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Theoretical Performance Analysis of Linear Fresnel Reflector Concentrating Solar System with Vertical Absorber

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A B S T R A C T

In this paper, the effect of reflector width on the performance of Linear Fresnel Reflector Concentrating Solar (LFRCS) concept with vertical absorber is examined. A theoretical model encompassing all the governing parameters is developed by taking into account the intricate phenomenal interdependencies and influences of parameters on the designs output. The designed and subsequently realized test LFRCS system with vertical absorber is evaluated major from the insight of concentration ratio. Two systems fitted with vertical absorbers with reflectors of varying and constant width arrangements have been investigated. Further, effect of different design parameters on the concentration ratio for both the systems is thoroughly investigated by using the derived formulas from the geometrical figures plotted from the system design. Materials with different reflectivity are considered for the study and their performance is evaluated based on the concentrated power. The reflector material with maximum concentrated power is selected for the design analysis. The final observations are recorded and their outcome emphasizes that the vertical absorbers with varying width outperforms the system with constant reflector width.

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INTRODUCTION

Concentration of solar radiation is necessary for efficient solar thermal and photovoltaic systems (Duffle *et al*., 1980) and Harry *et al*., 1983). Designs have been developed to utilize line focus solar concentrators for reducing the cost of the present systems. Harry *et al*., (1983), Mathur *et al*. (1984) and Marchi (1977) LFR is the lowest cost option for large scale solar electricity plant in the foreseeable future David *et al*. (2006) a detailed performance analysis needs to be done for better efficiency,, cost effective, suitability and efficiently use the solar radiation. Thus, analysis should be investigated for the distribution of local concentration ratio (LCR). The assumptions are made to facilitate the designing of Linear Fresnel Reflector Solar Concentrator (LFRSC) (i) The reflector elements are specularly reflective and (ii) the solar radiation incident normally on the reflector elements (Manikumar and Valan Arasu 2014).The same assumptions are followed in this paper. Linear Fresnel Reflector (LFR) technology is a potential scheme to concentrate solar power owing to its uncomplicated structural design and other techno-economic factors. Typically, an LFR solar collector encompasses three main components: mirror field, receiver and tracking system. The designs in particular may be classified based on the positioning of the absorbers vertical placed and horizontal placed. This section presents some of the prominent literatures discussing few design aspects, absorber positioning and other modeling aspects pertaining to LFR's. Mathur *et al*. (1991) presented elaborate information on optical designs of LFR solar concentrator with three different geometries: horizontal, flat vertical and tubular receivers. Concentration ratio was determined using analytical and ray trace technique. Following this, the optical design and performance of an LFR solar collector with a flat vertical receiver was carried out by (Negi *et al*., 1990). The ray tracing technique was employed to investigate the distribution of local concentration ratio on the surface of the receiver. Zhai (2010) estimated the thermal and optical efficiency for four types of cavity receptors with linear Fresnel lenses as concentrators. A comparative study was undertaken for evaluating the thermal performance of the four identical trapezoidal cavity absorbers for linear Fresnel reflecting solar device by (Panna Lal Singh *et al*., 2010). Martin Haagen (2012) presented the estimation of the prospective of generating solar heat

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for industrial processes with linear Fresnel collectors. A single variable sensitivity analysis examines the factors which influence the internal rate of return and thermal energy costs of solar process heat systems. Iuliana Soriga *et al*. (2012) employed linear Fresnel lens to concentrate solar radiation on a cylindrical cavity receiver. The inner surface of the receiver's glass tube is coated with a reflective layer. Consequently, most of the rays that penetrate the tube are trapped inside the cavity. Facao *et al*. (2011) employed a trapezoidal receiver as a part of the LFR system in order to analyze its optical as well as thermal performance by adopting ray tracing technique and CFD method. The overall heat transfer coefficient of LFR system was evaluated and a generalized correlation was proposed to predict the overall heat transfer coefficient. Further, there were discussions and reports on the durability of the reflectors pertaining more towards materials being used for the design. The focus was laid more on the erosion or the oxidation behaviour apart from its acumen for dust accumulation (Souka, 1996) and McIntire, 1982). Computational investigation of radiation and convection heat transfer is done in order to understand the heat loss mechanisms to maximize thermal efficiency (Tanzeen *et al*., 2011). A solar tracking mirror mechanism to system was added. This tracking has been designed to maximize the reception of available solar radiation (Ihsan *et al*., 2014). MATLAB based model of a Concentrating Solar Power plant (CSP), rated of 40 MW. The modeled system considers the technology and follows the layout. As that project contains the thermal storage, the input and output temperature are well-defined. The conversion to the electrical energy is obtained by a common fossil fuel power station. Then only the primary loop of the whole system has been considered for the proposed model to evaluate the thermal performance and the thermal efficiency (Silvano *et al*., 2012). A linear Fresnel reflector (LFR) solar collector with modified V-shaped cavity receiver was investigated both experimentally and theoretically in this paper. Simplified ray tracing technique was employed to optimize the optical design of the LFR system. The Monte Carlo ray tracing method was used to predict the optical performance of the proposed LFR system (Lin *et al*., 2013).There are few other literatures discussing concepts related to these studies from the insight of various other disciplines. However, the literatures pertaining to vertical absorbers in LFR's with constant reflector width configuration and variable reflector width configuration are either scanty or unavailable. In the present work a detailed evaluation of two designs of Linear Fresnel Reflector Concentrating Solar (LFRCS) system with vertical absorber has been undertaken. In this research study, an attempt is made to compare LFR's with vertical absorbers for varying and constant width reflector configurations. The distribution of local concentration ratio (LCR) on the absorber surface has been determined for the each design using the analytical technique. The formulas for the various parameters have been derived from the geometrical figures plotted from the system design. The basic objective and the scheme of work flow are presented in figure 1.

