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Review Article

Optical Design and Performance Analysis of Linear Focusing Solar Thermal Collectors

Izuchukwu Francis Okafor

National Centre for Energy Research and Development, University of Nigeria Nsukka, Nsukka, Nigeria

Email address:
izuchukwu.okafor@unn.edu.ng

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Abstract: Linear Fresnel solar collector is a focusing concentrator suitable for direct steam generation, industrial process heat, and solar space cooling system and hot water generation for different uses. The optical design and performance simulations, experimental and numerical studies on linear Fresnel solar collector were reviewed. Studies on the optical designs and ray-tracing simulations results indicated non-uniform solar flux distributions on the receiver absorber surface. The optical quality of LFC is low due to its higher incidence angle and the cosine factor. Studies on optimizing the optical errors that affects the optical performance of the LFC are lacking in the literature. Ray tracing results at 0^o incidence angle indicated three different optical losses-geometric configuration, material properties and focus errors losses. Studies on the lateral drift and uncertainty of the direction of the reflected rays, which adversely affect the concentration factor of the LFC are lacking in the literature. The optical performance of a LFC system can be improved through an optimized optical design - mirrors separation, shapes, width and their orientation.

Keywords: Linear Focusing Solar Collector, Optical Design, Performance Simulations, Optical Errors

1. Introduction

Linear Fresnel solar collectors are suitable for a wide range of applications, which include steam production for power generation, industrial process heating, solar cooling, institutional and domestic hot water system [1]. Linear Fresnel solar concentrators are also a viable option for direct steam generation power plants [2]. The direct steam generation system eliminates the need of using the expensive thermo-oil and complex heat exchangers and the superheated steam can be generated directly using the solar concentrator [3]. The direct solar steam generation is still at the prototype stage [4] and large amount of thermal storage is still a challenge, since steam storage is expensive [5]. Unlike parabolic solar collectors, linear Fresnel solar collectors do not require rotating joints and metal-glass welding at the ends of each receiver tube [6] and has low maintenance and operating costs. They also have relatively low construction cost with low wind loads and higher land use efficiency [7], which makes them suitable for installation where space is restricted. These features have motivated a number of research efforts to improve the general performance of linear Fresnel solar concentrator systems and for construction of solar thermal plants based on the linear Fresnel approach. The companies working on linear Fresnel reflectors claimed higher efficiency and lower costs per kWh than its direct competitor, parabolic trough, due to its high density of mirrors [8].

In the early 1990s, Paz Company in Israel constructed a linear Fresnel solar collector system with a geometric concentration of 18 and absorber pipe of 100 mm diameter. The absorber was coated with a selective surface and enclosed in a glass tube placed inside a downward facing secondary stage reflector. Oil was used as the primary heat transfer fluid. The arrangement was mounted at about 2.5 m above five rows of mirrors of 0.8 m width [9]. The optical performance of this system was substantially below the design figures and it was difficult to extract absorber thermal efficiencies from this report. In 1999 a Belgian company, Solarmundo erected a linear Fresnel collector prototype in Liege, Belgian [7]. The collector has 48 rows of mirrors with a total collector width of 24 m and area of 2,500 m^2, and a single absorber tube of inner diameter 18 cm. They indicated that the major advantages of the Fresnel collector system over parabolic trough collectors include use of inexpensive planar mirrors and simple tracking system, fixed absorber tube with no need for flexible high pressure joints, no use of vacuum technology and no metal glass-sealing, no heat exchanger was required due to direct steam generation and efficient use of land etc. They also noted that based on these advantages, the Fresnel collector has the potential of reducing the cost of solar collector field to about 50% compared to parabolic trough, due to its simplicity. The cost reduction due to economy of scale and due to optimal design of the collector could further reduce the investment costs for the solar field. The lower operation and maintenance costs of the linear Fresnel solar collector field could also lead to more savings. In Spain, MAN Ferrostaal Power Industry built its 1 MW linear Fresnel collector demonstration plant. Also in USA, Ausra built a 5 MWe compact linear Fresnel reflector demonstration power plant. The solar-field has an aperture area of 26,000 m^2, with three lines, each 385 m length with a mirror width of 2 m. The plant produces 354^{o}C superheated steam at 70 bar [10]. The plant uses multiple absorbers and closely packed reflectors such that individual reflectors would have the option of directing reflected solar radiation to at least two absorbers. This is unlike the linear Fresnel reflector which has only one linear absorber mounted on a single linear tower and one orientation axis for each reflector. In 2010, the first linear Fresnel concentrated solar power plant was built in South Africa and now two 150 kW module pilot systems are being constructed at Eskom's (South Africa's largest power utility company) research and innovation centre in Rosherville, Johannesburg [11]. Patel [12] noted that the LFSC has the possibility of achieving a low Levelized Cost of Electricity (LCOE) due to its simple construction, flat shape mirror, easy cleaning and better land use efficiency than other CSP technologies. They further stated that LFSC could be very useful for poly-generation (electricity, cooling, and water desalination from the same system) which could support reducing LCOE and thereby making it more competitive.

