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Integrated Biomass and Solar Thermal Power Plant - A Case Study

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Abstract— Renewable energy technologies are clean and meet the energy demand which is not met by conventional sources of energy technologies, The cost of Linear Fresnel Reflector (LFR) technology is low compared to other solar concentrating collectors and suitable for medium temperature heat recovery. The work focuses on experimental development and performance evaluation of LFR with a single axis tracking mode and integration of it with biomass power plant. In LFR collector, the sunlight is concentrated on a fixed absorber tube to heat the working fluid which passes through the tube and the heated working fluid is used for thermal applications. Six number of thin flat plane reflective mirrors with high reflectivity have been used to reflect the solar radiation on a focal line. There are three round copper tubes used as fixed receiver tubes placed at the focal line to absorb the concentrated heat. Although the current experimental model is small, it will bring a breakthrough of commercial solar energy concentration application technology in the near future, because of its low cost compared to parabolic trough collector. The thermal performance of the LFR solar device is studied experimentally during peak sunny hours. By integrating this technology with biomass power plant is attractive for their potential to increase power output, decrease dependence on Biomass fuels and to reduce greenhouse gases. The main objective of this work is to find the efficiency of LFR at VIT University, Vellore conditions. This work also extended to develop a biomass power plant with the integration of solar reflectors.

Index Terms— Biomass combustion, Biomass power plant, Concentrator devices, Integrated energy systems, linear fresnel reflectors, Renewable energy, solar thermal energy.

1 Introduction

1.1 Linear Fresnel Reflectors

Linear fresnel reflectors consists of long flat mirrors fixed horizontally on base [1]. Each mirror is tilted at an angle so that all incident sun rays falling on mirrors are reflected to a same focus. The absorber is placed on the focus so that the concentrated radiation is absorbed by the absorber. The absorber is nothing but a series of tubes or tubes which contains a heat transfer fluid. Absorber plays a very important role in the solar concentrating device for the collection of solar energy. In the solar collectors, Heat loss from the absorber occurs through convection and conduction and radiation modes [2], [3], [4], [5].

The solar collectors get heated up due to the incident radiation and then it emits radiation. Due to this radiation there will be heat loss from the absorber tube by which there will be decrease in thermal efficiency of the collector. Heat losses from the absorber should be less, to get maximum efficiency. The absorber should be a high thermal conductive material so that the radiation loss will be decreased. The absorber covered with glass cover to reduce the thermal losses. The non-evacuated solar absorber painted with ordinary black paint and covered with plane glass, yielded poor performance [6],[7]. Sharma et al found maximum convective heat transfer in the receiver tube when fluid flow was turbulent. Thermal performance of the linear fresnel concentrator was studied with a fixed concentration ratio. Linear fresnel reflector devices [8] have many advantages when compared with parabolic trough collectors, (i) it is useful for medium temperature range (100–250°C) applications [9] (ii) it is designed with linear flat mirrors and constituent materials for its fabrication are available in the market; (iii) the linear shape and the distances between the adjacent flat mirrors result in very less wind loading on the reflectors. So, it can be mounted on simple cost-effective supporting structure.

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1.2 Biomass

The potential for biomass boilers in India is vast with over 370 million tons of biomass being produced every year. Biomass is available from agricultural wastes, direct harvesting and as a by-product from industries such as rice mills, sugar mills and saw mills. However, due to problems with infrastructure and the seasonal variability of biomass in India, consumers are struggling to obtain a consistent fuel supply. Furthermore, while biomass is still competitive, prices have increased considerably in recent years [10].

Hybridization of solar thermal with biomass combines two energy sources that complement each other, both seasonally and diurnally, to overcome their individual drawbacks [11]. During the day the sun's rays can be harnessed by solar collectors and biomass feedstock can be burnt as a supplementary fuel to achieve constant base load operation. CSP plants benefit from hybridization or effective energy storage due to the variable nature of solar energy, particularly in India's monsoon season. Constant base load or full load plants are typically implemented as plant efficiency is maximized and unit cost of energy is minimized. However, solar energy could be used to increase plant output during the day [12]. In comparison to a biomass-only system, solar hybridization reduces biomass demand, thus improving energy security and decreasing land required for farming and storage [13].