Materials and methodology:

Design of LFRCS System:

The Linear Fresnel reflector Concentrating Solar (LFR) for flat vertical absorber is designed such that the solar radiation is incident normally on the concentrator aperture, after reflection from the constituent reflecting elements it illuminates both the surfaces of the absorber. This means, the reflecting elements on the left half of the concentrator illuminate the left surface of the absorber and reflecting elements placed on the right half illuminate the right surface of the absorber. Designs for LFR for flat vertical absorber are studied by (Negi *et al*., 1990). In the design, a suitable shift between two consecutive mirror elements is introduced, so as to avoid blocking of solar radiation reflected from any reflecting element by its adjacent reflecting element. In both the design, the reflecting element is characterized by four parameters: shift (S), location (Q) on the concentrator plane, tilt (θ) with respect to the concentrator plane and width (W). Materials used for study different reflective materials considered for analysis are Glass, Highly polished anodized aluminium sheet, acrylic sheet and chromium coated sheet using their reflectivity based on material the concentration ratio and concentrated power are calculated.

The ray radiating from the centre of the solar disc and striking the midpoint of the mirror element, reflects and reaches the focal point F and the extreme ray of lower edge of the mirror element reflects and touches the upper edge of the first mirror element and strikes to the absorber width thus the radiation and reflection from the second mirror is not blocked by the first mirror this is done by introducing space between consecutive mirror element it is done by necessary shift(s). These parameters are accounted for by a geometric function called a "view factor". The main assumption of this model is that, any absorption, emission or scattering of radiation can be ignored. The energy flux leaving in a given surface is composed of directly emitted and reflected energy. The reflected energy flux is dependent on the incident energy flux from the surroundings, which can be expressed in terms of the energy flux leaving all other surfaces (Manikumar *et al*., 2013).

Configuration and Design Parameters of Linear Fresnel Concentrating Solar System:

Several configurations based on the absorbers positioning/ arrangement of reflectors are reported. This study focuses on a particular system configuration / parametric formulations, whose details are presented in the subsection.

Two main systems are considered for this study,

1. LFRCS with vertical absorber of varying width reflector
2. LFRCS with vertical absorber of constant width reflector

The schematic flow diagram showing the various calculations done for the vertical absorber with varying width reflector in LFR solar system and the vertical absorber with constant width reflector in LFR solar system based on the design procedure are given in the figure 2 (a) and figure 2 (b) respectively.

Design of LFRCS system with vertical absorber of varying width reflector:

The LFR system with vertical absorber is mainly classified into two categories depending on the width of the reflector which may either be constant or varying. This study accounts for investigations addressing both the scenarios and finally summarizes the pros and cons of the system with different arrangement and configurations.

Figure 3 represents arrangement of reflector plates in LFR system design with Vertical absorber configuration with varying width elements, which is designed using conventional geometrical optics. In the present case, the aperture diameter, D, of the concentrator is fixed and the required number of reflecting elements is determined by optical considerations. The first reflecting element should be placed at an appropriate location (Q_1), so it can contribute to the concentration on the absorber surface.

An iterative approach along with simple geometrical optics is incorporated to determine the design parameters of the reflecting elements. The initial values for location, tilt, and shift are set as $Q_0 = d/2, \theta_0 = 0$ and $S_1 = 0$ and $W_0 = 0$ respectively, where d is the absorber width. The initial tilt θ_n, for all the n reflecting elements is set as 0 (Negi *et al.*, 1990). The angular sub-tense of the sun at any point on the earth (= 32') has been taken into account while designing the concentrators. The generalized formula for the various design parameters have been derived for each design.

Derivation of vertical absorber with varying width reflector LFRCS system Conditions:

- The reflected ray from the bottom of the reflector plate should reach the focal plane at –d/2 and the reflected ray from the top of the plate should reach at +d/2.
- The reflected ray from the bottom of n^{th} reflector should graze the top of $(n-1)^{th}$ reflector plate.

The two triangles CAB and BPQ are similar triangles and are used to derive the relation for shift between subsequent plates. Equating the base and height ratios of the two triangles,

$$\frac{S_n}{W_{n-1}\sin\theta_{n-1}} = \frac{\left(Q_{n-1} + W_{n-1}\cos\theta_{n-1}\right)}{f - W_{n-1}\sin\theta_{n-1} - d/2} \tag{1}$$

The location of the mirror element and its tilt with the concentrator plane are chosen such that the solar radiation reflected from it is not blocked by the previous mirror element and finally it produces an image on the surface of the absorber. Thus, a certain space is required between the two adjacent mirror elements. The necessary shift for the mirror element is obtained by rearranging the terms in equation (1), we get the shift of the n^{th} plate as,

$$S_n = \frac{\left(Q_{n-1} + W_{n-1}\cos\theta_{n-1}\right)W_{n-1}\sin\theta_{n-1}}{f - W_{n-1}\sin\theta_{n-1} - d/2} \tag{2}$$

From the figure 4 (a)

$$Q_n = Q_{n-1} + W_{n-1}\cos\theta_{n-1} + S_n \tag{3}$$

Substituting the value of S_n, in the (3) and modifying it for n^{th} and $(n+1)^{th}$ mirror element, the following expressions are determined which is useful for arranging the reflector plates in the reverse order.

$$Q_n = \frac{Q_{n+1}\left(f - W_n\sin\theta_n - d/2\right)}{f - d/2} - W_n\cos\theta_n \tag{4}$$

The first mirror element in the reverse order is placed at $D/2$ on both the ends.

In triangle CSQ,

$$\tan\left(2\theta_n + \xi_0\right) = \left(\frac{Q_n}{f - d/2}\right) \tag{5}$$

where, ξ_0 is the half of the angular sub-tense of the sun at any point on the earth(=16').