However, the short-fall of a linear Fresnel solar concentrator is that its concentration factors (10 - 40) are still notably lower than that of parabolic trough concentrators (300 - 1500), but this can be improved with good optical designs (the mirrors separation, their shape, width and orientation) [6]. Cheng [13] investigated and optimized the optical performance a linear Fresnel reflector solar collector using a 3D Monte Carlo ray-tracing model developed in FORTRAN. In this study, three mirrors were used to investigate the effects of the mirror aim lines, slope error and location on the optical performance. They noted that the optimized cylindrical mirror could achieve the same performance as that of the optimized parabolic mirror. They also found that uniform concentrated solar flux incident on the absorber tube could be improved by designing the aim lines and using the mirror with a certain slope error. Mathioulakis [14] investigated the effect of the optical path of the incident beam solar radiation on the performance of a linear Fresnel concentrating solar collector. They formulated model equations for calculating the effects of the reflection angles of the sun rays incident on the mirrors, as well as the incidence angles of the reflected rays on the collector cover, as a function of the sun position and the geometry of the collector. This study also indicated that in the actual operation conditions, the effect of reflection and the incidence angles in modeling the collector and in calculating the useful thermal power cannot be neglected. Huang [15] investigated the optical performance of a linear Fresnel solar concentrator installed on a solar azimuth tracker. An analytical model based on the reflection distribution and the reflector area was developed for calculating the intercept factor of the concentrator and for analyzing its annual performance. They found that with an optimized design, the annual mean overall efficiency of 61% is possible when the operational temperature of the receiver is 400 °C. They also found that with the azimuth tracker, the cosine factor, intercept factor and the overall efficiency are better than those of the parabolic trough collector, indicating a greater potential for harnessing the solar energy.

This work reviews the optical performance characteristics of a linear Fresnel solar collector highlighting potential areas of possible improvement. The advantages of the linear Fresnel solar collector over the parabolic trough solar collectors are also highlighted. The previous studies on the optical designs and performance simulations studies on linear Fresnel solar concentrators are reviewed to establish the gaps in the literature for further studies that could improve the optical performance of a linear Fresnel solar concentrator.

2. Linear Fresnel Solar Thermal Collector Types

Figure 1 is a representation of a linear Fresnel solar collector system. It has a compound parabolic type receiver cavity and the arrays of linear mirrors strips, which concentrate the solar radiation on a fixed receiver cavity mounted on a linear tower. Each of the mirror elements is tilted such that the incident solar radiation, after reflection from the mirror element, will impinge on the absorber placed along the length of the focal zone of the concentrator [16] and [17]. The mirrors are not completely flat, but have a very small curvature, produced by mechanical bending and they have only one tracking axis. The cavity consists of a second stage concentrator with a single absorber tube held inside the cavity and covered with a transparent glass. The second stage concentrator enlarges the target for the Fresnel reflectors and also provides insulation to the absorber tube [7].

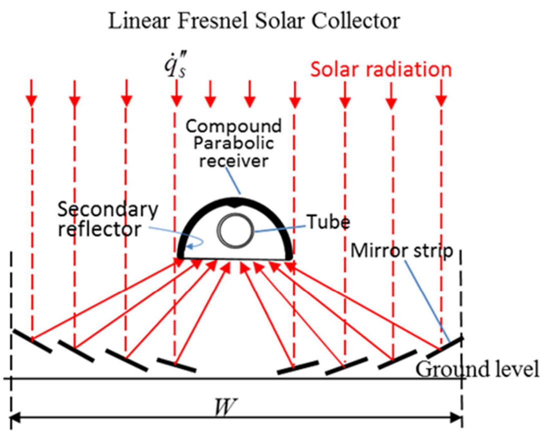

Figure 1. *Linear Fresnel solar collector with a Compound parabolic type receiver cavity.*

