sun altogether, by combining two parabolas together (Fig. 2), to form the 'Compound Parabolic Trough Solar Collector' (http://www.powerfromthesun.net/Book/chapter09/).

Non-imaging optical outward facing compound parabolas are useful for non-tracking, concentrating solar energy collectors that redirect solar insolation onto a flat plane at the rear of the solar energy collector.

A properly designed compound parabolic trough solar collector can focus solar energy from multiple directions to a common focal line (Fig. 3) that is the focal line for both parabolas. Such a compound parabola solar collector (CPC), need not to track the sun (http://www.fossilfreedom.com).

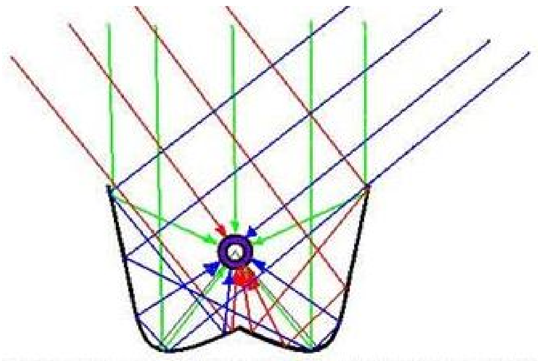


Figure 3: Different incident rays reflect on focus of CPC.

2.1 Reflector

The reflector of experimental device originally designed, made up of 8 mm thick glass Pyrex plate as a cover. The absorber plate consists of 1.5 mm thick black painted aluminium sheet with ply board insulation at the bottom and the two sides. Dimension of the collector was 2220 mm x 1230 mm. In inclination of 15^0 was provided facing south for maximum exposure to insolation in Assam.

Drying Experiments were carried during the month of February to study the increase of ambient temperature. To increase the intensity of solar radiation thereby to increase the temperature, a double parabolic concentrator was designed. Interior surface of the parabolic reflector was made up of glazed aluminium sheet which reflected the solar rays on the face of a receiver placed at the focal position of the concentrator. Metallic tubes of outer diameter 32 mm, thickness 15 mm and length of 1860 mm were placed as a receiver along the focus.

2.2 Design Calculations

The equation for the parabola in cylindrical coordinates is:

$$Z = \frac{r^2}{4f} \qquad (1)$$

Where, ‘r’ is radius and ‘f’ is focus.

The focal distance is given by the expression,

$$f = \frac{d^2}{16h} \qquad (2)$$

Where, ‘h’ is the depth of the dish.

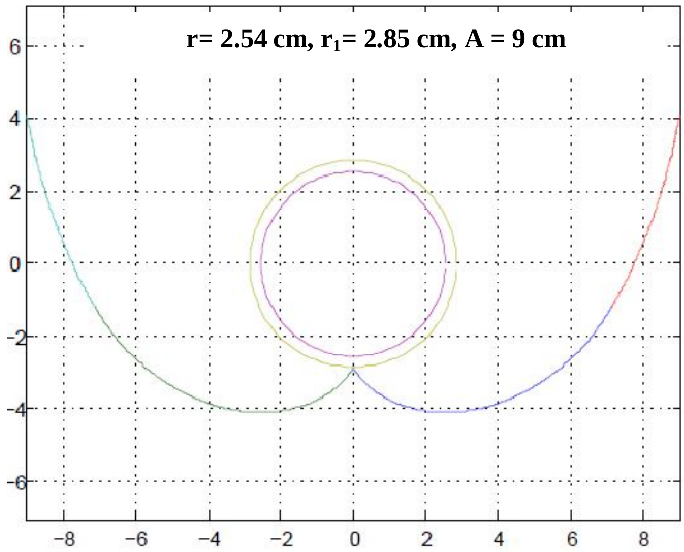


Figure 4: Graphical representation of CPC.

From this geometrical representation of double parabola (Ringeisen 2011), the total area covered and total arc length of the design was calculated.

Area of each parabola is:

$$S = \frac{2}{3} \times a \times b \qquad (3)$$

Where, a = vertical height and b = diameter of parabola

And arc length of the parabola is given by,

$$L = \frac{1}{2}\sqrt{b^2 + 16a^2} + \frac{b^2}{8a} ln(\frac{4a+\sqrt{b^2+16a^2}}{b}) \qquad (4)$$

For a= 8 cm and b = 12cm (from Fig.4)

$$L_1 = \frac{1}{2}\sqrt{12^2 + 16 \times 8^2} + \frac{12^2}{8\times8} ln(\frac{4\times8+\sqrt{12^2+16\times8^2}}{12}) =$$

20.9 mm = 209 mm

Similarly, L_2 = 209 mm and the total arc length covered by both parabola =L_1 + L_2 = 2L = 2 x 209 = = 418 mm

Therefore, half of each parabola = 104.5 mm.

The intersection of two parabolas cuts at a point which was at a distance of 70 mm from diameter of the parabola.

