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Linear Fresnel mirror solar concentrator with tracking

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Abstract

Solar energy is the most abundant, widely distributed and clean renewable energy resource. Since the insolation intensity is only in the range of 0.5 - 1.0 kW/m^2, solar concentrators are required for attaining temperatures appropriate for medium and high temperature applications. The concentrated energy is transferred through an absorber to a thermal fluid such as air, water or other fluids for various uses. This paper describes design and development of a 'Linear Fresnel Mirror Solar Concentrator' (LFMSC) using long thin strips of mirrors to focus sunlight on to a fixed receiver located at a common focal line. Our LFMSC system comprises a reflector (concentrator), receiver (target) and an innovative solar tracking mechanism. Reflectors are mirror strips, mounted on tubes which are fixed to a base frame. The tubes can be rotated to align the strips to focus solar radiation on the receiver (target). The latter comprises a coated tube carrying water and covered by a glass plate. This is mounted at an elevation of few meters above the horizontal, parallel to the plane of the mirrors. The reflector is oriented along north-south axis. The most difficult task is tracking. This is achieved by single axis tracking using a four bar link mechanism. Thus tracking has been made simple and easy to operate. The LFMSC setup is used for generating steam for a variety of applications.

Keywords: linear fresnel mirror concentrator; line focusing.

Nomenclature

A_g	total ground area covered by the reflector
A_m	total mirror area
B	width of the mirror strip
I_b	total beam radiation
L	length of mirror strip
M_s	mass flow rate in the receiver
Q_a	energy absorbed by the receiver
Q_s	heat absorbed by the fluid in the receiver
ΔT	change in temperature
Greek symbols	
ϕ	fraction of ground covered by the mirrors
α	absorbance of the receiver
η_o	fraction of solar radiation focused on to the receiver

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1. Introduction

Though solar energy is widely distributed, it is dispersed and available only at the rate of 500-1000 W/m^2. Hence solar thermal concentrating collectors are required for capturing and directing the energy to a target for producing medium and high temperatures.

Solar collectors such as flat plate collectors are non-concentrating type which typically heat the target only up to 70 º C and are hence useful for only low temperature applications. By using a concentrating solar collector the sun's rays can be focused on a receiver to raise the temperature of the fluid flowing inside the receiver. Among concentrating collectors currently linear focusing cylindrical collectors and point focusing paraboloid collectors are quite popular [1].

Due to the ease of fabrication and handling, interest has been evoked on developing Linear Fresnel Mirror Solar Concentrator (LFMSC) [2-3]. In this paper we present our work on the design and development of LFMSC with a tracking device for small scale applications, especially for raising steam. The system comprises a Reflector (Concentrator), Receiver (Target) and Solar Tracking System which uses Four Bar Link Mechanism [4-5].

2. LFMSC design and fabrication

2.1. Reflector

The Linear Fresnel concentrator mirror reflector consists of a large number of long, narrow, flat mirrors strips mounted on tubes which are placed on a flat base frame. When the sun rays fall on Fresnel mirror strip they get reflected from the mirror to the receiver. The individual mirrors are oriented in such a manner that axially incident parallel rays of light intercepted by the concentrator are reflected to a common line focus on the receiver. The Fresnel reflector is shown schematically in Fig-1.

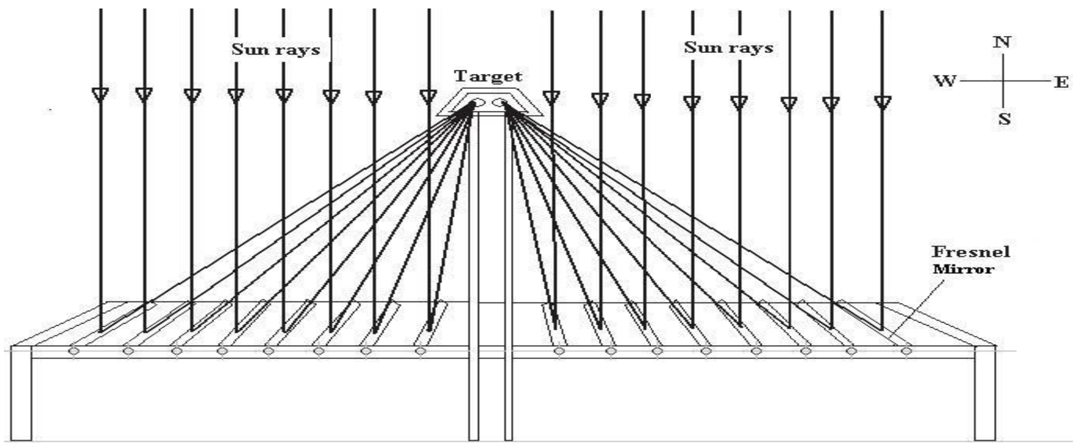

Fig. 1. Schematic diagram showing sun rays reflected to the Receiver by the Reflector.

