Experimental investigation and analysis on a concentrating solar collector using linear Fresnel lens

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ABSTRACT: Solar energy is used as an alternative source of energy for several domestic and industrial applications. Solar energy can be used in industries for quick and efficient water heating purpose or to generate low-pressure steam by concentrating more solar energy on a smaller area. This can be done by using concentrating solar thermal collectors. Concentrating collector technologies offer a favorable technique for the enormous use of solar energy. It gives a higher efficiency compared to the non-concentrating collector at high temperature due to its higher concentration ratio and a smaller amount of heat losses. Solar energy concentrating technology with linear Fresnel lens is a one of the effective way to utilize solar energy for water heating. The objective of the present work is to investigate and analyze the performance of concentrating linear Fresnel lens solar water collector. In the present work, polymethyl methacrylate sheet was used as Fresnel lens. A heat loss calculation was carried out at various mass flow rates, with and without the Fresnel lens. To study the effects of Fresnel lens on the performance of evacuated tube collector experiments were performed in the wide range of mass flow rates. The system efficiency was increased by 10 –17% due to the presence of Fresnel lens at different flow rates.

1 INTRODUCTION

There are two types of solar thermal collectors, the concentrating type and the non-concentrating type. The concentrating type collector usually contains parabolic mirrors to focus the incident solar radiation on the absorber surface. Flat plate collectors and evacuated tube collectors are the two most commonly used non-concentrating type of collectors. During the recent decade, linear Fresnel lens collector system (LFC) is initially examined and established. The first Fresnel lens is developed and invented by French physicist and engineer Augustin-Jean Fresnel is used for lighthouses in 1822. The first Fresnel lens collector was patent and prototyped by Frencia in Italy in 1964. Major investigation of Fresnel lens includes air heater, Fresnel lens for hydrogen generation, photo-bio reactor, solar powered refrigeration, photo-chemical reaction, linear Fresnel reflector technology and metal surface modification [2].
The linear Fresnel lens is photosensitive piece flat on one side and with a groove on the other side which concentrate sun rays by means of a series of parallel groove, away from the centre line in the form of a linear strip. Compared with conventional lens linear Fresnel lens having advantages like lightweight, small volume, less cost, and mass production high concentration ratio. Subsequently most Fresnel lens designers of concentrated solar energy application chose PMMA (polymethyl methacrylate) for their lens for high optical quality [3]. In this paper, a flat LFC, with axis tracking mode and U-tube absorber tube developed and tested.

2 CONFIGURATION OF FRESNEL LENS SOLAR COLLECTOR

A concentrating liner Fresnel lens solar collector which consists of an evacuated U-type absorber tube, linear Fresnel lens, water tank, pump, thermocouple, etc. Fig. 1 shows the experimental setup consists of two linear Fresnel lens arranged in series. Each Fresnel lens is

1800 mm long and 250 mm wide. The experimental setup consists of U-type evacuated absorber tube having a vacuum in annular space between two concentric transparent glasses. Tube has a selective coating on the outer surface of an inner tube to increase the absorption of the incoming solar radiation, and a copper U-tube with an aluminum fin to enhance the heat transfer. The outer diameter of the evacuated glass tube is 58 mm, the inner diameter is 47 mm, the absorber length is 1.8 m, and the outer diameter of the copper U-tube is 8 mm.

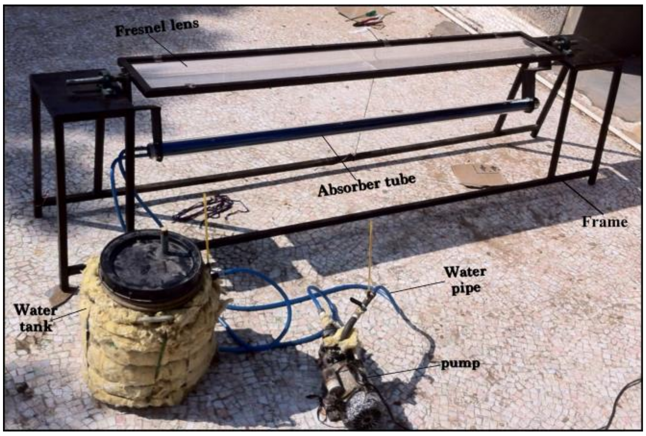

Figure 1.Experimental setup

2.1 *Design of the Fresnel lens*

A material called PMMA, popularly known as an acrylic glass, is to be used in the lens as it is much lighter. Fresnel lens is design based on the minimum thickness in such a way that it can neither be bent nor distorted. It has minimal absorptivity and ensures that maximum radiation passes [4]. The design of Fresnel lens is done in Auto-CAD as shown in Fig. 2 in which conventional lens of radius 200 mm is divided into equal parts, and then machining is carried out on the lens. CNC machining is used to generate longitudinal groove one conventional lens.