2. DESIGN CONSIDERATION FOR LINEAR FRESNEL REFLECTING CONCENTRATOR

The linear fresnel reflectors have mainly two elements: (i) Reflectors, (ii) Absorber. Fig. 1.Shows the schematic of linear fresnel reflecting concentrator with absorber Some assumptions are made to design the linear fresnel rejecting solar concentrator were: (i) the reflectors are perfectly tracked according movement of the sun from East to West, (ii) the mirror elements are capable of reflecting light, every mirror element were considered with equal width (W) . The tilt of each mirror element was adjusted so that the incident light rays to the aperture area [16], reached the focus point 'F' after one reflection. A distance (called shift) is maintained between adjacent mirrors so that a mirror shadow will not fall on the other [17].

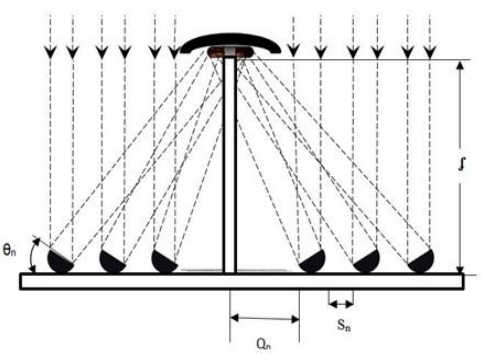

Fig. 1. Schematic diagram of linear fresnel reflectors with absorber

Every mirror is distinguished by three parameters: tilt (θn), shift (Sn) and location (Qn), as shown in Fig.1.

3. EXPERIMENTALSET-UP

The schematic diagram of experimental set up is shown in Fig. 2. It consisted of one tank, absorber set up, reflector set up, flow regulator, pump, thermocouples, etc. The tank is filled with water. The absorber set up consists of three copper pipes which are connected in series with L-bends. The reflectors set up consist of 6 linear reflectors which are placed in parallel. The water tank was kept at a position and connected to absorber set up. The water in the tank was passed through the absorber at a desired flow rate with help of pump. The absorber pipe was connected with tank by a tube. A flow regulator valve was fitted to control the water flow through the absorber pipe. A small pump (50 W capacity) was used to pump from water tank to outlet valve. Thermal performance of three set of similar absorbers with round pipe for linear fresnel solar concentrating collector were studied in the laboratory conditions. The details of the trapezoidal cavity absorbers are given below. Schematic diagram of experimental set up of linear fresnel reflectors is shown in Fig. 2. Absorber pipe was made of a set of three copper round tubes (outer diameter: 12.7 mm, thickness: 1.5 mm and length: 1000 mm).

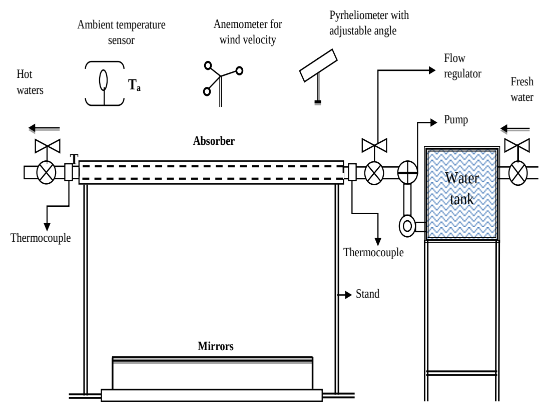

Fig. 2. Schematic diagram of experimental set-up of linear Fresnel reflectors with absorber for water heating test

Overall heat loss coefficient of the absorber (UL) was studied in the experiment. Observations were taken at different fluid temperatures on steady state condition. The average of the inlet and outlet fluid temperatures is estimated as absorber temperatures. The average air flow rate at the bottom of the absorber was measured by anemometer it was on an average of 2 m/s during the study.

4. TEST PROCEDURE

4.1. Thermal Efficiency of Reflector - Absorber System

The linear reflecting solar device with absorber was tested outdoors at VIT University, Vellore (12.980 N and 79.1330 E). The reflectors were arranged in North – South directions horizontal and East – West sun tracking Fig 3 shows the fabricated linear fresnel reflector device and absorber. The thermal efficiency test for reflector absorber system was conducted by maintaining the same mass flow rate of the heat transfer fluid (water) flowing through the absorber pipe with the help of flow regulator. A record of inlet (T_i), outlet (T_o) fluid temperatures, ambient temperature (T_a), solar beam intensity (I_b) at several intervals of time on the absorber and the mass flow rate of the fluid is made.