Rearranging we get the tilt angle of the n^{th} plate,

$$\theta_n = \frac{1}{2}\left[\tan^{-1}\left(\frac{Q_n}{f - d/2}\right) - \xi_0\right] \tag{6}$$

For formulating the width of the reflector plate, we equalize the image width to the width of the absorber,

Image width = absorber width, from figure 4 (b)

$$d = U_n + J_n + I_n \tag{7}$$

where

$$U_n = \left(Q_n + W_n\cos\theta_n\right) * \left(\cot\left(2\theta_n + \xi_0\right) - \cot 2\theta_n\right) \tag{8}$$

$$J_n = \left(W_n\cos\theta_n \operatorname{cosec} 2\theta_n\right) \tag{9}$$

$$I_n = Q_n * \left(\cot 2\theta_n - \cot\left(2\theta_n + \xi_0\right)\right) \tag{10}$$

$$\begin{aligned} d = {} & \left(Q_n + W_n\cos\theta_n\right) * \left(\cot\left(2\theta_n + \xi_0\right) - \cot 2\theta_n\right) + \left(W_n\cos\theta_n \operatorname{cosec} 2\theta_n\right) \\ & Q_n * \left(\cot 2\theta_n - \cot\left(2\theta_n + \xi_0\right)\right) \end{aligned} \tag{11}$$

Rearranging the terms, we get the width of the n^{th} plate,

$$W_n = \frac{\left(d - Q_n\left(\cot\left(2\theta_n - \xi_0\right) - \cot\left(2\theta_n + \xi_0\right)\right)\right)}{\left(\sin\theta_n + \cos\theta_n \cot\left(2\theta_n - \xi_0\right)\right)} \tag{12}$$

In general, the expressions for the parameters, shift (S_n), location (Q_n), tilt (θ_n), and the width (W_n) for the n th mirror element is given by,

$$S_n = \frac{\left(Q_{n-1} + W_{n-1}\cos\theta_{n-1}\right)W_{n-1}\sin\theta_{n-1}}{f - W_{n-1}\sin\theta_{n-1} - d/2} \tag{13}$$

$$Q_n = \frac{Q_{n+1}\left(f - W_n\sin\theta_n - d/2\right)}{f - d/2} - W_n\cos\theta_n \tag{14}$$

$$\theta_n = \frac{1}{2}\left[\tan^{-1}\left(\frac{Q_n}{f - d/2}\right) - \xi_0\right] \tag{15}$$

$$W_n = \frac{\left(d - Q_n\left(\cot\left(2\theta_n - \xi_0\right) - \cot\left(2\theta_n + \xi_0\right)\right)\right)}{\left(\sin\theta_n + \cos\theta_n \cot\left(2\theta_n - \xi_0\right)\right)} \tag{16}$$

Design of LFRCS system with vertical absorber of constant width reflectors:

Figure 5 represents arrangement of reflector plates in LFRCS system design with Vertical absorber configuration with constant width reflecting elements, which is designed using conventional geometrical optics. In the present case, the aperture diameter, D, of the concentrator is fixed and the required number of reflecting elements is determined by optical considerations. The first reflecting element should be placed at an appropriate location (Q_1), so it can contribute to the concentration on the absorber surface. An iterative approach along with simple geometrical optics is incorporated to determine the design parameters of the reflecting elements. The initial values for location, tilt, and shift are set as $Q_0 = d/2, \theta_0 = 0$ and $S_1 = 0$ respectively, where d is the absorber width. The initial tilt θ_n, for all the n th reflecting element is set as 0.

Derivation of vertical absorber with constant width reflector LFRCS system conditions:

- The reflected ray from the center of the reflector plate should reach the focus.
- The reflected ray from the bottom of n th reflector should graze the top of (n-1) th reflector plate.

In triangle ABF, from figure 6 (a).

$$\tan(2\theta_n) = \frac{Q_n + W/2\cos\theta_n}{f - W/2\sin\theta_n} \tag{17}$$

$$\theta_n = \frac{1}{2}\tan^{-1}\left(\frac{Q_n + W/2\cos\theta_n}{f - W/2\sin\theta_n}\right) \tag{18}$$

Here, W is the width of the constituent reflecting elements and f is the distance between the center of the absorber and the concentrator plane.

From the above expression (18), it is observed that close form expression for θ_n is not straight forward. Hence, it is obtained using the following iterative method.

$$if \quad \left(\tan(2\theta_n) - \frac{Q_n + W/2\cos\theta_n}{f - W/2\sin\theta_n}\right) < 0 \qquad then \quad \theta_n = \theta_n + \Delta\theta \tag{19}$$

$$else \ \theta_n \ is \ unchanged$$

As discussed earlier, initially θ_n is assumed as 0 and $\Delta\theta$ is a small angular increment and it is assumed as 1^o. θ_n is incremented by $\Delta\theta$ for every iteration and its corresponding S_n and Q_n are computed using equation (9) and (10) until the final value of θ_n is determined.

From triangle ABC, From figure 6(b).

$$\tan\left(2\theta_n + \xi_0\right) = \frac{S_n}{W\sin\theta_{n-1}} \tag{20}$$

$$S_n = W\sin\theta_{n-1}\tan\left(2\theta_n + \xi_0\right) \tag{21}$$

$$Q_n = Q_{n-1} + W\cos\theta_{n-1} + S_n \tag{22}$$

Substituting the value of S_n, in the above equation and modifying it for n th and (n+ 1) th plate the following expression, useful for arranging the reflector plates in reverse order is obtained.

$$Q_n = Q_{n+1} - W\cos\theta_n - W\sin\theta_n\tan\left(2\theta_{n+1} + \xi_0\right) \tag{23}$$

Next step is to determine whether aperture diameter D, is sufficient enough to include the next reflecting element. It is known that the aperture diameter D, of the concentrator can be expressed as

$$D = 2\left[Q_1 + \sum_{n=1}^{k}\left(W\cos\theta_n + S_n\right)\right] \tag{24}$$

