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DESIGN AND MANUFACTURING OF $2M^2$ SOLAR SCHEFFLER REFLECTOR

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ABSTRACT

Scheffler reflectors are efficient for the use of medium temperature applications and works with fixed focus. The current work is focused on the design and manufacturing of standing type 2 m^2 Scheffler reflector for a small size domestic cooking. The elliptical shape of the collector and the parabolic cross section of the collector have been solved. The minor axis, major axis and straight line slope has been solved to design the reflector parabola and elliptical frame for a parabolic. Distributions of crossbar on the reflector, depth and arc length for the different crossbars are calculated. For seasonal adjustment (equinox, summer and winter), equations has been developed, solved and plotted.

Keywords: *- Beam, fixed focus, Scheffler, solar, standing reflectors.*

I. INTRODUCTION

German Scientist Wolfgang Scheffler has invented a solar parabolic reflector for using Solar energy at low cost set up which can be used for medium temperature applications. A solar concentrating reflector tracks the movement of the sun, focusing sunlight on a fixed point. The focused light heat can be used for many applications like heating, steam generation, cooking, and water heating. Other than low temperature applications, there are several fields of application of solar thermal energy at a medium and medium–high temperature level. By various studies on industrial heat demand, it is identified that solar energy is predominant for applications (A. Munir et al., 2010; Bhirud and Tandale, 2006). Some of the industrial applications for medium temperatures are sterilizing, extraction, drying, air-conditioning, pasteurizing, etc. In developing countries like India and China cooking is often done through the burning of biomass such as wood, charcoal, animal, and agricultural waste. The popularity of biomass stems from its reasonable price as well as easy availability it doesn't converts energy efficiently. The burning of biomass is also harmful for the environment and causes several health diseases such as lung cancer, bronchitis, and severe burns. In India solar energy is available throughout the year, this energy can be used for many applications (Goswami et al., 1999). The main advantage of Scheffler technology is that it runs without expensive photovoltaic and can be constructed and repaired easily without technical people. The main difference between Scheffler reflectors and other parabolic solar mirrors are its convenience of use with and without shading effects on the parabola while tracking mechanism. It is possible to cook inside the house advantage in very high temperature countries where no one wants to stand outside in the midday sun to cook. The Scheffler reflectors can be classified into two categories viz. (i) standing type reflector and (ii) laying type reflector. The standing type reflectors area is at comfortable height when standing freely. The standing type results more power in winter than in summer.

II. METHODOLOGY

For designing of parabolic curve of Scheffler reflector, calculations are made with respect to the equinox with zero solar declination angle. The generalized equations of a parabola in x y-axis are used for the parabolic side view.

$$P(x) = m_p x^2 + c_p \qquad (1)$$

where m_p = slope of parabola and c_p = y-intercept of the parabola.

Slope (m) of parabola can be derivative from Eq. (1)

$$P`(x) = 2m_p x \quad (2)$$

From a data point P_n of the parabola curve in the positive coordinating axis where solar radiation is reflected at 90^0. At this point of the parabola curve, the tangent is cut at 45^0 and value of the y-coordinate is half of the x-coordinate axis to design the parabolic reflector.

For a surface area of 2 m^2, the x-coordinate of the point P_n is to be taken as 1.78. This coordinate axis tells the distance of the known point to the foci point, which it is also useful to find the average distance of the reflector surface to the foci point. A value is consider such that it keeps the distance small, but still leaves some distance is to be maintained in between the inner collector edge and the focal point in order to avoid shading or mirror image from the buildings ,towers--etc. that usually exists around the foci point. That`s why the collectors with a surface area will generally have a point P_n with a high distance due to minimize the shading losses.

Now derivate the Eq. (1) at the point such that is equal to the slope at the point. The tangential curve cuts at this point P_n at an angle of 45^0 with x-axis, so we drawn the graph by using values as shown in below.