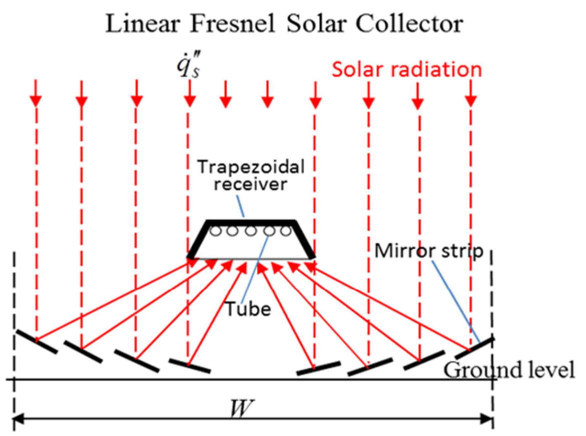

Figure 2. *Linear Fresnel solar collector with a trapezoidal type receiver cavity.*

Figure 2 is another linear Fresnel collector system with a trapezoidal receiver cavity type. The cavity has multiple absorber tubes with diameter smaller than that of the compound parabolic type, mounted inside the cavity and also covered with a transparent glass with air trapped inside the cavity. The back sides of the cavity are covered with insulator to reduce conduction heat loss and the front glass pane to reduce convective heat loss. The cavity also protects the absorber tubes from wind effects, rain and dirt. The trapezoidal receiver cavity is, however preferred [18] to a compound parabolic type, which has a single large diameter absorber tube [7], due to difficulties in generating steam in a horizontal tube. Abbas [6] noted that the variation of heat transfer coefficient when vapour quality changes could generate serious problems on transient regime. Jance [19] found that convective heat transfer in a trapezoidal cavity is small, and that the heat losses from the cavity are predominantly by radiation.

3. Design Parameters for a Linear Fresnel Solar Collector

The major parameters involved in designing a linear Fresnel solar collector are the width of the mirror stripes, width of the complete collector, number of parallel mirror stripes, height of the receiver absorber above the mirror plane, the space between the mirror stripes and the curvature of the mirrors [20]. Dostuçok [21] gave a schematic cross-sectional view of a linear Fresnel solar collector with a cavity absorber. It indicated titled constituent mirror elements of equal width (*W*) and the absorber placed at the height (*f*) above the primary mirror. They characterized each mirror by three parameters - location (Q_n), tilt (θ_n) and shift (S_n). These parameters expressed in Eqs (1) - (3) were obtained from the geometrical optics derived in Singh [22], Mathur [23] and Singh [24]. The reflected rays from the constituent mirrors are concentrated on the flat absorber plate mounted on the focal zone of the collector system.

$$Q_n = Q_{n-1} + W.\cos\theta_{n-1} + S_n \quad (1)$$

$$\theta_n = \frac{1}{2}\tan^{-1}\left[\left\{Q_n + \frac{W}{2}\cos\theta_{n-1}\right\} / \left\{f - \frac{W}{2}\sin\theta_{n-1}\right\}\right] \quad (2)$$

$$S_n = W.\sin\theta_{n-1}.\tan(2\theta_n + \zeta_0) \quad (3)$$

Here, ζ_0 is half of the angle subtended by the sun at any point on the earth (=16°) and n = 1, 2 … m, where m is the total number of mirror elements placed on each half of the reflector. The concentration ratio (C_R) for the collector expressed in Eq. 4 was obtained by summing the local concentration ratio of the mirror elements. Sharma [25], Singh [24], Choudhury and Sehgal [26] derived the Eqs 4 - 8 for determining the local concentration ratio (CI_n) for *n*th mirror element for a linear Fresnel collector with a flat absorber plane as follows:

$$C_R = 2\sum_{n=1}^{n=m} CI_n \quad (4)$$

$$CI_n = W.\cos\theta_n / (L_n + P_n + U_n) \quad (5)$$

$$L_n = \left[W\cos\theta_n.\sec 2\theta_n\right] \quad (6)$$

$$P_n = \left[f.\sec 2\theta \sin\xi\right] / \left[\cos(2\theta_0 - \xi_0)\right] \quad (7)$$

$$U_n = \left[(f - W\sin\theta_n)\sec 2\theta\sin\xi_n\right] / \left[\cos(2\theta_n - \xi_0)\right] \quad (8)$$