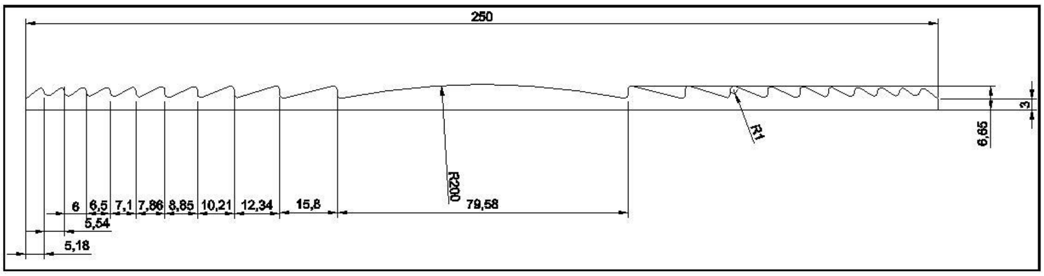

Figure 2.Auto-CAD design of Fresnel

2.2 *Design of absorber tube*

A selection of absorber tube diameter carried out in such a way that we can get a maximum heat transfer with low a pressure-drop. We can find the required diameter using the trial and error method by fixing the mass flow rate and calculate the heat transfer coefficient and pressure drop for the different absorber tube diameter. We have selected an 8 mm copper tube because having optimum heat transfer coefficient and comparative low-pressure drop. The plot for change in heat transfer, pressure drop with respect to the change in diameter of a tube is shown in Fig. 3.

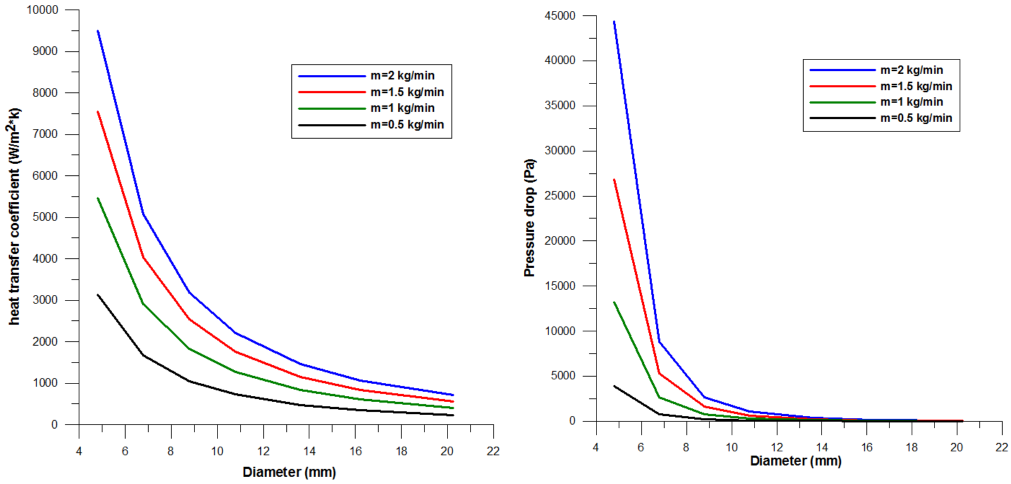

Figure 3.Variation of heat transfer coefficient and pressure drop with change in diameter.

3 RESULTS AND DISCUSSION

The experimental setup is located at 23.7º N, 72.32º E (A-block) Nirma University, Ahmedabad. The orientation of experimental setup in north to south direction; sun tracking is to be carried out from east to west. The experimental results are carried out with the Fresnel lens collector and evacuated tube collector for four different mass flow rates.

