Design and Analysis of Linear Fresnel Reflector for Water Heating

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Abstract- *This paper presents a new method for the optimisation of the mirror element spacing arrangement and operating temperature of linear Fresnel reflectors (LFR). The specific objective is to maximise available power output (i.e. energy) and operational hours whilst minimising cost. The method is described in detail and compared to an existing design method prominent in the literature. Many applications of thermal energy, both in industrial and power sectors require medium temperatures ranging from 50°C to 70°C. These applications include industrial process heat, refrigeration, air-conditioning and power generation using organic fluids. The flat plate solar collectors are suitable for low temperature applications maximum up to 80oC In this paper efforts are being made to design a rooftop linear Fresnel reflector (LFR) system. This paper discusses the design of a rooftop LFR module that is suitable to meet the medium temperature requirements, easy to produce and install like flat plate collector.*

Keywords: Linear Fresnel Reflector, Collector, Receiver, Absorber tube

1. INTRODUCTION

In recent years, many concentrating collectors have been proposed. There are basically two types of solar collectors, non concentrating or stationary, and concentrating. A non concentrating collector has the same area for intercepting and for absorbing solar radiation, whereas a sun-tracking concentrating solar collector usually has concave reflecting surfaces to intercept and focus the sun's beam radiation to a smaller receiving area. The high temperature concentrating solar thermal systems, like parabolic trough and linear

Fresnel, requires large open area and the system engineering is very complex. Flat-plate collectors are the most common solar collector for solar water-heating systems in homes and solar space heating. These collectors heat liquid or air at temperatures less than 80°C. These types of systems are used only for low temperatures applications like domestic hot water and space heating.

The linear Fresnel concentrators have less thermal efficiency compared to other types of solar concentrators, but the low cost of the LFR may compensate that, providing a solution to the cost problems of solar energy collectors on a large scale. The advantages of Fresnel Linear Concentrations include relatively simple installation and low wind load. It also includes the non-movement of the receiving tube and optimal utilization of available land area. In some stations using Fresnel concentrators, the shaded area under mirrors can be used (e.g. for parking lots) and supply basic needs to rural remote communities. The previous features of the LFR and the low cost of the operation and maintenance (O & m) [1]

Solar reflectors and collectors use a renewable and non- polluting type of energy source. They reflect and collect an energy that is so decentralized that every home can utilize it as desired. The techniques of construction are simple. It involves only the initial capital cost and does not attract any recurrent cost. Under initial review, it was discovered that on an average sunny day including the periods of cloud cover, the reflectors and collectors, collect enough energy from the sun that are equivalent to the energy supplied by conventional energy sources. Finally, its use will eventually reduce the family energy costs by reducing the amount spent on purchase of conventional fuels. Many solar reflectors have already been developed world wide.

The variables affecting reflector and collector efficiency fall into several groups.

1. Operating conditions (Isolation, tracking mode, operating temperature, flow rate, wind speed and other general weather conditions)
2. Properties of materials
3. Receiver type (absorber shape, evacuated or non-evacuated)
4 Concentrator geometry (concentration ratio)
Because operating conditions may vary from installation to installation. [2]

2. WORKING PRINCIPLE

Linear Fresnel reflectors, as shown Fig 1 use long, thin segments of mirrors to focus sunlight onto a fixed absorber located at a common focal point of the reflectors. A secondary concentrator is used to reflect the rays within the accepting angle. This concentrated energy is transferred through the absorber into fluid. Rooftop Linear Fresnel Reflector Solar Concentrator (LFR) is modular in type and can be interconnected number of units depending on the requirement. They can be connected in parallel–series to achieve given temperature and mass flow rate. The rooftop solar concentrating collector for medium temperature applications using linear Fresnel reflecting mirrors are designed. The receiver consists of one copper absorber tubes. The entire optical system is enclosed in a sealed glazed casing.

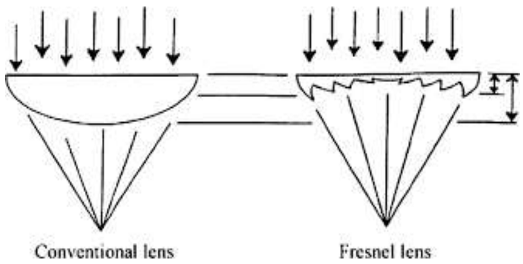

Fig.1 Fresnel lens

The principle of dividing an optical element in segments that have together the same (or a very similar) optical effect like the original optical element can be applied also to mirrors. So, it is possible, for instance, to divide a paraboloid mirror (parabolic dish) into annular segments (forming, thus, a circular Fresnel mirror), which focus the light that arrives in rays parallel to the optical axis onto the focal point of the paraboloid mirror. In an analogous way, a linear Fresnel mirror can be constructed substituting a parabolic trough by linear segments that focus the radiation that arrives in a plane parallel to the symmetry plane of the parabolic trough onto the focal line of the parabolic trough. Concerning the concentration of the radiation in a focal line, a linear Fresnel collector has a similar4 effect like the corresponding parabolic trough, i.e. like a parabolic trough with the same focal length and the same aperture.