Similarly, Sauceda and Velázquez [27] gave the concentration ratio for a linear Fresnel solar collector with a circular absorber tube with the external diameter (D_{ext}) as follows:

$$C_R = \frac{\sum_{n=1}^{n=m} W.\cos\theta_n}{\pi D_{ext}} \quad (9)$$

As earlier stated, the concentration ratio for a linear Fresnel solar collector, which changes along the day, is lower than that of a parabolic trough solar collector [[6] and however, this can be improved through an optimized optical design - mirrors separation, shapes, width and their orientation. In a LFC, the reflector mirrors are usually densely packed in order to possibly improve the concentration factor. Ahmed and Amin [28] explained that the major factor that limits the concentration factor of a LFC is the drift and uncertainty in the direction of the reflected rays, due to long distance between the mirrors and the receiver cavity. The closely packed mirrors to possibly improve the concentration factor, however, result in shadings and blockings of the reflected sun rays.

One major difficulty with the LFC is that avoiding the shadings and blockings of the mirrors lead to increased spacing between reflectors, which in turn lead to large ground utilization relative to the collector area [29, 30]. However, Kalogirou [16] stated that the blocking could be reduced by increasing the height (*f*) of the absorber tower, but this can increase cost. Nixon and Davies [29] carried out cost-exergy optimisation of the mirror element spacing arrangement and operating temperature for a linear Fresnel solar reflector and presented their results in terms of the exergy per total mirror area (W/m^2) and cost per exergy (US \$/W). They applied this method to analyze the cost data of a linear Fresnel reflector in Gujarat, India to maximize the available power output (i.e. exergy) and operational hours whilst minimizing cost. A comparison of this method with the existing design approach indicated that the exergy increased by 9% to 50 W/m^2 with an additional 122 hours of operation per year. A Compact Linear Fresnel Reflector (CLFR) was proposed by Mill and Morrison [31] as a new design configuration of the Fresnel reflector field that could overcome the problem of reflector mirrors spacing and shading. Figure 3 shows a schematic diagram of a LFC field compared to that of a CLFR field in Figure 4 with interleaving of mirrors, based on the rays diagram corresponding to noon conditions [5].

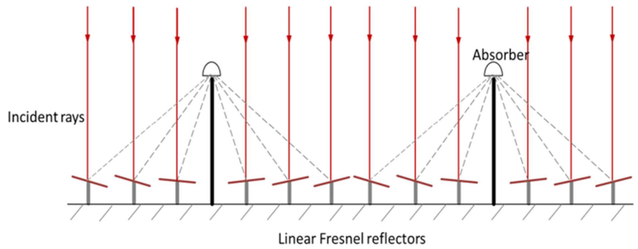

Figure 3. *Linear Fresnel Reflector without interleaving of mirrors.*

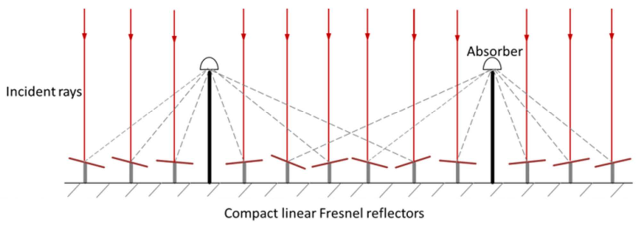

Figure 4. *Compact Linear Fresnel Reflector with interleaving of mirrors.*

In a CLFR, the reflector mirrors are closely parked such that the individual reflectors would have the option of directing reflected solar radiation to at least two absorbers depending on the position of the sun. Mills and Morrison [31] found that the net efficiency of their compact linear Fresnel reflector increased with incidence angle with a maximum at 60^o. A number of studies have been conducted on the optical designs and performance simulations for investigating in details the optical performances of a LFC system for possible improvements.

