A Review on Optimization of Fresnel Collector for Optical, Thermal and Economic Performance

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Abstract

For using the energy coming from the sun effectively we have to use some concentrating mediums to concentrate the solar energy at a certain place. Fresnel collectors are very commonly used type of solar concentrators out of various types of solar concentrators. Many researchers are trying to optimize the performance of Fresnel collectors so that maximum amount of solar power can be used for heating purpose. The optimization of performance of Fresnel collector is vital from industry point of view as it has lower economic cost compared to other concentrating solar power technologies. This paper proposes the research and practical work done on Fresnel concentrator for optimization of its optical, thermal and economic performance

Keywords: Concentrating Solar Power, Fresnel collector, optimization

I. Introduction

Solar energy is very large source of energy and inexhaustible for the coming millions of years. The power of sun obtained by earth is approximately 1.8 x 10^{11} MW. This figure is much more larger than the present energy utilization rate of earth including all the commercial energy. The advantage of using this abundant source is clean unlike fossil fuels and nuclear power that pollute the environment. Solar energy is available free to mankind and it is present almost at each point where humans live.

The main problem associated with the use of solar energy is that it is very dilute source of energy. Even in the hottest regions on earth, solar radiation flux available rarely exist 1 kW/m^2. The total maximum radiation available in some parts of the world along the equator at the best is found to be 7 kW/m^2. Because of this problem, concentrating solar power technologies came to the existence. The concentrating solar technology was developed with the aim to achieve higher temperature of working fluid. Linear Fresnel collector (LFC), Parabolic Trough collector, Sterling engine dish collector, concentrated tower technology are some of major concentrating solar technologies. Out of these, parabolic trough collector technology is majorly used in industries today. LFC technology has a great potential to reduce the cost incurred in Parabolic Trough technology. Hence a large research work is going on LFC technology.

Concentration of solar radiations is achieved using reflecting arrangements of lenses. The optical system then directs the solar radiations to small area of the absorber.

Certain losses occur because of optical system used in concentrating collectors. This losses cause drop in thermal, optical and economic performance of Linear Fresnel Collector. Hence, for optimization of LFC, its thermal, optical and economic performance should be optimized.

II. Literature Review

It is the only quest to increase the temperature of working fluid which has encouraged researchers to take up the study in the direction of use of concentrated solar technology. Study has been conducted to analyze use of various types of concentrated solar technology in the industrial applications. The thermal, optical and economic performance of linear Fresnel collectoris studied and comparative study with other concentrated solar technologies has been conducted by many researchers in recent years.

M. A. Moghiniet. al performed simulation based analysis of linear Fresnel mirror field and receiver to optimize the optical, thermal and economic performance. Basically, their work was focused on generation of low cost solar electricity by maximizing optical and thermal efficiency. The multi tube cavity receiver having constant aperture width was considered. A multi tube trapezoidal cavity was considered as receiver and mirrors were slightly curved. With the help of simulation software the receiver was optimized and and evaluated at different temperatures to assess its performance.

Jinghui Song et. al analyzed the optical losses of mirror field of Fresnel collector mathematically and design parameters were optimized. Various optical losses were obtained and based on that the optical efficiency was found out. The effects of parameters like height of receiver, width of mirror and gap between adjacent mirrors on optical efficiency was analyzed.

Hani Saitet. al analyzed that the Linear Fresnel collectors are the most effective one to reduce the expense of concentrating solar power. Also the performance of linear Fresnel collector was compare with the most extended technology which is parabolic trough collector. The reduced cost was obtained compared to parabolic trough collector in Linear Fresnel collector because of lighter structure.

F. Eddhibi et.al described a new method to design linear Fresnel collector for concentrating solar technology applications. They described the effect of geometry of linear Fresnel collector on the efficiency. The combinations of Monte Carlo methods and ray tracing were used for optical modeling to find effect of geometric parameter variation on solar energy that is collected.

Paola Boito et. al presented the methods for optical optimization of linear Fresnel collector. The position, width and focal length of mirrors were considered. The results showed that properly designed optical optimization lead to the improvement of 12% in performance of Fresnel collectors than that of initial optimization.

