A Simple Technique of Fabrication of Paraboloidal Concentrators

*Solar Energy, Volume 22, pp 463-465

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(*Received 13 April 1978; revision accepted 16 November 1978*)

Introduction

Paraboloidal concentrators have the ability to raise various absorbers and working fluids to high temperatures. The maximum concentration factor and temperature attainable in practice depends on the aperture size (area intercepting solar radiation), reflectivity, and accuracy of the surface contour, and the degree to which the concentrator approximate a true paraboloidal geometry. Paraboloidal concentrators have been used for various applications, from cooking[1] and driving hot-air operated pumps for lifting water[2], to providing power for space-craft[3] through a mercury-vapor driven electric generator. In recent times the merits of various types of non-imaging compound concentrators[4] which collect not only the direct beams of radiation but also part of the scattered component, has been described in literature.

It is generally believed that paraboloidal dish-shaped reflectors require relatively sophisticated fabrication techniques of metal spinning, plastic molding or 'die pressing'[5]. A practical and elegant technique of fabricating simple and compound paraboloidal concentrator, starting from a plane sheet of material is described below.

Aluminized Mylar which is known to be a very good reflecting material is now commonly available. Pasted on a suitable backing such as cardboard, paper-mache, tinned or galvanized iron, or thin aluminum sheets, it can be fabricated into inexpensive and practical solar concentrators.

Principle of Fabrication

Figures 1 and 2 illustrate the principle of construction of a paraboloid starting from a plane sheet of material. Figure 1 is a plot of the parabola $Y=X^2/4f$ representing a vertical section through a paraboloid having a focal length of f cm. If the paraboloid is slit symmetrically along eight radial directions and flattened out, then it would appear like an eight petalled flower as in Fig. 2. the non-shaded portion in Fig. 2 represents the reflector part, and the shaded portion that part of the plane sheet which has to be cut out and removed. A circle of circumference $2\pi R$ on the plane sheet would occupy a lesser circumference equal to $2\pi X$ in the paraboloid after fabrication. Thus the main consideration in the construction is to calculate the arc length of material that has to be cut out, namely $(2\pi R - 2\pi X)$ as a function of R. Note that the radial distance R between the origin and any point P on the plane sheet becomes the arc length alon the contour of the parabola between the origin and the same point P on the surface of the paraboloid.

To derive an expression for ***R*** in terms of ***X***, the following procedure is used:

Let ***dR*** be an element alon the parabolic arc, and ***dX*** and ***dY*** the correponding elements along the ***X*** and ***Y*** axes respectively (see Fig. 1).

Since: Substituting,

$$(dR) = (dX)^2 + (dY)^2$$

$$Y = \frac{X^2}{4f}$$

$$dY = \frac{2XdX}{4f} = \frac{XdX}{2f}$$

Substituting, Integrating,

$$dR^2 = dX^2\left[1+\frac{X^2}{4f^2}\right] \qquad dR = dX\left[1+\frac{X^2}{4f^2}\right]^{1/2} \qquad R = \int_0^x \left[1+\frac{X^2}{4f^2}\right]^{1/2} dX$$

Since $X^2/4f^2 = (Y/f)<1$ for shallow paraboloids, the higher order terms can be neglected in the binomial expansion for $[1+(X^2/4f^2)]^{1/2}$ and we have

$$R = X\left[1+\frac{X^2}{24f^2}\right] = X\left[1+\frac{Y}{6f}\right]$$

The relation is valid for shallow paraboloids only. For deep paraboloids the higher order terms cannot be neglected. Using the standard integral result, namely:

$$\int\left[x^2 \pm a^2\right]^{1/2} dx = \frac{1}{2}\left[x(x^2 \pm a^2)^{1/2} \pm a^2 \log\left(x \pm \left[x^2 \pm a^2\right]^{1/2}\right)\right] + C$$

The general equation for R can be shown to be given by

$$R = \frac{1}{4f}\left[X(X^2+4f^2)^{1/2} + 4f^2 \log\left(\frac{X+\left[X^2+4f^2\right]^{1/2}}{2f}\right)\right]$$

The total length of material that has to be cut out at each value of R, i.e. the circumferential shrinkage is given by $W = (2\Pi R - 2\Pi X) = 2\Pi(R-X)$. For Shallow paraboiloids, since:

$$R = \left[X + \frac{X^3}{24f^2}\right] \quad \text{we obtain} \quad W = \frac{2\Pi X^3}{24f^2} = \frac{\Pi X^3}{12f^2}$$

In practice this shrinkage is distributed into 2N equal linear segments, N being the number of petals. The length of the segment which is to be cut out, measured perpendicular to the radial vectors on either side at distance R from the origin, is given by (for shallow paraboloids)

$$\Delta W = \frac{W}{2N} = \frac{\Pi}{N}\left(\frac{X^3}{24f^2}\right)$$

PRINCIPLE OF FABRICATION OF PARABOLOID

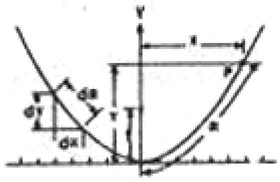

Fig. 1. Section through paraboloid.