Equation (24) can be modified and the following condition can be derived to determine if there is sufficient space to place the next reflecting element.

$$if \quad 2\left[Q_1 + \sum_{n=1}^{k}\left(W\cos\theta_n + S_n\right)\right] < D \quad then \ \ add \ one \ reflecting \ element \tag{25}$$

$$else \ no \ space \ for \ additional \ reflecting \ element$$

On the basis of similar geometrical optical considerations, the following generalized expressions for shift (S_n), location (Q_n) and tilt (θ_n) associated with the n^{th} reflecting element is determined as follows

$$Q_n = Q_{n+1} - W\cos\theta_n - W\sin\theta_n \tan\left(2\theta_{n+1} + \xi_0\right) \quad (26)$$

The necessary shift for the adjacent reflecting element required to prevent the previous reflecting element from blocking the radiation reflected element is given by.

$$S_n = W\sin\theta_{n-1}\tan\left(2\theta_n + \xi_0\right) \quad (27)$$

and

$$if \quad \left(\tan(2\theta_n) - \frac{Q_n + W/2\cos\theta_n}{f - W/2\sin\theta_n}\right) < 0 \qquad then \quad \theta_n = \theta_n + \Delta\theta \quad (28)$$

$$else \ \theta_n \ is \ unchanged$$

Here, n varies from $1, 2, ..., k$, and k is total number of mirror elements on each half of the concentrator.

Distribution of LCR on absorber surface for both the LFRCS system:

Negi *et al*. (1990) it is assumed that the solar radiation reflected from each reflecting element is distributed uniformly over the width of the image the reflecting element produces on the absorber surface. The concentration at any point on the absorber is determined by summing up the contributions of all the reflecting elements. For a LFR employing reflecting elements of uniform width, the contribution of any constituent reflecting element (say, n^{th}) to local concentration ratio (LCR) at any point within the image produced on the absorber by the reflecting element is given by

$$CI_n = \frac{W\cos\left(\theta_n\right)}{r_n} \quad (29)$$

where r_n is the width of the image produced on the absorber by the radiation reflected from the n^{th} reflecting element and is defined as

$$r_n = W\cos\left(\theta_n\right)\mathrm{cosec}\left(2\theta_n\right) + \left(\frac{Q_n}{\sin\left(2\theta_n\right)}\right)\frac{\sin\xi_0}{\sin\left(2\theta_n + \xi_0\right)} + \left(\frac{Q_n + W\cos\left(\theta_n\right)}{\sin\left(2\theta_n\right)}\right)\frac{\sin\xi_0}{\sin\left(2\theta_n - \xi_0\right)} \quad (30)$$

$$CI_n = \frac{W_n\cos\left(\theta_n\right)}{d} \quad (31)$$

Since each constituent reflecting element on one half of the concentrator illuminates the complete one surface of the flat vertical absorber, total concentration at any point on the surface of the absorber is given by

$$CR = 2\sum_{n=1}^{k} CI_n \quad (32)$$

Solar power (P_n) that reached the absorber, which is contributed from the nth reflector, is given by

$$P_n = \rho I_b W\cos\theta_n L \quad (33)$$

Where, ρ is the reflectivity of the reflector and is given in Table (2) and represents the intensity of beam radiation which is assumed as 800 W/m^2. Thus, the total concentrated power on the absorber due to the contribution from all the reflector elements is given by,

$$CP = \left(2\sum_{n=1}^{k} P_n\right) \quad (34)$$

RESULT AND DISCUSSIONS

In the present study, the area occupied by the Linear Fresnel Reflector Concentrating Solar (LFRCS) system is initially fixed and other system parameters like width of reflector plates, number of reflector plates, their tilt and relative positioning are determined using the expressions derived from the geometrical representation. Optimal design parameters are selected from the solutions which minimizes the material and land requirements. The design parameters of the LFRCS system are obtained by solving the expressions iteratively using MATLAB. In the iteration, the system parameters like width of reflector plates, number of reflector plates, and land area constraints are varied and the corresponding CR is computed. The parameters utilized in the iteration that yields the maximum CR are taken as the optimal design parameters. In literature, the number of reflectors are varied arbitrarily for the given design parameters. In the proposed work, the maximum no of reflectors is solved computationally using equation (25) and for the above mentioned design parameters the number of reflectors is determined. Negi *et al*. (1990) analyzed two flat vertical absorber LFRSC systems with mirror elements of varying and fixed widths and concluded that the CR of the vertical absorber with varying width is much higher than the design with fixed mirror elements. A CR of 12.9 is obtained for the vertical absorber placed at 0.5m focal height and by setting the absorber diameter d as 0.05 m in the literatures. In the present work the concentration ratio for the design values used is obtained as CR =29.5 for the design parameters computed for vertical absorber with varying width. The varying width system design done by Negi *et al*. (1990) had difficulties in fabrication due to smaller size of reflectors. In the present design the minimum size of the reflector in varying width system is 0.0217 m, which can be cut and fabricated easily. It shows that the realization of the obtained reflector width is practically feasible. In this paper, mirror elements of varying width with different orientation of absorber are implemented and the results obtained are discussed in the modeling of the two different designs.