Ken Craig et. al presented the optimization study based on simulation process for linear Fresnel collector for trapezoidal multi tube cavity processor. They mainly concentrated on using the maximum daily solar energy (optical optimization) by minimizing the thermal heat loss (thermal optimization) and also the plant cost (economic optimization).

III. Optimization of Optical Performance

For optical analysis the optical losses are calculated mathematically for mirror field of Fresnel collector and design parameters are optimized based on that. Various optical losses are obtained for various parts and from these optical losses the optical efficiency

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is calculated. Also, parameters like height ofreceiver and width of mirror has effects on the optical efficiency.

Certain factors that affect the optical efficiency of collector are incidence angle, shading and blocking, the offset of facula, etc.

The area that is perpendicular to the incident angle is called equivalent area. The equivalent area can be given as,

$$A\_p = L \cdot W \cdot \sum\_(n = 1)^N \cos\theta\_n$$

When the incident angle of light is zero then the energy reaching on mirror has maximum value. But it is not possible that the incident angle is zero and hence the cosine loss is bound to happen.

When mirror's length is smaller than absorber's length, it causes facula which results in off targeting of concentrated light and the offset distance is given by

$$L\_s = f \cdot \tan \theta\_z$$

If the incident angle is too small then shading and blocking can occur. When mirror isn't filled by light it is called shading loss and when back of the mirrors block the light it is called blocking loss.

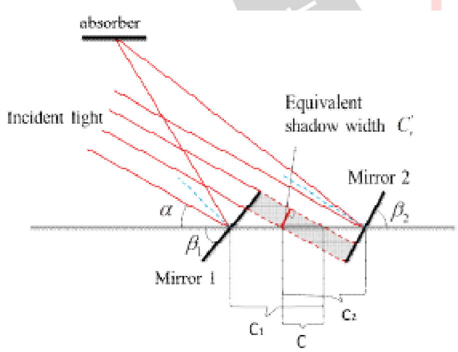

Fig 1. Shading loss

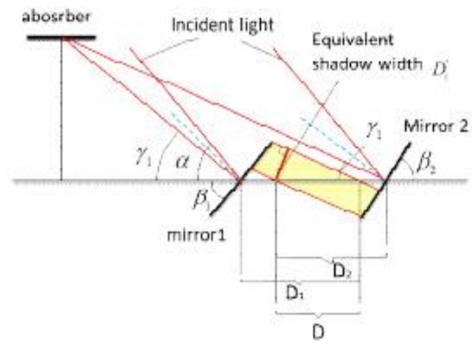

Fig 2. Blocking loss

Hence, for mirror the effective light receiving area is given as

$$A\_u = A\_p - L \cdot \sum\_(i = -n)^n \max\{C\_i, D\_i, 0\}$$

Shadow of absorber projected o mirror can be given by

$$A\_receiver = d/2(1 + \sin\alpha) \cdot L$$

From this, optical efficiency can be calculated as, $\eta\_optical = \eta\_\theta \cdot \eta\_E \cdot \eta\_end \ 〖\cdot \eta〗\_prop \cdot \eta\_track$

Where,

$$\eta\_\theta = A\_p/A$$

$$\eta\_E = A\_u/A\_p$$

$$\eta\_end = 1 - f/L \ (\cos\gamma\_s)/(\tan\alpha\_s)$$

and, $\eta\_prop = \rho\_m \, \tau\_r \, \alpha\_r$

This shows that the most dominant losses are cosine loss and shading blocking loss. But shading blocking loss varies with design parameters like height and width of mirrors. Also the incident angle has effects on total optical efficiency when its value is small and hence performance of collector is best in the noon.

IV. Optimization of Thermal Performance

In case of concentrating solar technologies, the heat is majorly transferred by radiation mode of heat transfer. Hence, it is bound to happen that the major heat loss is also by the

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radiation mechanism. Many numerical and experimental analyses have shown and proved this fact. Hence it is obvious that if radiation heat loss is lowered then automatically the heat loss will be optimized. View area approach can be effectively used for the thermal optimized modeling of collector layout. It is faster approach and perfectly suits for radiation mechanism. Hence, it is convenient for the purpose.