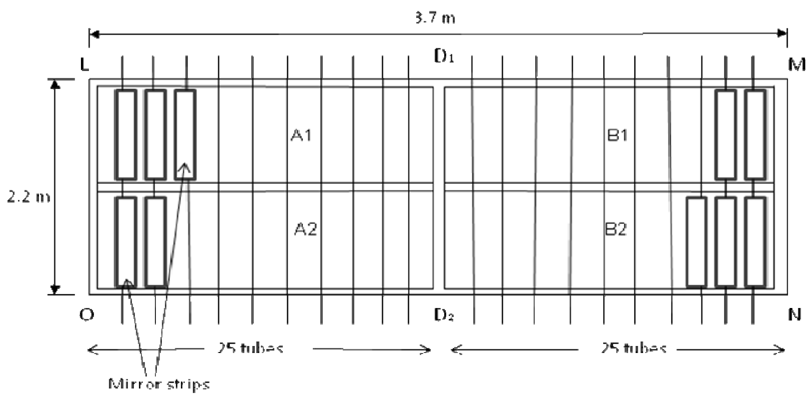

Fig. 2. Top view of Reflector

For each individual mirror the three specifying parameters, namely the clearance, tilt and width, were determined such that the concentrated radiation field produced is within the pre-specified location on the receiver giving a high concentration factor. In the experimental setup as shown in Fig. 2 the base frame LMNO is divided into two sections (A and B) in the middle by a support (divider D1-D2). 50 tubes of 2.2 m length were supported on the base frame through the carefully aligned drilled holes. Each section of the reflector is divided into two parts A1-A2 and B1-B2 as shown schematically. There are 25 mirror strips of 1 m length and width of 0.05 m, mounted on the tubes in each part. Thus a total number of 50 mirror strips are mounted on 25 tubes in section A and the same number in section B making a total of 100 mirror strips in the reflector.

2.2. Receiver (Target)

The receiver as shown in Fig. 3 consists of a pipe, which is folded and housed within a semi cylindrical (trapezoidal) outer casing with insulating packing of glass wool in the space between. To minimize radiation and convection losses it is covered by a glass plate at the bottom. The receiver is mounted at an elevation of few meters above the horizontal surface and parallel to the plane of the mirrors. It can be raised using pulleys and moved on rollers for shifting. Water as thermal fluid, enters from the inlet of the pipe which is fixed at the focal line of the reflector. It gets converted to steam by the time it reaches the outlet. A steam separator may be placed at the outlet to collect the steam and bypass the water back into the inlet loop.

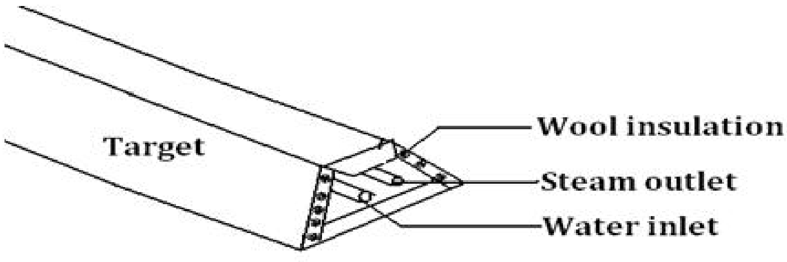

Fig. 3. Target with Internal parts

2.3. Tracking mechanism

The orientation for the reflector setup has been chosen to be along the Horizontal North South axis rather than the polar axis. The latitude of Delhi being 30° and India being in the tropical zone and sufficiently close to the equator, we do not require polar configuration with declination angle, which is more advantageous farther away from the equator. Tracking was achieved by a four bar link mechanism in which the rotational motion provided to one tube gets transmitted to others also. In this way we can get equal deflection of all the tubes, making tracking easy. The tracking system shown in Fig. 4 uses the concept of parallelogram linkage as shown in Fig 5, which is a double crank mechanism. The motion transmitted to a single tube by a gear mechanism is transmitted equally to all the other tubes. The gears are rotated at the rate of 15^0 per hour by a small motor.