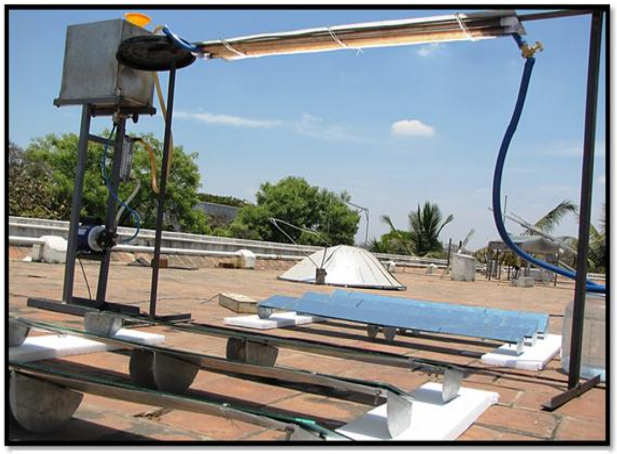

Fig. 3. The fabricated Linear fresnel reflector device and absorber

Thermal efficiency (η_{th}) is calculated from following formula:-

$$\eta_{th} = \frac{mC_p(T_o - T_i)}{I_b \times A_a} \times 100 \qquad (1)$$

Where m and Cp are the mass flow rate and the specific area of the aperture of the reflector, and T_i and T_0 are the inlet and outlet water temperatures respectively. Calibrated thermocouples insulated which were used for measuring the temperature of water at the inlet and outlet of the absorber. These thermocouples were connected to a digital thermometer with display to record their outputs. Pyrheliometer is connected to a muiltmeter for recording beam radiation [18]. Pyrheliometer is calibrated according to sun position before taking the readings. Table 1. Shows the tabulated values.

5. WORKING OF INTEGRATED BIOMASS AND SOLAR POWER PLANT

The agricultural waste such as Rice husk is transported to the power plant for storage .it is then supplied to fuel handing system where it is crushed into small pieces by shedders. The crushed fuel is then fed into the boiler through belt and screw conveyers [19] .The paddy husk is temporarily stored in the bunker though belt conveyers

5.1 Biomass power plant

In the boiler the fuel is burned and the water from steam drum is converted in to high pressure steam which is further superheated in primary and secondary super heater [20] .The super-heated steam is passed through the steam turbine at 485^0C and 61 Kg/cm$_2$ thus the turbine converts heat energy in to mechanical energy and then by generator the electricity is generated at 4Mwh. Fig. 4. Schematic diagram of 4.5 MW biomass power plant.

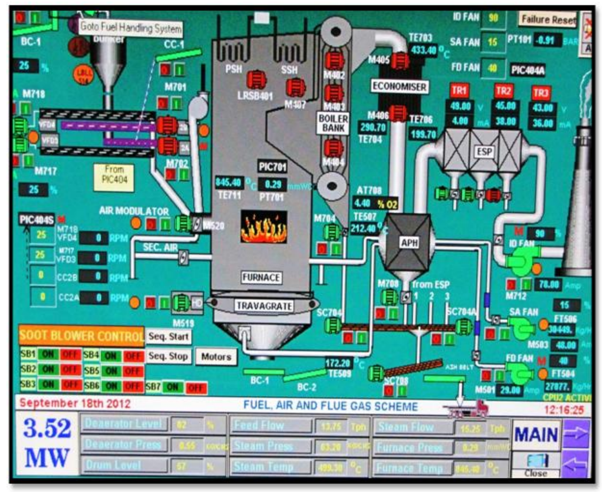

Fig. 4. Schematic diagram of 4.5 MW biomass power plant

The pressure of steam decreases and its volume increases it is then passes out from steam turbine in to the condenser where the condensate is produced the condensate is extracted by Condensate Extraction Pump (CEP) and passed through ejector. The water required for steam generation is supplied to deaerator from ejector. The excess water required for steam generation is supplied from water treatment plant to deaerator to maintain the water level and it is maintained at above 100^0C to remove the air from the water, then it is passes through economiser by Boiler Feed pump (BFP) to increases the temperature of steam .The steam from economiser is passed through evaporator by steam drum and mud drum. The steam in the condenser is cooled by supplied cooled water from the cooling tower. In condenser the cooled water is further supplied cooled water circulate with the help of pump which condenses the large pressure wet steam.

5.2 Integration of LFR in biomass power plant

As show in the Figure 5 the LFR is parallel integrated in the biomass power plant .The water from deaerator is splitted after BFP to LFR system where the water is heated by solar energy as shown in the LFR experimentation, after that the heated water is joined at super heater and the cycle continues as shown in the fig. 5.