4. Optical Performance Efficiency of a Linear Fresnel Solar Collector

Thomas and Guven stated that if the optical characteristics of a mirror reflector material are assumed temperature independent, the optical analysis of the collector could be decoupled from the thermal analysis. They concluded that the optical efficiency could be modeled and analyzed independently without the knowledge of the thermal design and vice versa. Thus, they expressed the optical efficiency (η_o) as a function of the parameters in Eq. (10).

$$\eta_o = \rho_\theta (\tau\alpha)_{eff} \gamma_\theta \cos\theta \qquad (10)$$

Eq. (10) indicates that the optical efficiency varied with the angle of incidence (θ) between the aperture surface normal and the incoming radiation. Other parameters in Eq. (10) that influence the optical efficiency include the specular reflectance (ρ_θ) of the reflective surface, effective transmittance-absorptance factor $(\tau\alpha)_{eff}$ and instantaneous intercept factor (ρ_θ). Kalogirou [33] gave that the intercept factor includes the effects of all the optical errors - random errors (apparent changes in sun width and scattering effects due to random slope errors), systematic errors (gross errors in manufacture or operation of the collector) and non-random errors which include the reflector profile errors and misalignment of the receiver with respect to the focal plane. Extensive studies on these errors for the LFC are lacking in the literature. These errors ought to be minimized in order to improve the overall efficiency of the collector. Gharbia [34] compared the optical performance of a LFC and a PTC and they concluded that the optical quality of the LFC is lower due to its higher incidence angle and the cosine factor. They noted that because of this limitation, the LFC technology is still not much applied in the ISCCS or in regenerative Rankine cycles. The simple optical design of a LFC system leads to its lower optical efficiency. Gazzo [35] indicated that its focal line is usually distorted by astigmatism and that a sharp line focus is never formed, even when slightly curved mirrors are used. A second stage concentrator is, thus, needed inside the receiver cavity to refocus the missing rays on the absorber tube. Also, that the sun rays are not hitting the LFC mirror perpendicularly and this leads to more cosine losses than that of PTC. Jannet [36] found that it requires about 33-38% more mirror aperture area for the same solar energy yield compared to the parabolic trough. However, Jance [19] noted that improvement in optical efficiencies of a LFC is presently attracting attention in the areas of structural design and reflector material performance and durability.

5. Optical Design Approach for a Linear Fresnel Solar Collector

He [37] carried out a design method for arranging the mirror elements for a linear Fresnel Reflector Solar Concentrators without outer cover on the absorber receiver using ray tracing method and geometrical analysis for improving the mirror elements efficiency. The design considered mirror elements of equal width and varying width and varying height of absorbers.

Negi *et al.* [38] carried out a design and performance characteristics of a LFC with a flat vertical absorber. Two different design approaches were used. Analytical and ray trace techniques were also used to determine the distribution of the local concentration ratio (LCR) on the surfaces of the absorber for the two designs approaches. They showed that the first design approach with a pre-specified width of the flat vertical absorber offered better performance in terms of concentration on both surfaces of the absorber. But from the practical considerations, it appeared cumbersome since it required mirror elements of varying width, which could be too small to fabricate. The performance of the second design approach did not compare well with that of the first design. But the design still showed other advantages such as ease of fabrication and the ability to give uniform concentration on the absorber surfaces. For the concentration distribution on the absorber surfaces, the ray trace technique results appeared to be more realistic than those obtained from the analytic technique. The first design approach gave a non-uniform distribution of LCR, while the second design approach gave a considerably more uniform distribution of LCR on the absorber surfaces.

Goswami *et al.* [17] also conducted optical design and concentration characteristics of a linear Fresnel reflector solar concentrator with a triangular absorber using the same design approaches described in Negi *et al* [38]. The ray trace and analytical techniques also described in Negi *et al.* [38] were used to investigate the distribution of LCR on the two sides of the triangular absorber. For the first design approach, the analytical technique gave uniform LCR distribution on the absorber surface. The ray trace technique gave a relatively non-uniform LCR on the absorber surface. The peak value of LCR obtained from the analytical technique was lower by about 17%. They found that the ray trace technique appeared to be more realistic when compared to those of the analytical technique. For the second design approach, an analytical technique gave non-uniform distribution of concentration on the absorber surface. The ray trace technique for the second approach gave a considerable reduction in the width of uniformly illuminated region of the absorber. Also, for the second design approach, the peak value of the LCR obtained by using the analytical technique was lower by about 16%. They found that the LFC with a triangular absorber had better performance in terms of uniform concentration on the absorber surface than the LFC with a flat vertical absorber. The LFC design derived from the pre-specified width of the sides of the triangular absorber offered a better performance in terms of peak value of concentration on the absorber surface. The peak value of LCR obtained for the second design was considerably less than that of the first design approach.