In both the above mentioned designs, the value of CR decreases with an increase in the values of d thus the careful selection of the diameter of the absorber for the LFRCS system is essential (Negi *et al*. 1990). Also, consecutive mirror elements block the reflected radiation and a fraction of solar radiation incident over the aperture of the LFRC system is lost. The losses can be reduced and limited by providing an ample distance between consecutive mirror elements by introducing a shift S. This introduces an inherent constraint in the system design. The sum of the shifts provided between the mirror elements is directly proportional to the energy loss. In the proposed work, the shift S, tilt θ and width W are computed. In this scenario, the actual number of mirror elements that can be placed in the given design is obtained by following an iterative procedure. It is known that the aperture diameter D, using equation (25)

Modeling for varying width reflector design:

The performance of the vertical absorber with varying width reflectors in terms of concentration ratio is analyzed. The aperture diameter for the experiments is fixed as D=2 m and the absorber diameter “d” is varied from 0.01 to 0.1 m. For every absorber diameter, the focal height “f” is diverged from 0.1 to 1.0 m and the respective concentration ratio is plotted. From the graph in figure 7, it is clear that the maximum concentration is obtained when the focal height f=0.2 m and absorber width is d=0.03 m. The number of reflectors is determined as N = 31. The system is modeled with the said parameters and the maximum concentration ratio obtained is CR = 29.5. Table 1 shows the final design parameters Tilt, Location, Shift, and Width for the reflectors of varying width vertical absorber LFRCS system.

Modeling for constant width reflector design:

The performance of the vertical absorber with constant width reflectors in terms of concentration ratio is analyzed. The aperture diameter for the experiments is fixed as D=2 m and the absorber diameter “d” is varied from 0.01 to 0.1 m. For every absorber diameter, the focal height “f” is diverged from 0.1 to 1.0 m and the respective concentration ratio is plotted. From the graph in figure 8, it is clear that the maximum concentration is obtained when the focal height is f=0.2 m and absorber width is d=0.03 m. The number of reflectors is determined as N = 24. The system is modeled with the said parameters and the maximum concentration ratio is obtained as CR = 2.102.

Reflectivity of reflector materials and their concentrated power:

The Reflectivity of the solar collectors materials play an important role in reflecting the rays towards the absorber which in terms gives the maximum concentrated power. The different reflective materials considered for analysis are Glass, Highly polished anodized aluminium sheet, acrylic sheet and chromium coated sheet using their reflectivity a study presented by (Manikumar & Valan Arasu, 2012) based on the study the concentrated power is calculated for both the LFR designs that is the system with varying width reflectors and constant width reflectors shown in the table 2.

Conclusion:

This paper analyzes the theoretical performance of LFR concentrating solar system with vertical absorber with varying or constant width reflectors. From the results, it is evident that the LFRCS system with the vertical absorber with varying width reflectors offers a better performance in terms of concentration on the surfaces of the absorber. The performance of the LFR concentrating solar system with vertical absorber and constant width reflectors does not compare constructively with that of the varying width design. The performance of both the design for various reflecting materials is also analyzed. For both the designs, glass yields higher concentrated power compared to highly polished anodized aluminium sheet, acrylic sheet and chromium coated sheet. Thus, glass is preferred as the reflecting material over the others, whereas other materials have their own advantages based on its properties of flexibility and low weight. Hence, there is a trade off and the appropriate material can be chosen according to the design requirement. In summary, the vertical absorber with varying width LFR concentrating solar system produces better performance in terms of concentration ratio.

Table 1: Output values for vertical absorber with varying width.

Sl:No	No of Reflector	Different parameters of the Reflector			
		Tilt (θ) degree	Location (Q) m	Shift (S) m	Width (w) m
1	1	2.33	0.048	0.0000	0.0217

2	2	2.41	0.049	0.0000	0.0220
3	3	2.52	0.051	0.0000	0.0223
4	4	2.63	0.054	0.0000	0.0227
5	5	2.77	0.056	0.0000	0.0231
6	6	2.93	0.060	0.0000	0.0236
7	7	3.11	0.063	0.0000	0.0241
8	8	3.32	0.067	0.0000	0.0248
9	9	3.57	0.072	0.0000	0.0356
10	10	3.85	0.078	0.0000	0.0365
11	11	4.18	0.084	0.0001	0.0375
12	12	4.56	0.092	0.0001	0.0386
13	13	5.00	0.101	0.0001	0.0388
14	14	5.50	0.111	0.0002	0.0397
15	15	6.09	0.122	0.0002	0.0433
16	16	6.75	0.136	0.0003	0.0454
17	17	7.52	0.152	0.0005	0.0477
18	18	8.39	0.170	0.0007	0.0489
19	19	9.37	0.191	0.0010	0.0534
20	20	10.49	0.216	0.0015	0.0567
21	21	11.74	0.244	0.0021	0.0574
22	22	13.13	0.277	0.0031	0.0585
23	23	14.66	0.315	0.0045	0.0597
24	24	16.33	0.359	0.0064	0.0638
25	25	18.11	0.410	0.0091	0.0688
26	26	19.98	0.470	0.0128	0.0639
27	27	21.92	0.538	0.0178	0.0690
28	28	23.89	0.617	0.0245	0.0640
29	29	25.84	0.709	0.0331	0.0717
30	30	27.73	0.815	0.0439	0.0730
31	31	29.54	0.936	0.0573	0.0767

Table 2: Concentrated Power calculated for various reflecting materials with constant and varying width reflector in LFRCS system.

Sl. No.	Reflector Material	Reflectivity (ρ)	Concentrated Power, for constant width reflectors, CP (kW)	Concentrated Power, for varying width reflectors, CP (kW)
1	Glass	0.98	1.0405	1.7306
2	Highly polished anodized aluminium Sheet	0.86	0.9131	1.5187
3	Acrylic Sheet	0.78	0.8281	1.3774
4	Chromium Coated Sheet	0.6	0.6370	1.0595