It is a very common assumption for view area approach that if the areas of the absorber tubes which are opposite to mirror are reduced it would directly change the performance by lowering the thermal losses. Hence the view area of absorber tubes to the mirror field should be lowered.

Consider a multi tube cavity which is trapezoidal in shape and the mirrors are slightly parabolic curved. The multi tube cavity is as shown in the figure 3. To confine the view area, the constraint factors are to be defined. Hence, from the left and right corners, the adjacent tube and tube centre distance should be considered. To capture the view area for each individual tube, two central angles ($\alpha_{(ith\ tube)}^{left}$ and $\alpha_{(ith\ tube)}^{right}$) are defined as shown in figure 3.

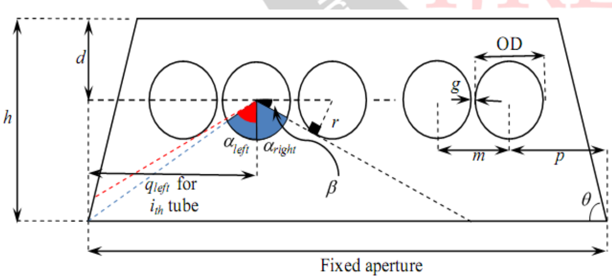

Fig 3.Trapezoidal multi tube cavity

For the i_{th} tube per unit length, the view area is given by,

$$\text{View area}_{(ith\ tube)} = r \times (\alpha_{(ith\ tube)}^{left} + \alpha_{(ith\ tube)}^{right})$$

Where,

$$\alpha_{(ith\ tube)}^{left} = Min\{[\pi/2 - \sin^{-1}(r/m)],\ \tan^{-1}((0.166 + [(i-1) - 0.5(N_t - 1) \times m)/(h - d'))\}$$

And,

$$\alpha_{(ith\ tube)}^{left} = Min\{[\pi/2 - \sin^{-1}(r/m)],\ \tan^{-1}((0.166 - [(i-1) - 0.5(N_t - 1) \times m)/(h - d'))\}$$

Therefore, for tube bundle,

$$view\ area\ of\ tube\ bundle = \sum_{(i=1)}^{(N_t)} \text{view area}_{(ith\ tube)}$$

V. Optimization of economic performance

The actual costing of the linear Fresnel collector plant cannot be determined until the project is commercially completed and published. There are many projects which are still in developing phase all around the world. The levelized electricity cost is affected by the plant cost factor which is given by,

$$\gamma_{(plant\ cost\ factor)} = 1.225 \times [C_m \times N_m + C_e (4 + H) + C_d (N_m - 1)G + C_r] + 3 \times N_m \times (W + G)$$

This means that the reduction in plant cost factor reduces the overall total plant cost.

VI. Conclusion

1) In the present study, basics of optimization techniques for linear Fresnel collector technology as optical, thermal and economic performance are explained on the basis of the work of some previous researchers.

2) The main Focus is given on factors by which optical and thermal losses can be reduced and lower the plant cost
3) Mathematical relations are given for various losses and the cost factor.
4) The relations given are useful for proper designing of linear Fresnel collector plant.

VII. Future scope

Currently the benchmark technology in the field of concentrated solar technology is parabolic trough collector technology. But the cost requirement for this technology is high compared to other technologies. Hence, it is important to develop the Linear Fresnel technology to overcome the high cost problem. The optimized linear Fresnel collector can reach the temperature obtained by parabolic trough collector with low cost. With the use of software this optimization work can be completed in less time and hence simulation tools can be used for the work.

VIII. Nomenclature

A_p	Equivalent area
L	Length of absorber
W	Width of absorber
θ_n	Incident angle
L_s	Offset distance
θ_z	Zenith angle
A_u	Effective light receiving area
d	Diameter of tube cavity
η_θ	Cosine efficiency
η_E	Shading efficiency
η_{end}	End efficiency
ρ_m	Reflectivity of material
τ_r	Tranmittance
α_r	Absorption rate of cavity wall
r	Tube radius
m	Tube pitch
N_t	Number of tubes
h	Cavity depth
d'	Tube bundle offset from top
C_m	Mirror cost
C_e	Elevation cost
C_d	Mirror distance cost
C_r	Receiver cost

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