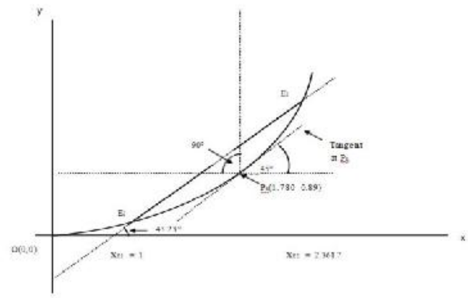

Fig. 1 Description of parabola constraints for Scheffler reflector

$$P\ (1.78) = \tan 45^0$$

$$P(1.78) = ½\ (1.78)$$

$$P(1.78) = 0.89$$

From Eqs. (1) and (2) the values of m_p and c_p are calculated as 0.2797 and 0 respectively. The parabola equations for the equinox are given as:

$$P(x) = 0.2797x^2 \quad (3)$$

In order to construct a balanced reflector, let two critical points x_{E1} and x_{E2} are considered on a graph sheet as 1 and 2.3617. The reason behind to consider these values is to built a balancing parabola in order to obtain the reflector with a nominal force. In this way, the line joins these two points E1 and E2 of the parabola curve represents a simple elliptical frame the Scheffler reflector. This line E1 &E2 is not a parallel line to the tangent at point of intersection Pn (which makes 45^0 with x-coordinate) but makes a 43.23^0 angle .The structure is balanced and needs to generate a little force to move the reflector. As the general equation of this straight line is given by

$$G(x) = m_g x + c_g \quad (4)$$

Where mg = slope of the line

c_g = y-intercept of the line.

Differentiating Eq. (4) with respect to x

$$G'(x) = m_g$$

$$m_g = \tan 43.23^0$$

$$G'(x) = \tan 43.23^0$$

$$m_g = 0.94$$

The coordinate x of point E1 (X_{E1}) is selected to be 1 and the coordinate y is calculated to be 0.31 by using Eq. (4). By substituting the values of x, y and m_g in Eq. (4). The y-intercept (C_g) is calculated to be 0.94 and the equation of the straight line becomes:

$$G(x) = 0.94x - 0.94 \quad (5)$$

The coordinate x of point E2 (X_{E2}) is calculated by comparing and solving Equation (1) and (4), the general form of a quadratic equation is as follows:

$$x^2 - (m_g/m_p)x + ((c_p/m_p) + (c_g/m_p)) \quad (6)$$

Through solving Equation (6) with the help of a quadratic equation to get two points of intersections (x_{E1} and x_{E2}) of the parabola curve and straight line, we get:

$$x_{E1} = (m_g/2m_p) + [(m_g/2m_p)^2 - (c_p - c_g)2/m_p]^{0.5} \quad (7)$$

$$x_{E2} = (m_g/2m_p) - [(m_g/2m_p)^2 - (c_p - c_g)2/m_p]^{0.5} \quad (8)$$

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The straight line passing the curve represents a cutting plane of an ellipse with axes ratio(a/b) = cos a, where "2a" and "2b" are the minor and major axis respectively. For a given parabolic , the cut section of the lateral part will makes an ellipse and its projections on the ground (horizontal plane) will form a circle. So, the semi-minor axis of the ellipse and radii of projections on the ground will become the same. The projections of this ellipse on the horizontal plane (xz-plane) are a circle with a radius of r. The equation for the diameter calculation of circle (2a) is for a Scheffler reflector by subtracting Eq. (8) from Eq. (7) and is given by:

$$2a = 2[(m_g/2m_p)^2 - (c_p-c_g)^2/m_p]^{0.5} \quad (9)$$

The semi-minor axis of the ellipse is 1.37 m and semi major axis of the Scheffler reflector is mathematically calculated to be 1.88 m by Sub dividing the axes ratio of (cos 43.23^0).