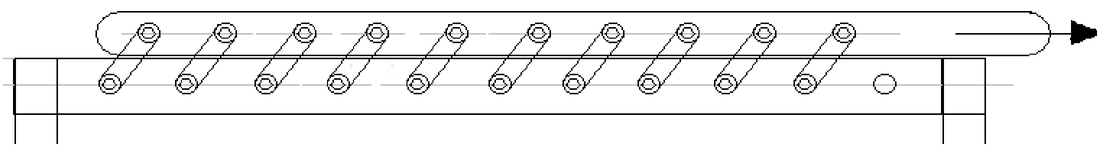

Fig. 4. Tube and Link Mechanism

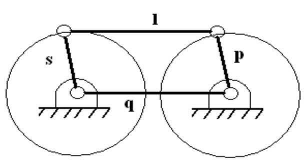

Fig. 5. Parallelogram Linkage between Tubes (s + l = p + q)

2.4 Steam output estimation

The mirror strips in the reflector system are to be laid such that both in winter season when sun is low and summer season, when sun is high, there is no shade of one mirror on the other mirror. Therefore the mirrors cover only a fraction of ground (ϕ), which is calculated as

$$\phi = \frac{A_m}{A_g} \quad (1)$$

where, and A_m = (N x a_m) is the total mirror area, N being the number of mirrors, and a_m the area of single mirror strip. A_g is the total ground area covered by the reflector.
The energy absorbed by the receiver is given by the equation

$$Q_a = I_b \times A_m \times \eta_0 \times \alpha \quad (2)$$

where, I_b is the total beam radiation on Am and η_o is the fraction of solar radiation focused on to the receiver, and α is the absorbance (The ratio of absorbed to incident radiation) of the receiver.

3. Experimental model at IIT Delhi

In the current setup the number of mirror strips (N) are 100 (50 each side) of length (L) 1 m, width (B) 0.05 m, and thickness (T) 0.003 m.

Clearance (C) of 0.02 m is kept between mirrors to avoid blocking.

Thus the total reflector area (N xA_m) = (100×0.05×1) = 5 m^2 for 100 mirrors

Total ground area (A_g) covered is (100× (0.05+0.02) ×1) = 7 m^2

Fraction of ground covered $\phi = \frac{N \times A_m}{A_g} = \frac{5}{7} = 0.714$

Total energy absorbed by the receiver, Q_a is calculated by using Eqn. (2)

Solar radiation flux or the beam radiation available (I_b) is taken as, I_b = 700 W/m^2

Putting the values of A_m = 5 m^2, ηo x α = 0.5 in Eqn. (2)

Total energy absorbed Q_a = 1759 Watt (J/s) = 6300 KJ/hr

Q_s, the heat absorbed by the fluid in the receiver is given by

$$Q_s = M_s \text{ x } Cp \text{ x } \Delta T + M_s \text{ x } L = M_s \text{ x } [Cp\, \Delta T + L] \quad (3)$$

Where, M_s is the mass flow rate of water at inlet which is assumed to be fully converted to steam at outlet, Cp the specific heat of water, ΔT the temperature difference, and L the latent heat of vaporization of steam.

M_s can be calculated for different situations, by balancing the heat supplied to heat absorbed ($Q_a = Q_s$),

and putting the respective values of Cp = 4.178 KJ/Kg-k, L = 2257KJ/Kg and ΔT in Eqn. (2)

For example if steam is produced at atmospheric pressure from water at 30^{0}C, ΔT = 100 – 30 = 70,

M_s works out to be ≈2.5 Kg/hr

If the steam is needed above atmospheric pressure (say at 1.5 bar), ΔT = 120 – 30 = 90 as boiling point at 1.5 bar is approximately 120 ^{0}C. In this case M_s reduced to 2.4 Kg/hr

In case larger quantities of M_s is needed, a setup with a larger reflector area A_m has to be taken. In another set of experiments a system with A_m = 13 m^2 was setup. In this case for steam production M_s at 1.5 bar (i.e. at 120^{0}C) comes out to be 6.3 kg/hr.

Photographs of the experimental system fabricated are shown in Fig. 6(a-c).

Photographs of the experimental system fabricated are shown in Fig. 6(a-c).

(a) (b) (c)

Fig. 6. (a) fresnel concentrator setup, (b) another view of setup with tracking timer, (c) Tracking motor with gear box and linkage mechanism

4. Conclusion

Linear Fresnel Mirror Solar Concentrator system with mechanical tracking device was designed and fabricated. Four bar mechanism used here in is an innovation which makes the handling and operation facile. In this modular system using mirror strips as reflector the solar radiation is concentrated on the receiver at the focal line. The absorbed energy is carried by water as thermal the fluid to raise steam at desired pressure for small scale applications.

With a reflector area of 5 m^2, 2.4 kg/hr steam can be produced at 1.5 bar pressure, and with a reflector area of 13 m^2, 6.3 kg/hr steam can be produced at 1.5 bar.

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