Similarly from (Fig. 4) the arc length of parabola at the intersection where, ‘a’ and ‘b’ were 10 mm and 60 mm were 64.16 mm.

So, the arc length of the parabola from the intersection to the diameter which needed to be subtracted in the design: = 104.5 - (64.16/2) = 2.42 mm

Therefore, arc length required for the design $= 418 - (72.42\ x\ 2) = 273.16$ mm

Using Fig. 4, the following calculations were done:

a) For d = 120 mm and h = 80 mm, using Equation-2 the focus ‘*f*’ of each parabola was calculated to be 11.25 mm.
b) Diameter of the compound parabolic concentrator = 180 mm

The overall dimension of solar receiver was 1860 mm in length and 1220 mm in breadth. A total of six parabolic concentrators were placed with equal spacing of 15 mm (Fig. 5) over previously constructed flat plate collector. The collector was also placed on a directional support according to two axes to ensure a nominal follow-up of the sun to reduce the shadow effect of adjoining CPC’s thereby further increase the effective drying time. For the same reason, a space of 40 mm each was left open in the two sides of the collector area.

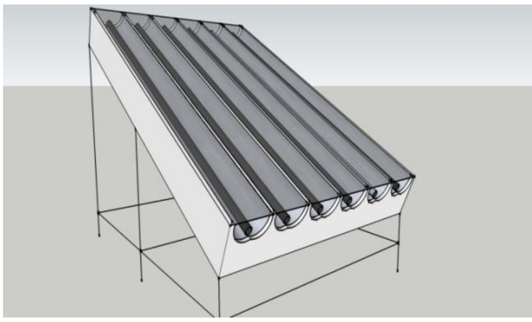


Figure 5: Modified compound parabolic solar concentrator.

3. Results and Discussion

The observations recorded for simple flat plate collector (Design stage-I) are presented in Table-1. The highest temperature was recorded to be 33^0Cover ambient of 25.5^0 C and an average temperature rise of 5.9^0 C was observed over ambient during the study period.

After incorporation of compound parabolic concentrators (Design stage-II), to trap the maximum solar radiation and increase the intensity of incident ray, a maximum temperature rise of 46 ºC was achieved, which was 11^0 C above ambient (Table-2).Average temperature rise of 9.5^0 C was observed during the period. It could be seen that about 4^0C temperatures was increased compared to normal solar flat plate collector dryer.

Instant falling of temperature occurrence was observed after 2.00 to 2.30 pm due to change of direction of Sun and the effective drying time and temperature were affected. To increase the effective drying time, a manual tracking facility was incorporated along the two axes. Horizontal and vertical tracking incorporated on receiver by 11.54^0 and 4.68^0 respectively. The benefit of this improvisation could be seen in Table-3 (Design stage-III).

Table 1: Design stage-I data sheet.

Date	Max Ambient temp(0C)	Ambient RH %		Collector temp (0C)	Increase in temp (0C)	Average (0C)
		Max	Min			
4.2.13	26.0	61	36	32	6.0	
5.2.13	24.5	64	35	31	6.5	
6.2.13	25.0	66	36	30	5.0	5.917
7.2.13	25.5	64	41	33	7.5	
8.2.13	23.5	67	43	29	5.5	
9.2.13	26.0	67	36	31	5.0	

Table 2: Design stage-II data sheet.

Date	Max Ambient temp(0C)	Ambient RH %		Collector temp (0C)	Increase in temp(0C)	Average(0C)
		Max	Min			
24.5.13	30	97	81	39	9	
25.5.13	30	96	68	37	7	
27.2.13	33	93	71	43	10	
28.5.13	34	98	71	44.5	10.5	9.5
29.5.13	36	96	70	45.9	9.9	
30.5.13	35	98	71	46	11	
31.5.13	35	94	90	44	9	

Table 3: Design stage-III data sheet.

Date	Time	Ambient Temp(0C)	Ambient RH %		Collector Temp(0C)	Increases Temp(0C)	Average (0C)
			Max	Min			
12.6.13	10.30	35.0	73	42	44.0	9.0	
	12.30	37.2			48.0	10.8	
	16.00	35.0			44.5	9.5	
13.6.12	10.30	38.2	70	30	52.4	14.2	11.2 0

	12.00	38.4			53.1	14.7	C
	16.00	35.0			44.0	9.0	

After facilitation of solar tracking, the duration of effective temperature was increased by 1.5 hours more than the earlier, up to 4:00 p.m. From the above table, it could also be seen that, the average temperature was increased to about 11.2 ^{0}C.

4. Conclusion

It could be inferred that, the basic design modification from solar flat plate collector to compound parabolic solar collector for the same area can significantly increase temperature of the air. During the study of Design Stage-II, ambient relative humidity percentages were much higher in comparison to study period of Design Stage-I. The average increase of air temperature by 9.5^{0} C is likely to be even higher during relatively dryer period of the year owing to about 40% RH differences due to seasonal variation of climatic condition.

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