Mathur *et al.* [39] worked on the optical design and concentration characteristics of linear reflector solar concentrators for three different absorber configurations-flat horizontal, flat vertical and tubular. They used the second approach in Negi *et al*. [38] and Goswami *et al*. [17] to investigate the three different absorber configurations and found that the differences between values of the tilt and shift of the constituent mirror elements were relatively small. They also used analytical and ray trace techniques in Negi et al. [38] and Goswami *et al*. [17] to investigate the distribution of local concentration ratio (LCR) on the surface of the three absorber configurations. They found that the results for the analytical technique did not match with that of the ray trace technique for both flat horizontal and flat vertical absorber surfaces. This was attributed to the assumption that the solar radiation reflected from any constituent mirror element was distributed uniformly over the width of the image it produced on the absorber surface. They also found that the ray trace technique for both flat horizontal and flat vertical absorber surfaces gave a considerable reduction in the width of the uniformly illuminated region. For the tubular absorber, the analytical technique gave a region with uniform illumination on the geometrical axis of the concentrator. The ray trace technique showed a peak at the central portion of the illuminated circular cross-section and decreased rapidly on both sides. They observed that a considerable portion of the tubular absorber did not receive radiation reflected from the constituent mirror elements. This portion of the absorber could be insulated to reduce thermal losses from the absorber.

Sootha and Negi [40] carried out a comparative study of optical designs and solar flux concentrating characteristics of a linear Fresnel concentrator with tubular absorber. Two different design approaches described in Negi et al. [38] and Goswami *et al*. [17] were compared. In the first approach, the concentrator parameters were generated from a pre-specified size of the absorber, while the widths of the constituent mirror elements were varied. In the second design approach, the concentrator parameters were generated from a pre-specified equal width of the mirror elements. Generalized equations for the design parameters for each design of LFC were derived for the tubular absorber. The ray trace technique described in Negi *et al.* [38] and Goswami *et al*. [17] for the local concentration ratio (LCR) distribution on the surface of tubular absorber was determined for each of the design approach. It was found that the concentration decreases when the diameter of the absorber (in the case of the first design) or the width of the mirror elements (in the case of the second design) increases. They found that a significant portion of the circular cross-section of the absorber was not illuminated from the solar rays reflected from the constituent mirror elements as a result of the plane geometrical configuration of the LFC. This finding is the same as that of Muthar *et al.* [39]. They found that the surface area factor aspect ratio for the two designs of concentrator did not show much variation. This indicated that the cost of the reflectors and, hence, the total cost of the concentrator could be the same for two designs.

6. Optical Performance Simulation of the Linear Fresnel Collector

Barale *et al.* [41] conducted optical performance simulation of a linear Fresnel collector prototype being built in Sicily, to optimize the geometry of the linear Fresnel collector for the FREeSuN project. Ray-tracing for the optical modeling was performed with the Raytrace 3D and Opticad TM software. The model considered all the relevant optical loss mechanisms - reflector surface errors, tracking errors, shading and blocking due to structure and tracked mirrors etc. They found that if the receiver was too far from the primary mirror plane, the contribution of errors would drastically reduce the optical performance. They also found that using uniform mirror curvature (one adapted curvature for all mirrors) would prevent the efficient focalization of all the mirror rows. In contrary to parabolic trough, in LFC systems a 40° shift from the north-south direction of the longitudinal axis did not produce relevant optical losses. They also investigated different secondary receiver designs - vacuum receiver and air receiver using advanced concepts for non-imaging optics. It was revealed that the air receiver tube design has a better annual optical energy gain than the receiver with vacuum-absorber tube, which suffered refraction at glass tube, blocking by receiver box and astigmatism.

Pino *et al.* [42] conducted experimental validation of an optical model a linear Fresnel collector system using the solar cooling plant with an absorption chiller located in the School of Engineering University of Seville, Spain. The two-dimensional optical model was solved using MATLAB. It was found that the tilt angle errors and the measured values from the solar plant were below 0.3^{o} independent of the mirror row. Also, the errors between the optical model results and the measured tendency for inclination of row one mirror for one day operation were below 0.3^{o}. The optical model results for the non-lit pipe and the measured values for the non-lit pipe stretch gave similar results. The model results showed good agreement with the measured values from the plant. They attributed the differences between the model results and measured values from the plant to the following factors - continuous focus and non-focus of mirrors when the maximum output temperature was reached and cleanliness of the elements of the system.