III. DISTRIBUTION OF CROSSBARS ON THE SCHEFFLER REFLECTOR FRAME

To construct a Scheffler reflector, it considered to determine the exact position of crossbars on reflector frame. The frame of Scheffler reflector which will be in elliptical can be determined by equation of ellipse and ellipse equation is:

$$(x/b)^2 + (y/a)^2 = 1 \quad (10)$$

where as a= the semi-minor axis of the ellipse and b = semi-major axis of ellipse. To locate any point "y_n" with respect to "x_n" on the elliptical frame, can be written as:

$$\boldsymbol{y_n = \cos \propto \sqrt{b^2 - x_n{}^2}} \quad (11)$$

Eq. (11) is used for calculating the position of crossbars on elliptical frame of reflector. Any number of points can be taken for crossbars, but seven crossbars are sufficient to make section of parabola for $2m^2$ Scheffler reflector. By taking center of ellipse as origin, major axis along x-axis and middle crossbars passes through origin. By calculating the other cross bars can be located at ± 0.2338m, ±0.4676 m, ±0.7015 m from origin along major axis and the respective points on minor axis are calculated as ±0.6803, ±0.6587, and ±0.5892 m.

IV. CALCULATION OF EQUATIONS FOR THE CROSSBARS ELLIPSES

The cutting planes of the crossbars are perpendicular to the reflector frame of seven straight lines (q_1 to q_7) The inclination angle of cutting plane of crossbars is found to be -46.77° by subtracting the angle of cutting plane of the reflector frame from 90°. These cutting lines are also ellipses with axis ratio. (a_q/b_q) = cos 46.77°. Starting point from the middle crossbars (q_4, passing through P_c), we take from the basic equations of the line and is given as:

$$q_4(x) = m_{q4}x + c_{q4} \quad (12)$$

Slope of middle crossbar is calculated as

$$m_{g4} = \tan(-46.77) = -1.06 \quad (13)$$

The *x*-coordinate of the point of intersection (C_f) of the middle crossbar and the reflector frame is the central point of X_{E1} and X_{E2} and y-coordinate is calculated by substituting this value of *x* in Eq. (13) and is given as follows

$$q_4\,(1.68) = 0.85142 \quad (14)$$

Substituting the values of m_{q4}, $q_4(x)$ and x in Eq. (13), the y-intercept (C_{q4}) for the middle crossbar is calculated and the equation of the middle crossbar (q_4) for 2 m^2 surface area of Scheffler reflector is given as:

$$q_4(x) = -1.06377x + 4.45923 \quad (15)$$

It is develop from that the slopes for all the cutting crossbars are the same as these are perpendicular on the same cutting plane of the Scheffler frame. As the crossbars are equally distributed, so the difference between two successive *y*-intercepts is calculated. The equations for the 4^{th}, 5^{th} and 6^{th} crossbars are calculated by adding 0.70080, 2(0.70080) and 3(0.70080) in the y-intercepts values of Eq. (13) respectively. Similarly, the equations for 3^{rd}, 2^{nd} and 1^{st} crossbars are calculated by subtracting 0.70080, 2(0.70080) and 3(0.70080) from the *y*-intercepts values respectively.

The equations for all crossbars can be generalized as $q_n(x) = m_q x + C_q n$. Similarly, for semi minor axis (a_{qn}) of any ellipse of a crossbar, can be modified for crossbars and reflector frame and is generalized as:

Equations, Semi-minor and Semi- major axis of Different Cross Bars

Table 1 Semi-minor and semi major axis equations of different cross bars

Cross Bars	Y-Intercept	equation of Cutting of cross section bars on xy-plane	semi-minor Axis(aqn)(m)	Semi -major axis(bqn)(m)
1	1.58	q1=-1.06377x +1.57822	2.38005	3.47503
2	1.92	q2=-1.06377x +1.91956	2.62393	3.831126
3	2.26	q3=-1.06377x − 2.2609	2.847	4.15681
4	2.6	q4=-1.06377x − 2.6224	3.05381	4.457813
5	2.94	q5=-1.06377x + 2.94358	3.24749	4.74155
6	3.29	q6=-1.06377x +3.28492	3.46126	5.05367
7	3.63	q7=-1.067377x−3.62626	3.63633	5.30929

$$\mathbf{qn} = \sqrt{\left(\frac{\mathbf{m_{qn}}}{\mathbf{2m_p}}\right)^2 - \frac{\mathbf{c_p - c_{qm}}}{\mathbf{m_p}}}$$

where subscript "n" represents the number of crossbar Similarly, y-intercepts, equations of the cutting sections on xy-plane, semi-minor axis and semi-major axis for all the seven crossbars are calculated

V. CALCULATION OF DEPTHS AND ARC LENGTHS FOR DIFFERENT CROSSBARS

After the calculation of equations for different crossbars, the depths and lengths of arcs for different crossbars are calculated for the construction of Scheffler reflector. The depth of reflector for nth crossbar (Δ_n) is calculated from the following formula

By substituting the values of "Z" in

$$\Delta_n = \frac{a_{qn} - \sqrt{a_{an}^2 - y_n^2}}{cos 46.77}$$

We can see that all the crossbars are the parts of the ellipses that differ slightly from the circle segment. For the solar concentrator optics, different approximations are valid to concentrate energy cheaply rather than to form a precise image. As the small segments are used of large ellipses, these small elliptical segments are taken as the parts of circle segments. In this case, since it is along the crossbar, a small placement deviation means also a small angle deviation. For nth crossbar, radius (R_n), depth (Δ_n), arc length (b_n) and angle made with half arc length ($ß_n$) are

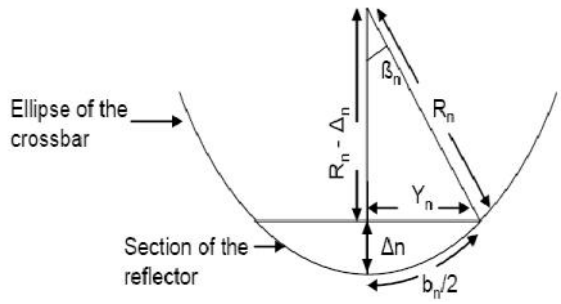

Fig.2 Radius, depth and arc length details for the nth crossbar.

It is evident from

$$R^2_n = (R_n - \Delta_n)^2 + y^2_n$$

Table 2 Depth and lengths of different arcs of crossbars for a 2 m^2 Scheffler reflector

Cross bars	Y_n(m)	Depth (m)	Radius, R_n	Angle	Half arc length	Arc length
1	0.450	0.06193	3.6673	7.0052	0.45159	0.9031
2	0.5892	0.09783	3.0525	11.1289	0.59291	1.1858
3	0.6587	0.11278	2.9627	12.8456	0.66425	1.3285
4	0.6803	0.12040	3.0768	12.7376	0.68595	1.3719
5	0.6587	0.09855	3.3791	11.2406	0.66294	1.3258
6	0.5892	0.07375	4.0257	8.4160	0.59090	1.1818
7	0.450	0.04080	5.5373	4.6613	0.45048	0.9009

The arcs of different radii are marked on the bending templates as given in Table 2. Mild steel round bars (10 mm thickness) are used for the crossbars and are cut according to the required arc lengths as detailed in Table 2. These lengths are then bent with respect to marked circular curves on the templates. After going through the straightness tests, these curves are then welded on the marked positions of the reflector frame. These welded curves are then thoroughly examined for precision and evenness with the help of a jig. The reflector frame is

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painted with primer and suitable paint to avoid corrosion.

