Experimental analysis of solar collector with single pass at different mass flow rates

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Abstract- *The main purpose of this paper is the experimental investigation of a solar collector that uses Fresnel lenses and heats the air using single pass system. In the present system, Fresnel lenses are used in order to concentrate the solar beam and generate heated air. Solar air dryer collectors are covered conventionally by normal glass, tempered glass or acrylic glass. Fresnel lens are introduced, by aiming to reduce surface area of collectors. In the present work, performance of solar collector is analyzed experimentally, using Fresnel lenses at single pass.*

Keywords- Focal Length, Fresnel Lenses, Heat Transfer Coefficient, Reynolds No, Solar Drier, Thermal Conductivity

I. INTRODUCTION

Solar technology can be a proper solution to fulfill the energy demands in India. Fresnel lens is an effective way to concentrate solar energy. This project is focused on concentrating solar energy and getting high temperatures using Fresnel lens. This project provides an up-to-date review of solar Fresnel lenses and its benefits to make solar technology accessible. We analyzed some of the existing solar concentrators used in the solar technology for the past four decades and performance of each concentrator is explained and compared. Solar radiation is concentrated by reflection or refraction through mirrors or lenses. The mirrors can be plane and are known as heliostats, or parabolic; the lenses can be simple lenses or Fresnel lenses (FL). Concentrators are used to improve the solar energy caption in specific applications. In a lens, the refraction phenomenon is produced in the surface, while the bulk material between the two surfaces doesn't have any influence in the refraction. In 1748 Georges- Louis Leclerc had the idea of reducing lens weight and size acting on the lens surface, but it was a French mathematician and physicist, Augustin-Jean Fresnel, who built, in 1820 the first lighthouse using Leclerc's design. The FL is a flat optical component where the bulk material is eliminated because the surface is made up of many small concentric grooves. Each groove is approximated by a flat surface that reflects the curvature at that position of the conventional lens, so each groove behaves like an individual prism. There are two basic FL configurations: linear and circular A linear FL has linear parallel grooves and the focus is a line. A circular FL has circular concentric grooves and the focus is a small circle. FL manufacture processes have developed. First designs were cut and polished in glass. [1] In 1950 they started to be made by pressing hot glass in metal molds, and since the eighties they are made of plastics. Modern plastic FL, cheaper and lighter than a conventional lens of the same size, has high optical quality. The Fresnel lens reduces the amount of material required compared to a conventional lens by dividing the lens into a set of concentric annular sections. An ideal Fresnel lens would have infinitely many such sections. In each section, the overall thickness is decreased compared to an equivalent simple lens. This effectively divides the continuous surface of a standard lens into a set of surfaces of the same curvature, with stepwise discontinuities between them. In some lenses, the curved surfaces are replaced with flat surfaces, with different angle in each section. Such a lens can be regarded as an array of prisms arranged in a circular fashion, with steeper prisms on the edges, and a flat or slightly convex center. In the first (and largest) Fresnel lenses, each section was actually a separate prism. 'Single-piece' Fresnel lenses were later produced, being used for automobile headlamps, brake, parking, and turn signal lenses, and so on. In modern times, computer-controlled milling equipment (CNC) might be used to manufacture more complex lenses. Fresnel lens design allows a substantial reduction in thickness (and thus mass and volume of material), at the expense of reducing the imaging quality of the lens, which is why precise imaging applications such as photography still use conventional bulky lenses. Fresnel lens has been widely used in many applications, such as solar collector, Light Emitting Diode (LED), magnifier, lighting and camera lens. [2]

II. LITERATURE REVIEW

The early Fresnel lenses made of glass were used soon after their practical discovery by Augustin Jean Fresnel in 1822 as collimators in lighthouse. Glass is an attractive option when lenses are to be used at high temperatures or when they are used for glazing. In 1951, Miller made the world's first plastic material Fresnel lenses with high precision and excellent surface quality. The prismatic elements were very fine and were not visible to the average unaided eye and a high degree of correction for spherical aberration had been achieved by moulding with the help of high precision moulds. It was shown that these lenses had many applications as light collecting elements where weight and space were limited such as large condensers, large field lenses in finders, camera viewing screens, and translucent screens for projection which were considered as the early imaging systems. Boettner described the design and construction of Fresnel-type optics particularly suitable for use with area-type photoelectric receivers which was a point-focus system. Szulmayer and Nelson both presented and investigated a solar concentrator based on linear Fresnel lens, which could reach temperatures between 60 and 143°C for water heating, steam production, desiccants (silica gel) regeneration, as well as thermoelectric power generation. The daily collection efficiencies were typically 50% at concentration ratios of near 5. Rice also proposed a solar concentrator with linear Fresnel lens which has series of elongated, generally rectilinear, side-by-side, parallel solar ray focusing surfaces. [3]Various solar collectors has been made by researchers all over the globe. Some of them are:

M. Hasan Nia 2014, Fresnel lens and thermoelectric module (TE module) were utilized in order to concentrate solar beam and generate electrical power. The energy of concentrated sunlight on the heat absorber of TE module is transferred to cold water reservoir. Heat transfer in TE module leads to temperature difference in its both sides and finally electrical power is generated. The main components of this system consist of a mono axial adjustable structure, a thermoelectric generator (TEG) and a Fresnel lens with an area of 0.09 m^2. Results revealed that matched load output power is 1.08W with 51.33% efficiency under radiation intensity of 705.9 W/m^2. In order to apply TE module capacity optimally for electrical generation, it is recommended to employ an array of Fresnel lenses which transfer heat to TE module by an intermediate fluid. [4]

M. Ouannene (2009) designed, built and studied a parabolic solar concentrator. The characteristic equations and the experimental results showed that the favourable conditions of getting better solar concentrations are; first is the best hour of getting maximum solar energy is 13h: 30 to 14h:30 and second is the concentrator is more effective if the solar tracking is perfect. [5]

Preservation of fruits, vegetables, and food are essential for keeping them for a long time without further deterioration in the quality of the product. Several process technologies have been employed on an industrial scale to preserve food products; the major ones are canning, freezing, and dehydration. Among these, drying is especially suited for developing countries with poorly established low-temperature and thermal processing facilities. It offers a highly effective and practical means of preservation to reduce postharvest losses and offset the shortages in supply. Drying is a simple process of moisture removal from a product in order to reach the desired moisture content and is an energy intensive operation. The prime objective of drying apart from extended storage life can also be quality enhancement, ease of handling, further processing and sanitation and is probably the oldest method of food preservation practiced by humankind (Mujumdar, 2007) [6]

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III. EXPERIENTAL SETUP

In this experiment, copper tube is located at the focal point of the Fresnel lens .Fresnel lens concentrates sunlight on its focal point and enhances solar intensity in this zone. As a result of this heating the air temperature will increase. The exposure of lens exactly under sun rays is considered manually over the copper tubes. The main component of this system consists of wooden frame, wooden box, two copper tubes, Fresnel lens, and valves. The lens can be adjusted manually in appropriate direction with the help of wheel at the base and the screw that connects the frame and the box. The Fresnel lens is of order 28.5 × 28.5 cm^2. The experiment consist of 6 Fresnel lens of an area of 4873.5 cm^2. With the help of focused rays air is heated through copper tubes of 7 mm diameter and length 890 mm at varying Reynolds no. To prevent heat losses the copper tubes are enclosed inside the wooden box with a transparent glass covering on one of the side in order to verify that the focus is on the cu pipe. Also, to increase the absorptivity of the whole system the wooden box is painted black from inside. A blower is utilized for forced draught. Two passes arrangement were made inside the collector unlike a heat exchanger, a single pass, in which air comes through the blower and passes through both the tubes separately then passes out. The other arrangement is of double pass in which air enters through one copper pipe, heated up and then the same air passes through the other copper tube and heated up again. The experiments were carried out from May 25, 2015 to September 5, 2015 in Parandwadi, located near somatnephata, Pune(latitude: 18.698° and longitude: 73.658°).Experiments were performed from 10.30 am to 4.30 pm on every sunny day. Temperature is measured with the help of thermocouple at inlet, outlet and over the cu pipe at six different locations so as to obtain the average surface temperature. Ambient temperature of air is also recorded, for necessary calculations and investigations.

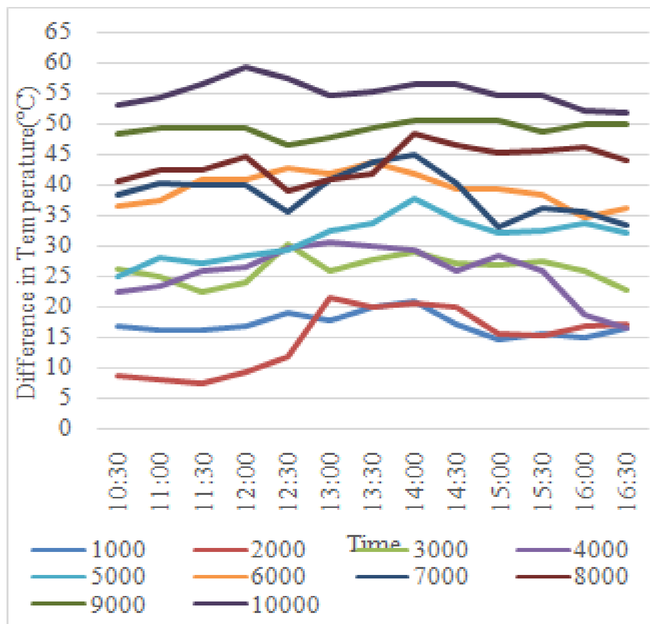
The table and graph here depicts the difference in temperature between the inlet and outlet of a single pass system that uses the Fresnel lens:

Difference In Temperature Vs Time (Single pass)