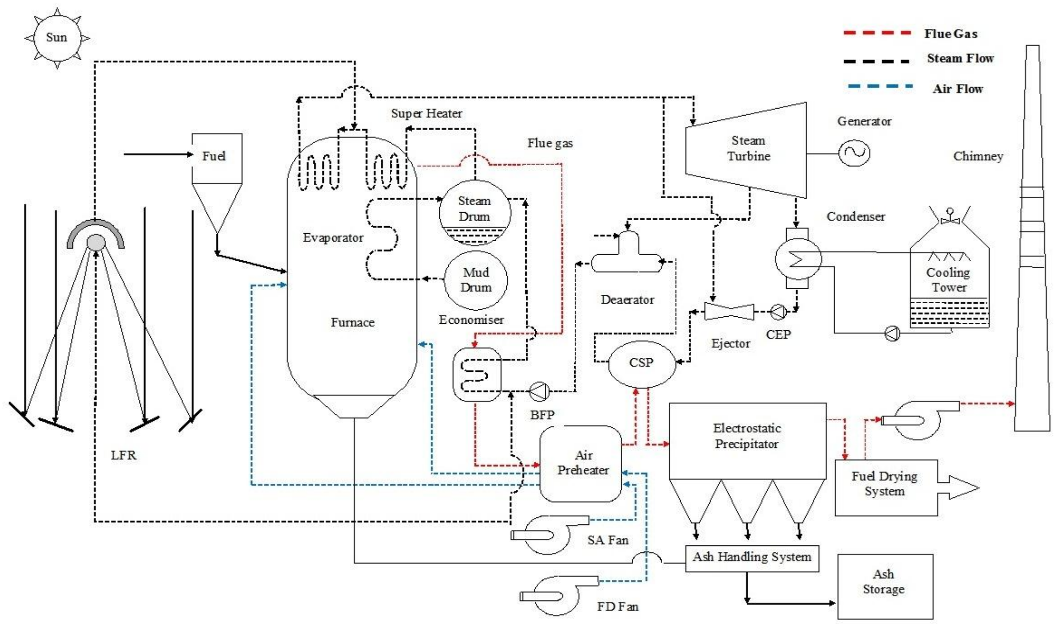

Fig. 5. Schematic diagram of integrated biomass and solar thermal power plant

6. RESULTS AND DISCUSSION

The results of the efficiency measurement are presented in Table.1.the average thermal efficiency of the concentrator is 68.61%. This is due to the good reflectivity of the six mirror elements. The readings are taken when the sun is at zenith. The use of three copper pipes as absorber is an advantage because of its high thermal conductivity and more absorber area. Fig.6 shows variation of efficiency with time based on aperture area, total used area of reflector system. But there are heat losses by conduction, convection, radiation due to no glass covers.

The efficiency of linear fresnel reflector system is more than parabolic trough collector and cost of this device is around Rs 3000 which very much less than parabolic trough collector. The tracking of adjusted manually according to the position of sun. Fig. 7, Fig. 8 shows the variation of efficiency and based on the total area of system and reflective area

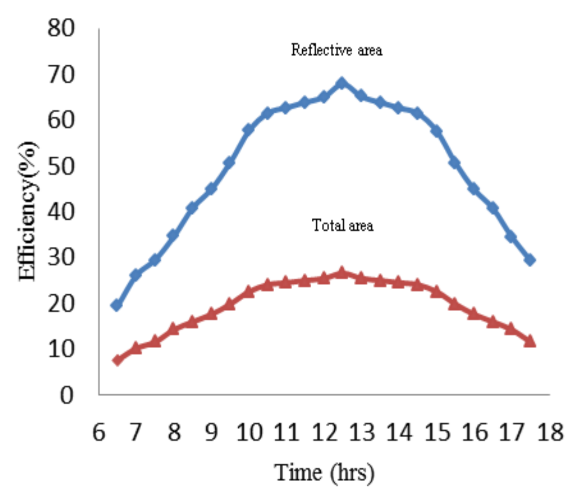

Fig. 6. Variation of efficiency (ηo) with time for the linear Fresnel reflector device