3. DESIGN

In Optical design, tilt of each constituent mirror element is very important. Thin segments of mirrors to focus the sunlight onto a fixed absorber located at common focal point of reflector. The tilt (θ) of each mirror element is chosen such that a ray normal to the plane of the aperture of the collector and striking the mirror midpoint after reflecting will reach the focal point. The distance between two adjacent mirror elements should be such that they avoid blocking of radiation reflected from any mirror. Tubular absorber of appropriate size placed in the focal plane of LFRSC would intercept all the solar radiations reflected from the constituent mirror elements. The design parameters are:

- Width (W)
- Shift (S)
- Location (Q)
- Aperture plane (XX')
- Tilt with aperture plane (θ)
- Focal distance (F)
- Aperture diameter (D)
- Absorber outer diameter (do)
- Absorber inner diameter (di)
- Sun subtends angle (ξo)

The absorber along with the secondary concentrator will cast a shadow on the aperture plane of the concentrator and hence no mirror element is placed underneath the absorber. The radius of the tubular absorber is taken to be equal to the length of the largest perpendicular dropped from point F on the reflector rays. While initiating the design of LFRSC with the tubular absorber. The first approximation is taken as the radius of tubular absorber may be taken equal to the half of the width of the mirror element [1] Hence to begin with the first mirror is placed at a distance $W/2+f \tan(\xi_0)$ from the centre of aperture plane. The value of the R should be less than the one half of the width of the mirror. Therefore shading will not be occurred. Then the location of the first mirror element Q1 as $Q_1 = R + f \tan\xi_0$

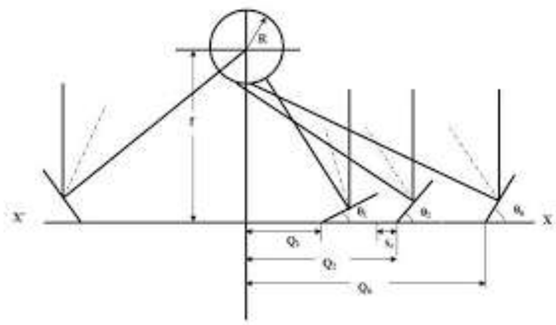

Fig 2: Tubular Absorber

we have to introduce certain space between the first and second mirror. So this is called Shift associated with the second mirror. The shift of the second mirror is $S_2 = W\sin\theta_1 \tan(2\theta_2+\xi_0)$ The location of the second mirror element and its tilt with aperture plane (XX') is $Q_2 = Q_1 + W\cos\theta_1 + S_2$ On the basis of similar geometrical considerations generalized expressions for the Shift(S) location With $\theta_1=0$, $S_1=0$, and $Q_1 = W/2+f \tan\xi_0$ as initial values for iteration and n varies from 1,2,3………K, K being the total mirror elements placed on either half of the concentrators Considering the values

W = 50mm d = 25mm F = 300mm ξo = 16'= 0.00465421 radians Q1 = W/2+f tanξ0 Then Q1 = 26.39mm

By considering the all above values the values of tilt, shift and location can be calculated by solving the above equations for each mirror element using iteration method. The values are tabulated as follows.

Table 1: Reflector Location Parameters

Sr.no	Location (mm)	Shift (mm)	Tilt (deg.)
1.	26.39	0	4.9
2.	131.46	1.50	9.55
3.	188.83	4.44	13.95

Based on the above values, the 3 mirrors are placed symmetrically for each absorber. For complete module with 1 absorbers, 6 mirror elements are placed at proper distances. [1]

4. THERMAL ANALYSIS

A steady state thermal analysis of the collector at various solar beam radiation input has been done to estimate the performance of the collector. The usable energy gain of absorber is calculated after deducting the heat losses from absorber. The heat losses are:

1. Radiation Loss from absorber.

2. Convection loss within the space of the collector, i.e. the space between the absorber and reflecting mirror enclosed within the glass covers.

The mode of heat loss is natural convection due to the temperature gradient present in the enclosed space.

3. Convection loss from glass covers to the ambient.

CONDUCTION: For the non-uniform flux distribution of the radiation on the absorber's surface, substantial temperature gradients may exist across the absorber's surface and due to high surface temperature of the absorber, the conduction losses through the support structure may also be significant

CONVECTION: Since the focal point of Fresnel reflectors are located outside the reflectors, placing the absorber in an open sunny location usually exposes it to cooling breeze: This increases the convective losses through forced convection by wind. The analysis of this loss will be complex since the wind speed changes from time to time. To reduce loss of heat from the absorber by forced convection.This will now reduce the analysis to free convection by the air in the gap between the absorber and casing.