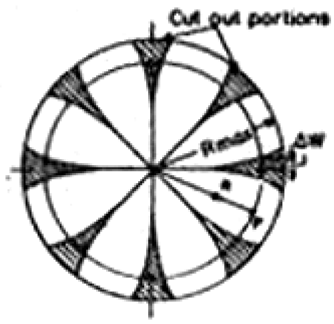

Fig. 2. Flattened paraboloid.

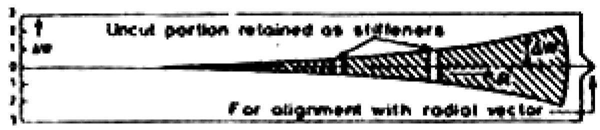

Fig. 3. Template for marking.

The shaded area which represents the portion to be cut out on either side of a radial vector is shown in figure 3.

The procedure adopted for deep parabolaoids is identical except that the R has to be evaluated for each value of X using the exact relations. Then the D W is calculated from

$$\Delta W = \frac{\Pi}{N}(R - X)$$

Details of the Prototype Paraboloidal Concentrator Fabricated at Trombay.

Using the technique described above, a 1 m diameter prototype paraboloidal concentrator was fabricated out of 1 mm thick commercial Aluminium sheet. Aluminised mylar was first pasted neatly on the plane sheet (cut circular to ~ 12o mm diameter)** using Favicol adhesive, ensuring that no wrinkles or air pockets are present. The equation for the parabola aimed for was Y = X2/115cm, having a focal length of 28.8 cm.

A card board template similar to Fig. 3 corrosponding to the above parabola was prepared. The portion to be cut out (shown shaded in Fig. 3) was marked off on the Aluminium sheet by means of brush and paint on either side of 16 symmetrically drawn radial vectors.After cutting out the unwanted painted portion, the 16 petals were raised and fixed in position with their edges touching each other by means of suitable arrangement such a wire clips, rivets, or screws and nut. A circular 30 cm dia circular region was left uncut as the circumferential shrinkage there was less than 0.15 percent.

This uncut portion in the center played an important role by providing mechanical rigidity to the fabricated paraboloid. The resultant paraboloid was found to be self supporting and structurally quite rigid. Fig 4 shows a photograph of prototype paraboloid fabricated at Trombay. With care and gently pressure it was possible to make the upper portion of the paraboloid more circular and less polygonal in shape. The maximum width of each petal was 20 cm. Mechanical measurements made.

Laser beam Tests

The size of the focal region of the paraboloid was measured by means of a portable He-Ne Laser Unit. The Laser used had a power of 10 mW with a beam diameter of 2.5 mm, at a waave length of 630 nm (red region). The paraboloid was mounted on a horizontally on a framework such that it could be rotated around a central axis. A sheet of graph paper on a card board backing was mounted along the central verticle plane in the focal region of the paraboloid. The laser beam was made to shine vertically downward on the reflector by means of mirror arrangement. The paraboloid was rotated and the extreme points on the graph illuminated by the reflected laser spot were marked off.

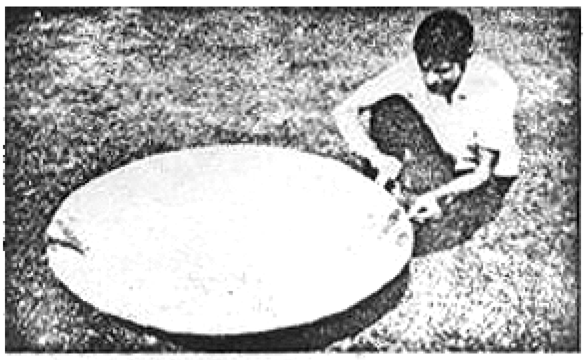

Fig. 4. Prototype paraboloid fabricated at Trombay.

There was a abrupt horizontal shift in the reflected spot by 10 cm when the incident laser beam crossed over from one petal to next. The shape of wach petal was also individually examined , and the scatter or drift of the reflected laser spot was observed. It was thus determined that the focal region was ~ 10 cm in diameter and the focal length was 22+ 5 cm from the bottom. This was less than the expected value of 28.5 cm as the bottom uncut portion was flat.

Water heating experiment

The performance of the concentrator was assessed through water heating/boiling measurements. 0.8 l of water contained in a glass flask blakenned in the bottom by means of black enamel paint was placed in the focal region. An A-frame wooden structure was used to adjust the concentrator.

0.8 lit of water boiled in 15 min. This corresponds to ~ 300 W of absorbed Solar power. Giving an efficiency of ~ 35% (on the basis of 1kW/m2 of intercepted radiation) The efficiency was found to be dependent on nature of absorbing vessel, its shape, size, and degree of blackening. In some cases presence of outer clear glass enclosure around the absorber vessel increased efficiency significantly.

Summary and conclusions

Measurments of the performance of paraboloid concentrator constructed out of aluminized mylar pasted on sheet meta backing, using fabrication method described in this paper, confirmed adequacy for various applications. The technique can be easily extended to compound parabolic concentrators (CPC) and other non imaging two axial collectors also. If analytical expression between R and X is found to be cumbersome, an analogue technique of directly measuring R by means of a string or by other method may be adopted after drawing desired parabola or compound curve to full scale on the floor or wooden board.

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*This paper was earlier presented at the National Solar Energy Convention held at Jadavpur University, Calcutta, in November, 1976.

** Note that it need not be circular. One could also make a Paraboloid using a rectangular sheet, using the principle described in this paper.