TABLE 1

THERMAL EFFICIENCY (η_{th}) OF THE LINEAR FRESNEL REFLECTOR

Time (hr)	Intensity of beam radiation I_b(W/m²)	Ambient temperature (T_a)°C	Inlet temperature (T_i)°C	Outlet temperature (T_o)°C	Mass flow rate of the water m(kg/sec)	Thermal efficiency (η_{th})%	Average thermal efficiency %
6.5	239.909	25.9	26	27	0.01	19.377	
7	268.134	26.5	27	28.5	0.01	26.110	
7.5	268.134	27.1	27.5	29.2	0.01	29.470	
8	282.247	27.7	27.9	30	0.01	34.580	
8.5	296.359	27.9	28.1	30.7	0.01	40.780	
9	310.471	28.5	28.9	31.9	0.01	44.920	
9.5	311.882	28.8	29	32.4	0.01	50.680	
10	314.705	29	29.2	33.1	0.01	57.610	
10.5	317.529	29	29.3	33.5	0.01	61.490	
11	318.939	30	30.1	34.4	0.01	62.670	49.367
11.5	320.350	30	30.2	34.6	0.01	63.850	
12	321.761	30	30.3	34.8	0.01	65.010	
12.5	423.370	30.1	30.32	36.5	0.01	67.82	
13	321.761	30	30.3	34.8	0.01	65.010	
13.5	320.350	30	30.2	34.6	0.01	63.850	
14	318.939	30	30.1	34.4	0.01	62.630	
14.5	317.527	29	29.3	33.5	0.01	61.420	
15	314.705	29	29.2	33.1	0.01	57.59	
15.5	311.882	28.8	29	32.4	0.01	50.610	
16	310.471	28.5	28.9	31.9	0.01	44.850	
16.5	296.359	27.9	28.1	30.7	0.01	40.69	
17	282.247	27.7	27.9	30	0.01	34.480	
17.5	268.134	27.1	27	29.2	0.01	29.320	

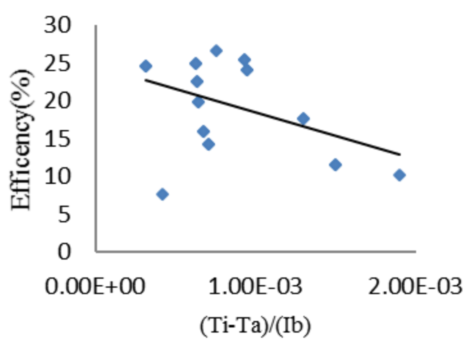

Fig. 7. Variation of efficiency (η_o) with (Ti-Ta)/(Ib) based on Total area

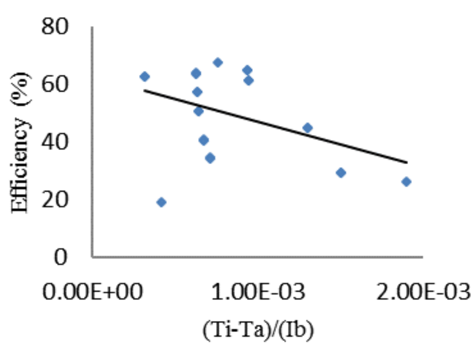

Fig. 8. Variation of efficiency (η_o) with (Ti-Ta)/(Ib) based on Reflective area

7. Conclusion

These are several merits due to integration of LFR with Biomass power plant i.e. increase in power output, thermal efficiency, exergy efficiency. Improvement with integration of Linear Fresnel reflectors to rise water temperature. Improvement in performance with fuel drying Control in fuel feed rate with variable solar radiation, Optimized biomass usage is maintained.

TABLE 2

Nomenclature

Symbol	Quantity
A_a	surface area of the absorber pipe (m²)
A_c	aperture area of the fresnel solar re? ecting concentrator (m²)
C_p	speci? c heat of the ? uid (kJ/kg/°C)
CR	concentration ratio
?	height of the absorber above primary mirror re? ector plane (m)
Ib	Solar beam intensity normal to the aperture plane (kW/m²)
m	fluid mass ? ow rate (kg/s)
Ti	inlet ? uid temperature (°C)
To	outlet ? uid temperature (°C)
Ta	ambient temperature (°C)
UL	overall heat loss coef? cient (W/m² /°C)
Q_n	distance between the nth mirror and center (m)
S_n	shift or space between nth and nth-1 mirror (m)
θ_n	tilt of the nth mirror
ηo	instantaneous thermal efficiency of the fresnel re? ecting solar concentrator–receiver

m = meter, J = joule, T = temperature, kg = kilogram, .

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