	1000	2000	3000	4000	5000	6000	7000	8000	9000	10000
10:30	16.8	8.8	26.1	22.5	25	36.5	38.5	40.5	48.3	53.3
11:00	16.1	8	25	23.5	28.2	37.3	40.3	42.5	49.5	54.5
11:30	16.2	7.5	22.4	26	27.1	40.9	39.9	42.4	49.5	56.5
12:00	16.8	9.5	24	26.6	28.3	40.8	39.8	44.5	49.5	59.5
12:30	19	11.9	30.2	29.7	29.3	42.6	35.6	39.1	46.5	57.5
13:00	17.8	21.5	25.9	30.6	32.6	41.8	40.8	40.8	47.8	54.8
13:30	19.9	20	27.6	29.9	33.6	43.6	43.6	41.8	49.5	55.5
14:00	20.8	20.5	29	29.4	37.8	41.8	44.8	48.3	50.6	56.6
14:30	17	19.8	27	26	34.3	39.2	40.2	46.6	50.6	56.6
15:00	14.7	15.7	26.7	28.5	32.1	39.2	33.2	45.2	50.7	54.7
15:30	15.5	15.3	27.3	25.9	32.6	38.4	36.4	45.4	48.7	54.7
16:00	15.1	16.8	25.7	18.6	33.7	34.6	35.6	46.2	50.2	52.2
16:30	16.6	17.1	22.6	16.5	32.3	36.1	33.4	44	50	51.9

We can observe that with the increase in the Reynolds no there is an increase in the difference between the temperatures. A close observation shows that a maximum temperature difference of 59.5°C is attained at Reynolds no 10000 at 12:00 noon, also an average rise of 55.25°C in the temperature of air is possible by the single pass system using Fresnel lens at Re=10000.

The following graph depicts the behavior of the time versus temperature difference for various Reynolds number:



Graph 1: Time vs Temperature Difference

IV. NUMERICAL ANALYSIS

The rate of useful energy collected is expressed by considering enthalpy rise of the air as

$$Q = mC_p(T_{outlet} - T_{inlet})$$

Mass flow rate of air is expressed as

m = ρ. A.V

Where, ρ = Density of air at the ambient Temperature

A= Area of the pipe

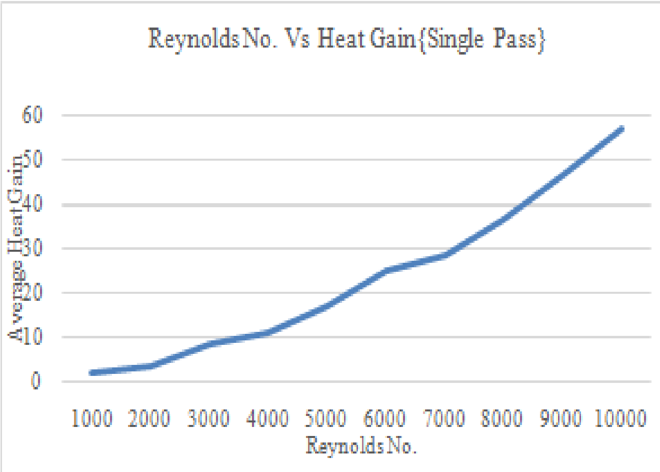
V= Velocity of the air inside the pipe.

Also,

$$C_p = 1007 J/kgK$$

$$\text{Temperature difference} = (T_{outlet} - T_{inlet})$$

The graph below depicts the average heat gained due to thetemperature differences throughout the day at all the Reynolds No.



V. CONCLUSION

It can be concluded that a rise in Reynolds no. in single pass type collector there is a rise in the temperature of the outlet air. An increase in the difference of temperature, and the mass flow rate of air causes a significant rise of average heat gain of air i.e. from 1.78 J/s to 57.07J/s for a Reynold no of 1000 to 10000 during the sunny days. Thus the model can be a time saving and heat controlled solar collector in the near future.

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REFERENCES

[1] W.T.Xie. Concentrated Solar Energy Applications using Fresnel lens: A Review. Renewable and Sustainable Energy Reviews, Shanghai: Elsevier Ltd., 2011, Vol. 1. 2588-2606.

[2] Li Pei-Wen. Tuscon .Modeling of Solar Tracking for giant Fresnel Lens Solar Stoves.: Elsevier Ltd., 2013, Vol. Solar Energy 96. 263-273.

[3] Chung-Feng JeffreyKuoAnalysis of Processing Parameters in Fabrication of Fresnel lens Solar Collector. 003, Taipei: Elsevier Ltd., 2012, Vol. Energy Conversion and Management 57. 33-41.

[4] Lin M. Performance investigation on a Linear Fresnel Lens Solar Collector using Cavity ReceiverSolar Energy 107, Fargo: Elsevier Ltd, 2014, Vol. 2. 50-62.

[5] RyuKwangsunConcept and Design of Fresnel Lenses for Concentration Solar System. 80, Daejeon, Republic Of Korea: Elsevier Ltd., 2006, Vol. 3. 1580-1587

[6] M.HasanNia. Shahrood.Cogeneration Solar System Using Thermoelectric Module and Fresnel Lens.: Elsevier Ltd., 2014, Vol. 2. 305-310.