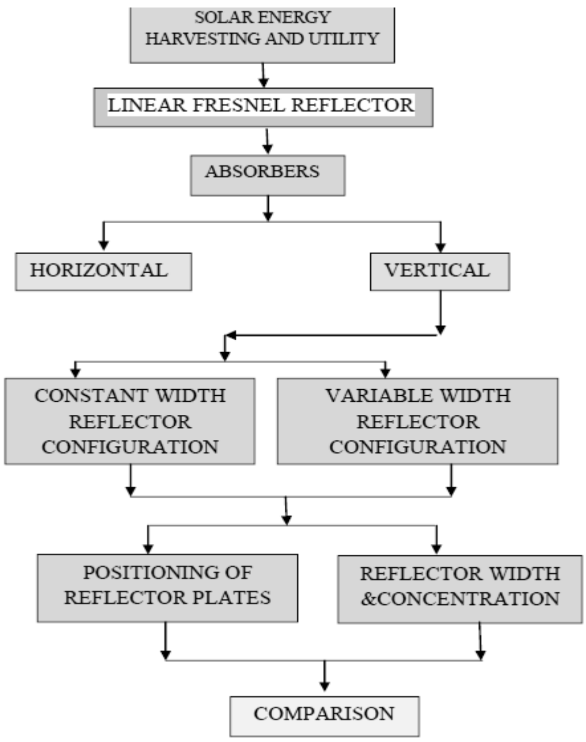

Fig. 1: schematic block diagram of the work flow.

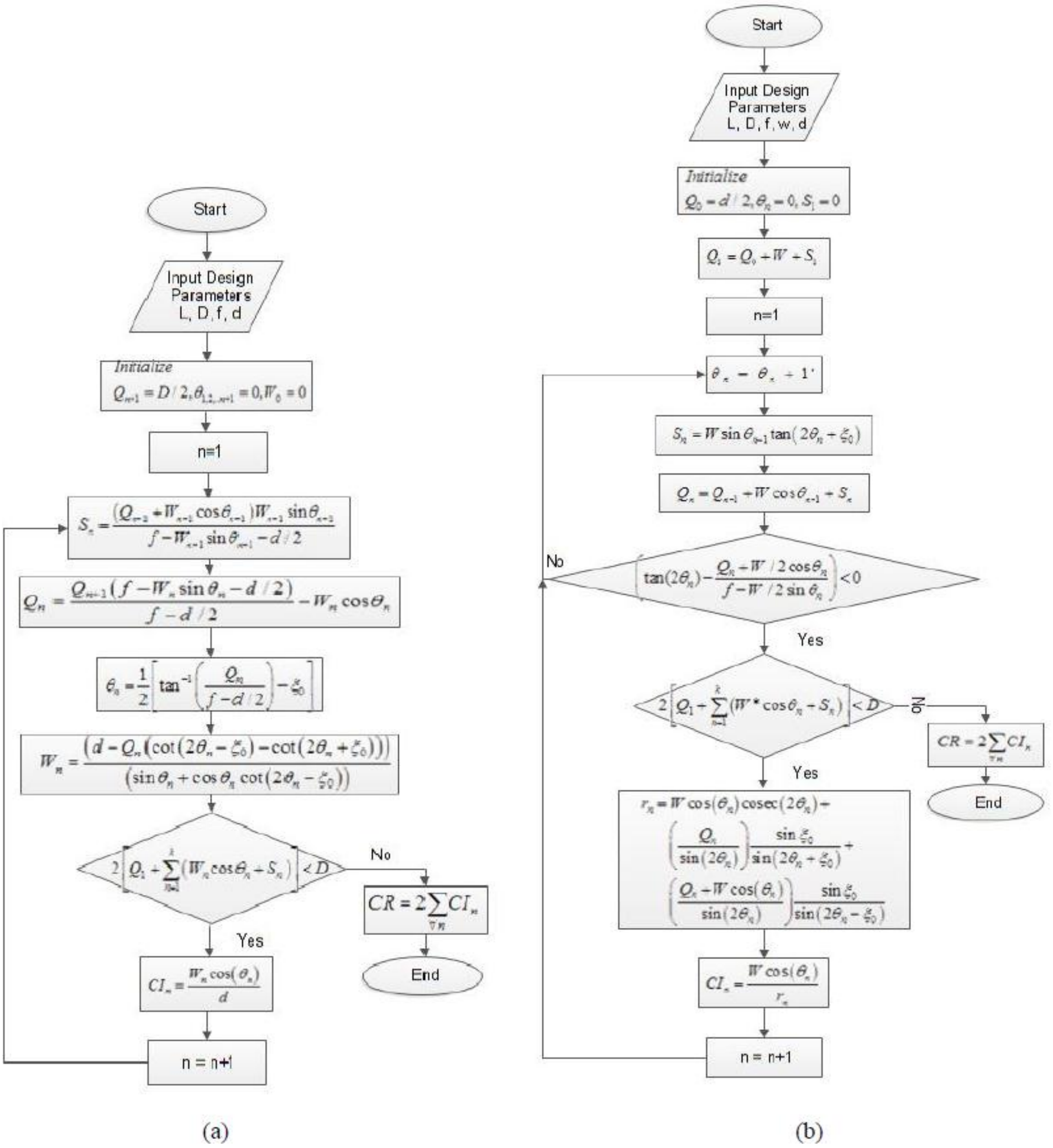

Fig. 2: Flow chart: (a) varying width reflector system (b) constant width reflector system.

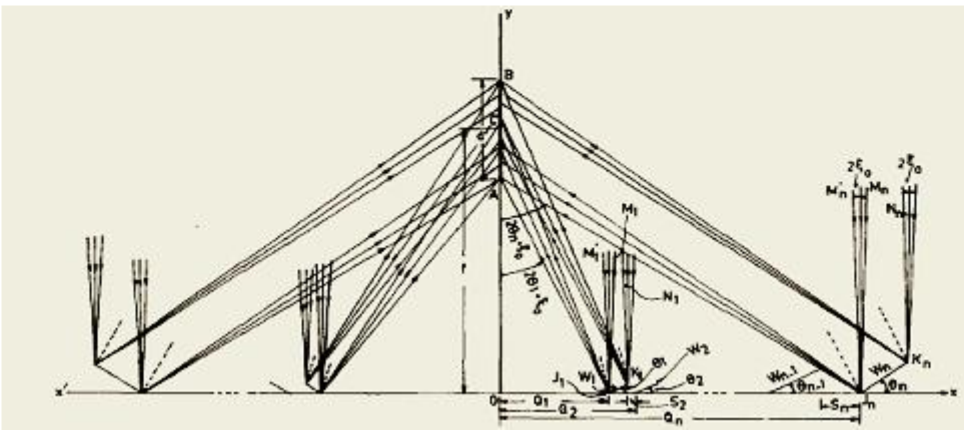

Fig. 3: A linear Fresnel reflector concenerating solar (LFRCS) system with vertical absorber and varying reflector width.