RADIATION: Solar radiation arrives on the earth's surface at a maximum flux density of about 1 kW/m2 in a wave length band between 0.3 and 2.5m.

Radiation losses are to the sky and or the environmental. Solar collectors absorb radiation at wavelengths around 0.5m and emit radiation at wavelengths around 10m [2]

5. ASSUMPTIONS

Some assumptions were taken into consideration to increase the simplicity of the model and analysis. These assumptions were as follows:

1. The steady state condition was assumed for a small period of the sun movement.
2. The absorber tube and the glass cover temperature were assumed to be uniform through the small segment.
3. The temperature variant through the segment thickness of the copper and mirror is neglected (one- dimension)
4. The properties of the copper, glass, and fluid are functioned in their temperature.
5. The effective focal length was considered for all mirror rows instead of a separate focal length for each row.
6. The flow inside the absorber tube is fully developed [3]

6. RESULT

Important parameters in the design of the primary collectors are the width of the stripes, the width of the complete collector, the number of parallel mirror stripes, the height of the absorber above the primary mirror plane, the space between the mirror stripes and the curvature of the mirrors. For all of these parameters an optimal measure has to be found:

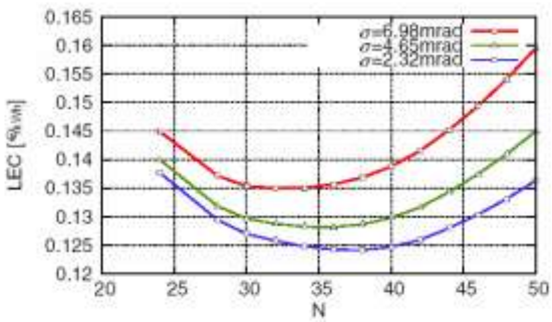

Fig.3: Dependency of the levelized electricity costs on the number of primary mirror lines.

- The width of the individual mirror stripes should not be too narrow because this would mean that for the same aperture area a very high number of mirror stripes would be needed (with a corresponding more complex space frame structure and tracking mechanism). On the other hand, they should not be too broad because this would reduce the effectiveness of the operation principle of the Fresnel mirror type

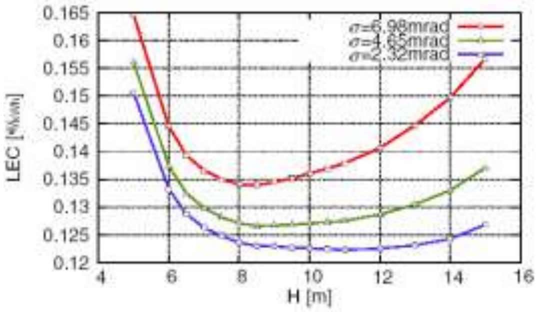

Fig.4: Dependency of the levelized electricity costs on the height of the absorber tube above the primary mirror plane.

-The optimal height may be larger for systems with a higher optical accurateness. At very small heights, the levelized electricity costs are less dependent on the reflection accuracy because of the shorter way of the reflected light from the mirrors to the receiver. Blocking and shading among the different mirror rows.

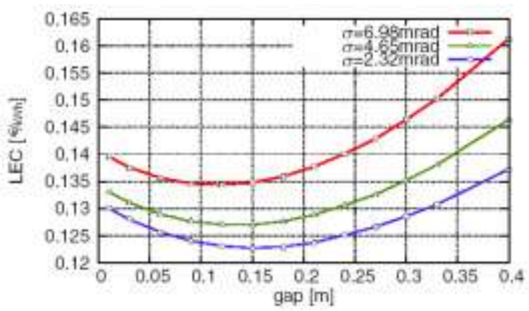

Fig.5: Dependency of the levelized electricity costs on the gaps between the mirror lines

-The gaps between the mirror rows should not be too big. Large gaps imply a large collector width with distant mirrors without aperture area gains. On the other hand, the gaps should not be too small because small gaps imply higher shading and blocking between the mirror rows

Performance calculations :

<u>*Solar water heater efficiency*</u> :