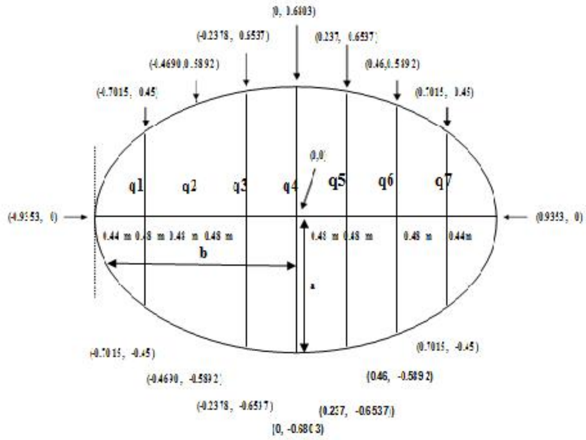

Fig. 3 Intersection points of seven crossbars (q_1–q_7) on an elliptical reflector frame

Thereafter, aluminum profiles are fixed on the reflector frame to shape the base for the aluminum reflectors. These aluminum profiles are tied with crossbars with the help of steel wires. Aluminum reflecting sheets are pasted on these profiles with silicon glue to shape the required lateral part of the paraboloid. Of the material investigated, highly secular aluminum has an excellent chance to meet the requirements for medium concentrating technologies like parabolic troughs for example. They offer a solar weighted reflectance of 88–91 %, good mechanical properties and are easy to recycle Aluminum profiles from Alcan Company, Germany are normally used with reflectivity at more than 87 %.

DAILY TRACKING SYSTEM FOR SCHEFFLER REFLECTOR

Both standing and laying Scheffler reflector rotating along with an axis of rotation with an angular velocity of angular velocity of one revolution per day to counter balance the effect of every day earth rotation. The tracking mechanism normally comprises of small self -tracking PV system or clock -work operated by gravity.

VI. CALCULATION OF SEASONAL PARABOLA EQUATIONS

In order to adjust the reflector with respect to the changing solar declination, the reflector has been provided with a telescopic clamp mechanism to adjust the inclination of the reflector by half of the change of the solar declination angle and to attain the required shape of the parabola for any day of the year. In order to attain the required parabola equation, a fixed point B with on the parabola curve is selected which is the common point for all seasonal parabolas and at the same time acts as the central pivot point for the required shape change of the crossbars. As the point B lies on the same parabola, the y-coordinate by substituting the value of the x-coordinate in Eq. The general form of a parabola equation for any day of the year is given below.

$$D(x) = m_d x^2 + c_d$$

$$\text{Declination } (\alpha) = 23.45 \sin[(360/365)(284 + n)]$$

Where 'n' is the day of the year and 'a' is solar declination varies from -23.5° to + 23.5° from December 21 to June 21 respectively. First of all, the general equation of seasonal parabola equations for standing Scheffler reflectors (2 m^2) in the northern hemisphere is calculated. The coordinates of new set of points at any day of the year are calculated by using the "Rotation Matrix" $(\mathbf{X_d}, \mathbf{Y_d}) = (\mathbf{X}, \mathbf{Y}) * \begin{bmatrix} +\cos\alpha & +\sin\alpha \\ -\sin\alpha & +\cos\alpha \end{bmatrix}$

This equation shows that the coordinates X_d and Y_d depend only on the fix pivot points "B(x, y)" selected on the Scheffler reflector and the solar declination. For a selected reflector, the coordinates depend only on the solar declination and are calculated.