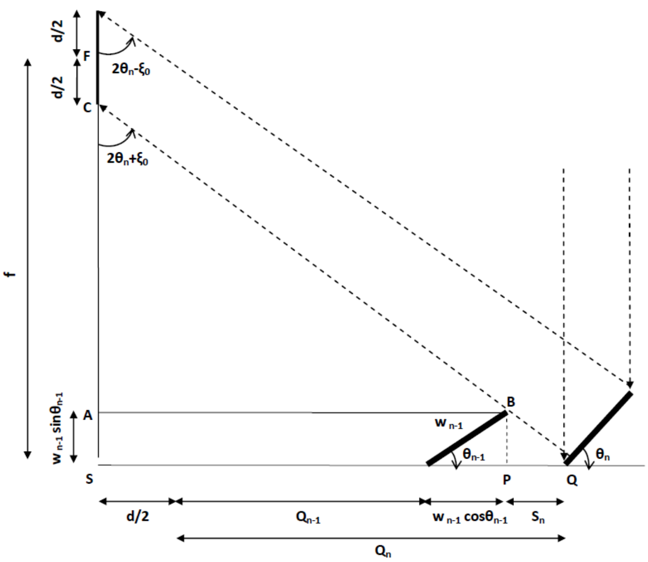

Fig. 4: (a) detailed view of (LFRCS) with vertical absorber and varying reflector width.

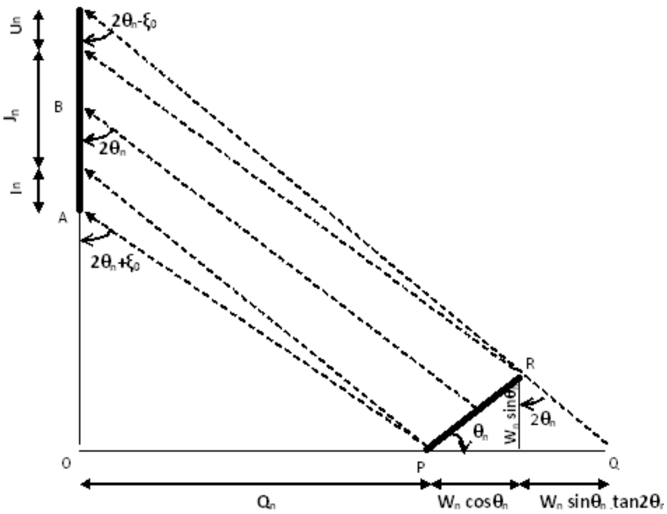

Fig. 4: (b) detailed view of (LFRCS) with vertical absorber and varying reflector width.

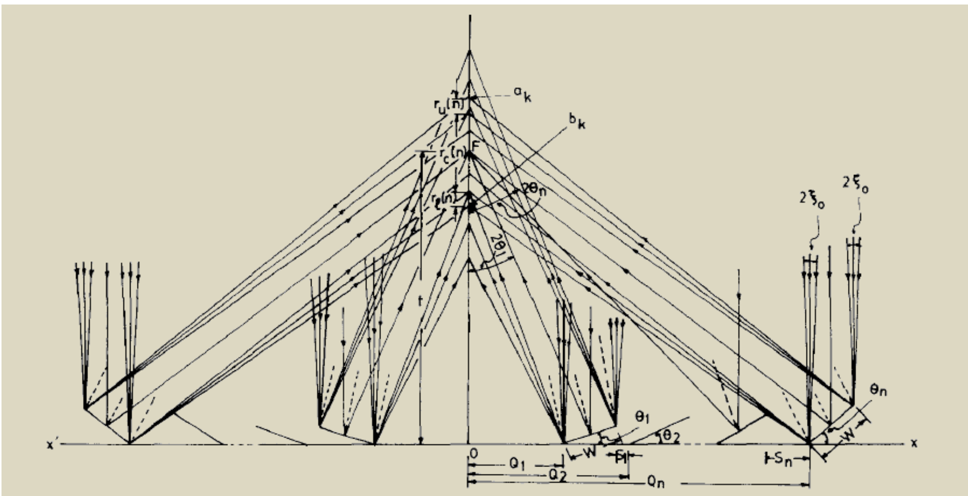

Fig. 5: A linear Fresnel reflector concenerating solar (LFRCS) system with vertical absorber and constant reflector width.

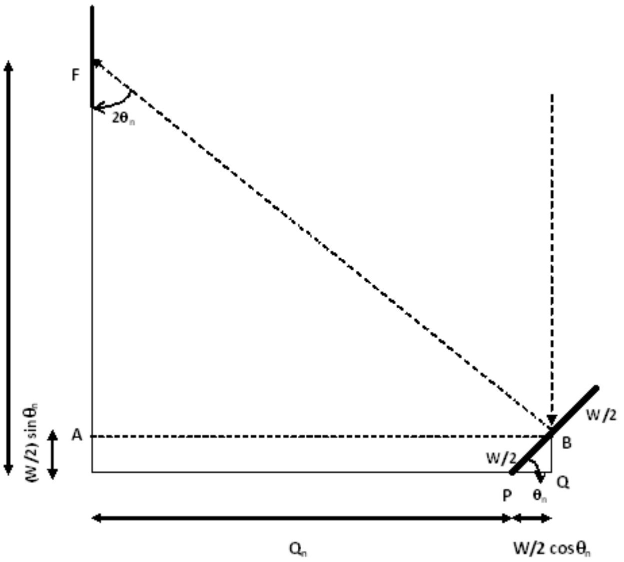

Fig. 6: (a) detailed view of (LFRCS) with vertical absorber and constant reflector width.