Efficiency of the integrated solar water heater is defined as a ratio of amount of heat stored in the tank till evening to the total solar input received by the collector for the same period of time *i.e.*

$$\eta_{overall} = \frac{m\, s \times (T_f - T_a)}{I\, A_a\, \Delta t}$$

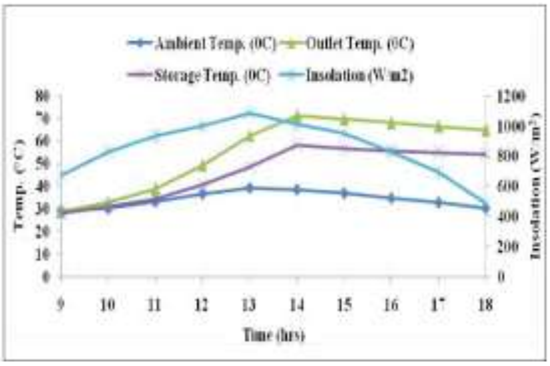

Fig.6 Evaluation Of Fresnel Lens

Table 2 : Performance of Fresnel reflector under full load

Time(hrs)	Amb. Temp. (°C)	Outlet Temp. (°C)	Storage Temp.(°C)
9:00	29.16	28.88	28.24
10:00	30.22	33.12	31.38
11:00	33.28	39.1	34.52
12:00	36.78	49.54	40.82
13:00	39.4	62.64	48.66
14:00	38.64	71.42	58.3
15:00	37	69.92	56.8
16:00	34.8	68.34	55.86
17:00	32.88	66.66	55.14
18:00	30.46	65.12	54.26

7. DISCUSSION

A critical analysis of the results derived with the copper tube showed that the reflector was able to raise the temperature of the disc to an average temperature of 70oC. It was also able to heat 3 Ltr. of water within an average time of 30minutes for tests carried out between 10.00 am and 1.00 pm. For tests carried out between 12 pm and 3 pm an average water boiling time of 24-28 minutes were recorded. The difference in the boiling time could be traced to the fact that solar intensity is normally higher during the afternoons than in the mornings. This therefore shows that the temperature generated with the Fresnel reflector is directly related to the weather condition of the time and day of testing.

8. FURTHER WORKS

Since the performance of the reflector is strictly connected to the weather more efficient reflectors that can produce higher temperature should be developed and used. The fragile mirrors used as reflectors should be replaced with developed flat sheets electroplated with shinning surfaces. Automatic tracking mechanism should also be developed and incorporated to make the tracking less labour intensive.

9. CONCLUSION

The water is heated by the Reflector and the pump circulates water in the setup. There is gradual increase in temperature of water in the setup which is indicated on the temperature sensor. There is heat transfer between the system and the surrounding by natural convection. When the reflected is switched on, there is forced convection between system and the surrounding i.e. there is increased heat transfer rate. The mirror of the setup also play an important role to increase the heat transfer rate of the setup. The coolant flows from the inlet to the outlet through tubes mounted in a parallel arrangement to reflector. The pipe conduct the heat from the tubes and transfer it to the water flowing through the setup. If the fluid flows very smoothly through the tubes, only the fluid actually touching the tubes would be hot directly. The amount of heat transferred to the tubes from the fluid running through them depends on the reflection of mirror and tube and the fluid touching it. So if the fluid that is in contact with the tube gets hot quickly, mores heat will be transferred. By creating turbulence inside the tube, all of the fluid mixes together, keeping the temperature of the fluid touching the tubes up so that more heat can be extracted, and all of the fluid inside the tube is used effectively. The inlet and outlet temperature, water inlet and outlet temperature are observed and calculations are carried out.

10. REFERENCES

[1]K. Gouthamraj, K. Jamuna Rani, G. Satyanarayana Mechanical Engineering Department,K L University, Guntur, Design and Analysis of Rooftop Linear Fresnel Reflector Solar Concentrator, Volume 2, Issue 11, May 2013

[2] Manukaji John, Development of a Solar Fresnel Reflector and Its Tracking Stand Using Local Material, ISSN : 2248-9622, Vol. 5, Issue 1(Part 5), January 2015, pp.22-30

[3] Mohamed H. Ahmed, Performance Analysis of the Solar Linear Fresnel Reflector, Volume: 06 Issue: 01 | Jan 2019

[4]P.M Kapurkar And A.K. Kurchania. Performance Evalution Of Fresnel Lens Concentrated Solar Water Heater Cum Distillation Unit. International Journal Of Agricultural Engineering (IJAE) Volume 6|Issue 1| April 2013

[5] Cesare Silvi , The Pioneering Work On Linear Fresnel Reflector Concentrators (Lfcs) In Italy. Italian Group For The History Of Solar Energy(GSES) .

[6] Mohamed Salah Mahmoud, Utilization Of Fresnel Lens Solar Collector In Water Heating For Desalination By Humidification Dehumidification Process.Fifteenth International Water Techonology Conference (IWTC)-15 2011.

[7] Nilesh Ramesh Patil, Design And Optimization Of Solar Water Heating System By Using Fresnel Lens With 2-Axis Tracking, International Journal Of Automotive And Mechanical Engineering, September 2014.