Häberle *et al.* [7] studied the optical performance of the Solarmundo line focusing Fresnel collector using ray tracing. This study performed three-dimensional ray tracing with the OptiCAD program, assumed the divergence of the beam radiation to be homogeneous over a wide angular range to cover most of the circumsolar radiation. The intensity of all the absorbed rays at the absorber tube was 60% for the given parameters and assumptions that the perpendicular incident radiations were absorbed and transformed into heat at the absorber surface. The ray tracing simulations results showed that the intensity was very evenly distributed (between 80% and 100% intensity) in the lower part and very low in the upper part of the tube, thus indicating non-uniform irradiation heat flux on the absorber tube. The absorber of the linear Fresnel collector, which received the incident heat flux from the underneath independent of position of the sun, offered an advantage for operating a stratified two phase flow, where liquid fluid is in lower part of the tube and steam in the upper part.

Abbas *et al.* [6] studied solar radiation concentration features in LFC reflector arrays to characterize the concentration process and to analyze the use of different optical designs. The study found that the concentration factor variation along the day could be minimized with a good optical design- selection of mirrors separation, shapes, width and their orientation. As noted by Mohamed and Amr [28], they found that the main factor that limited the concentration factor of the LFC was the drift and uncertainty on the direction of the reflected rays due to the long distance between the mirrors and the receiver. This was attributed to the divergence of the reflected beam and possible errors on the mirror surface and tracking. They explained out that the concentration factor depended quite a lot on the profile of the mirrors. They also found that the solar field in LFCs was only perpendicular to the impinging radiation when the sun was at its zenith, while parabolic trough concentrator was perpendicular to it at all times. The study analyzed the use of different optical designs for the LFC, including circular-cylindrical and parabolic-cylindrical mirrors with different reference positions. They studied the effect of the sun location on the lateral drift of the reflected beam on the optical performance of a LFC solar field. The studies by Negi *et al.* [38] and Goswami *et al*. [17] neglected the effect of lateral drift of the reflected beam on the optical designs and performance analysis of the LFC reflector they conducted. A new approach to analyze and optimize the performance of Fresnel arrays was proposed and this was based on the newly formulated optical property that could be used to evaluate the drift of the reflected sunbeams from the mirrors as they rotate to follow the sun. They observed that the maximum deviation depends on the width of the mirror and this must be limited for maximum optical efficiency to be achieved. From this an optical design process was suggested to minimize such lateral drifts and to minimize the concentration factor variation along the day. A new mirror layout was defined for keeping a constant value of the radiation impinging onto the receiver from effective sunrise to effective sunset.

Sultana *et al.* [43] conducted Ray trace simulations for a low-cost solar thermal micro-concentrating collector with linear Fresnel reflector system to determine optical efficiency. They used SolTRACE, an optical modeling code developed by National Renewable Energy Laboratory. The total optical performance of the collector was based on the solar power absorbed by the absorber tubes. They considered the cosine losses of direct normal irradiance (DNI) due to the solar transversal and longitudinal incidence angles. They found that as the absorbed power decreased, the efficiency increased from 68% to a peak of 82% at a 60° transverse angle and then decreased to 77% at 75°. The optical losses due to shading, missing and blocking of rays decreased with an increase in the transversal incidence angle to a minimum of 4.9% at 60°, before increasing again. This variations in the net efficiency is similar with the trend found by Haberle *et al.* [7] and for the Solarmundo solar collector system, the peak efficiency occurred at the transverse angle of 70°.

7. Conclusion

This work has reviewed the optical designs and simulation performance studies of a linear Fresnel solar thermal collector highlighting areas of possible improvement. It reviewed experimental and numerical studies on optical performance of a linear Fresnel solar thermal collector system. The optical designs and ray-tracing simulations results indicated non-uniform solar flux distributions on the receiver absorber surface. The concentration factor of a LFC is notably lower compared to that of a PTC and this limitation is still a challenge and poses constraints in deployment of LFC. Improvement in optical efficiencies of a LFC is presently attracting attention in the areas of structural design and reflector material performance and durability. With optimized optical design- selection of mirrors separation, shapes, width and their orientation, the limitations of a LFC can be minimized.

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