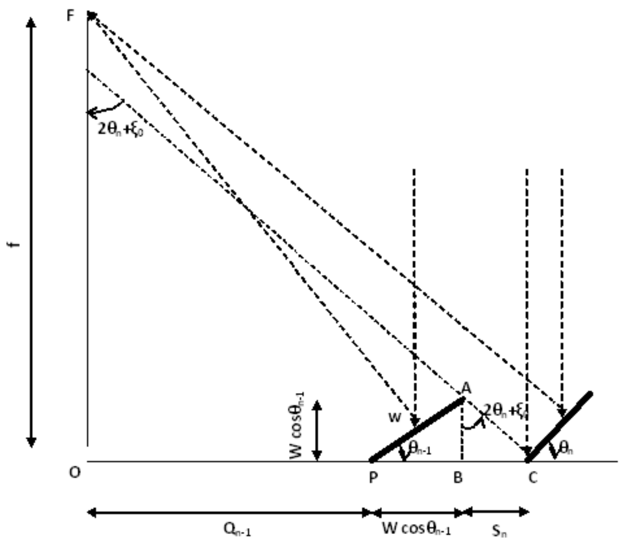

Fig. 6: (b) detailed view of (LFRCS) with vertical absorber and constant reflector width.

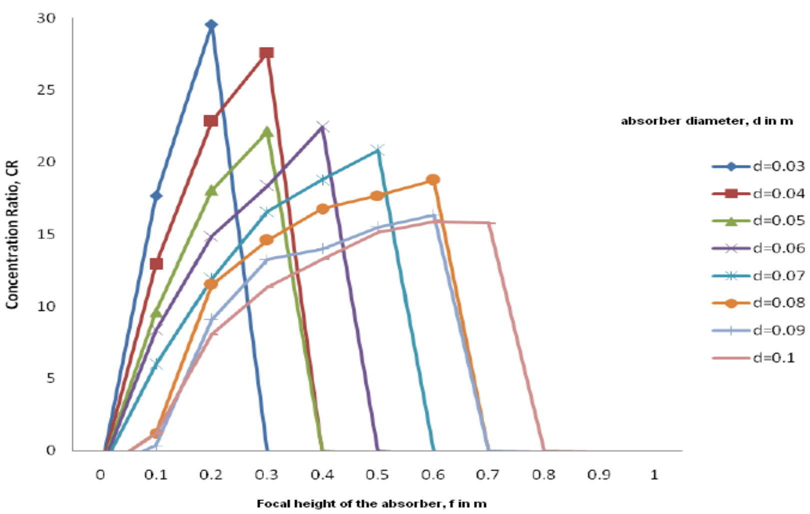

Fig. 7: Performance analysis in term of concentration ratio for varying width reflecting elements.

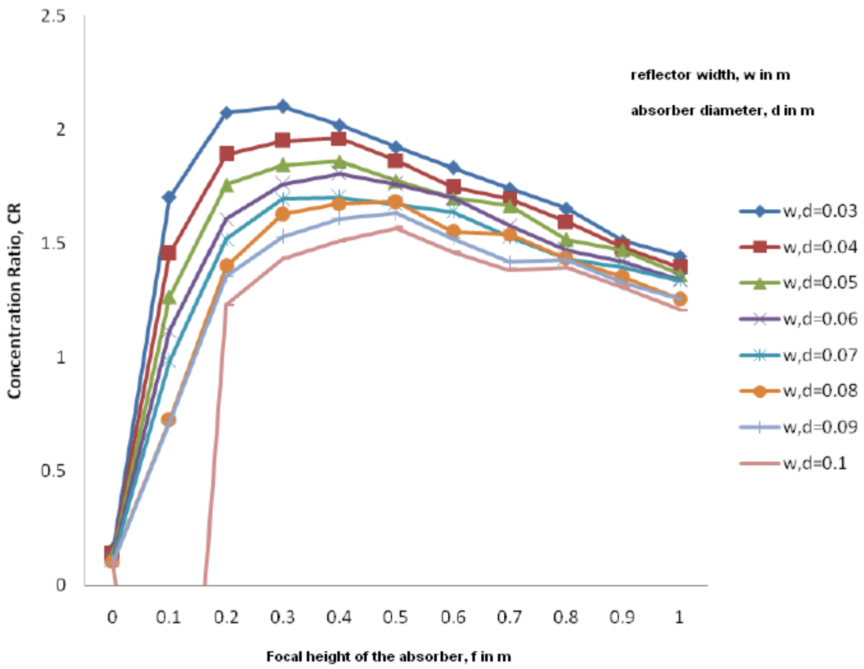

Fig. 8: Performance analysis in term of concentration ratio for constant width reflecting elements.

Keywords: Nomenclature

Symbol	Description
Q_n	Location of the n^{th} reflector from the centre (m)
P_n	Power reflected from n^{th} plate in (kW)
n,k	Number of reflector
W_n	Width of the n^{th} reflector (m)
d	Diameter of the absorber (m)
S_n	Shift between the n^{th} reflector (m)
L	Length of the absorber (m)
f	Height of the absorber center from the base (m)
D	Aperture diameter (m)
N	Number of reflectors
CP	Total Concentrated Power (kW)
CR	Concentration Ratio
CI_n	Concentrated Power from n^{th} reflector (kW)
θ_n	Tilt angle of n^{th} reflector (degrees)
ξ_0	Half of the angular sub-tense of the sun at any point on the earth(=16')
ρ	Reflectivity of the reflector
I_b	Beam radiation (W/m^2)

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