Table 3 Material used for the 2m^2 Scheffler reflector manufacturing

Sl. No	Material used for fabrication
1.	Flat angles
2.	Sheet metal for reflector
3.	L-angle rods (1.5 x 1.5 inch) x (6 mm)
4.	Stand hallow pipe (dia-6 inch , height -2 m, thickness-5 m)
5.	Monument rod (stained steel & s. s full thread rod)
6.	Four flanches (dia. -9 inches thickness -6 mm)
7.	Blots and nets
8.	12 Washers
9.	Black paint for painting the reflector

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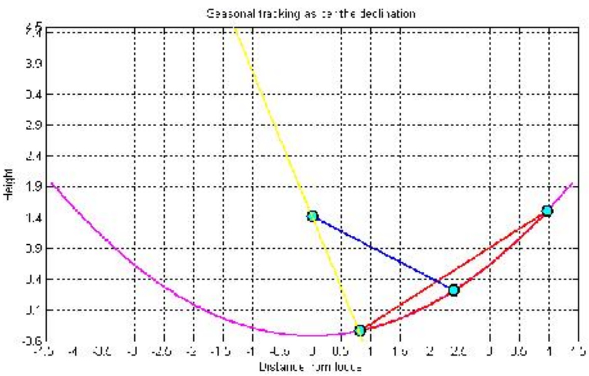
VII. FABRICATION PROCEDURE

First the reflector surface or fame for 2 m^2 Scheffler reflector has been developed using above design data tables such cross bars length, arc length. Collect the rods for designing the reflector bend the rods for respective depth and join the rods with help of welding instruments as per as the width taken in mathematical calculations. As metal sheet is considered and on the cross bars on which mirrors can be parted which is used for reflection of light falling on the reflector. For the standing the reflector a stand is connected first base stand is connected which gives base to the whole system in that two hallow iron pipes are used one is to fix on the ground and other one is fixed on the stand .an u-shaped rod is fixed on this hallow pipes which is connected to base full thread s.s rod is taken on its end is connected to the reflector and another end is connected to l-shape rod is used for the tracking the whole in single axis system.

Fig.4 Manufactured 2 m^2 solar Scheffler reflectors at VIT University, Vellore



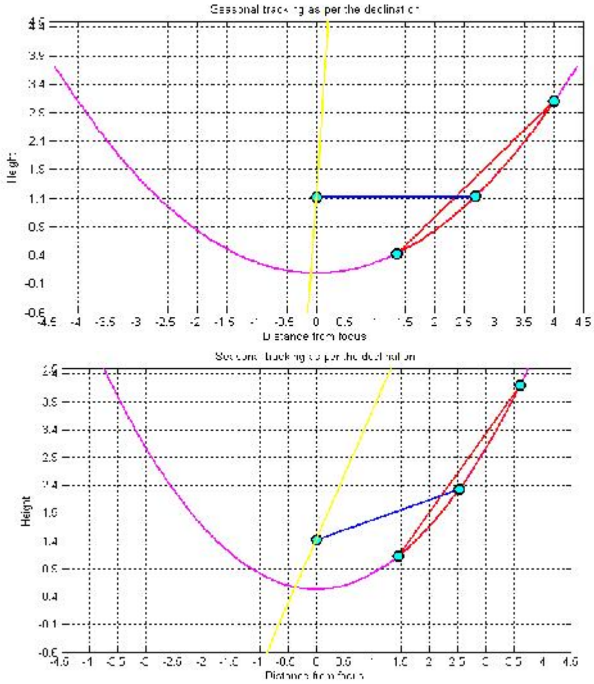


Fig.5 Tracking stages during the start of year (January 1st), after the 3 months and after the six months

VIII. CONCLUSIONS

The dimensions for 2 m^2 Scheffler reflector have been calculated from the co-ordinate geometry of elliptical and parabolic surfaces. The reflector has been constructed that can provide fixed focus for equinox winter and summer. The slope and y-intercepts for the 2 m^2 surface area of Scheffler reflector with respect to equinox are 0.2797 and 0 and slopes of the parabola equations for two extreme positions of summer and winter in the northern hemisphere are 0.45, and 0.2042 respectively. The y-intercepts of the parabola curves for summer and winter are 0.33 and -0.3302 respectively. The parabola equations on June 21st and December 21st in the southern hemisphere are found same as the parabola equations on December 21st and June 21st in the northern hemisphere for reflector

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