3.1 *Performance curves of Fresnel lens solar collector*

The purpose of experimentation is to find out thermal efficiency of the Fresnel lens collector. During the test water temperature inside the tank is measured using the MS-1208 sensor at an interval of 30 min. Beam radiation is measured by a digital pyranometer.

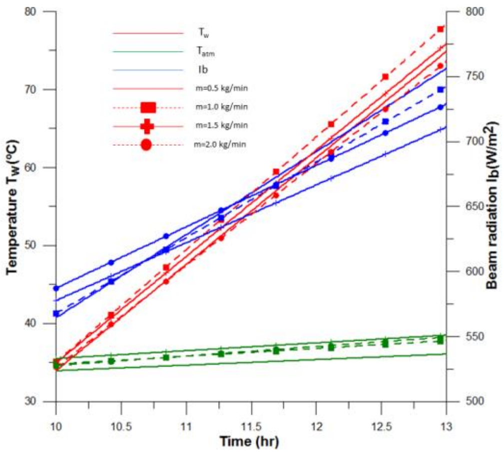

Figure 4.Temperature vs. time.

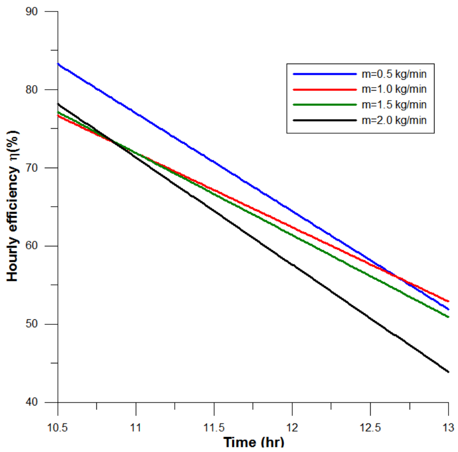

Figure 5.Hourly efficiency vs. time.

Fig. 4 shows a variation of water temperature, ambient temperature and beam radiation with time. From the experimental result, it is found that 1 kg/min. Fig. 5 shows variation of hourly efficiency with time; from result it is found that hourly efficiency decreases as time increases.

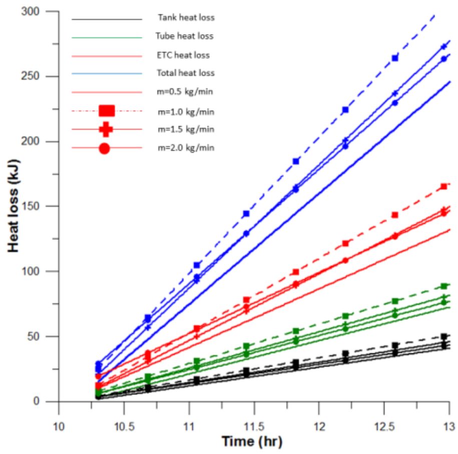

Figure 6.Heat loss vs. time.

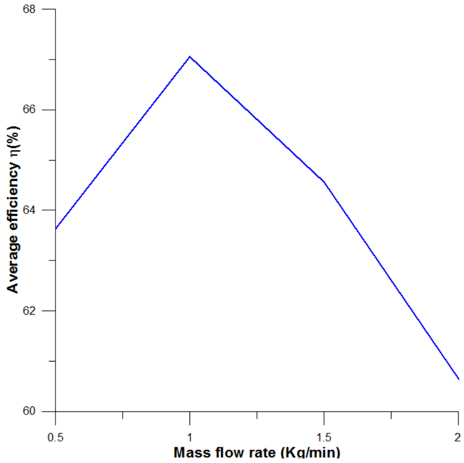

Figure 7.Average efficiency vs. mass flow rate.

Fig. 6 shows heat loss increases as the water temperature increases, in the morning, at lower water temperature, heat loss is less and as the temperature increase heat loss also increases at the afternoon. Fig. 7 shows the variation in the average efficiency with the change in mass flow rate. Maximum efficiency 67.05 % is found at 1 kg/min mass flow rate.

3.2 *Performance curves of evacuated tube collector*

The experimental result was also taken by removing Fresnel lens, which is called as evacuated tube collector to validate the result of Fresnel lens collector.

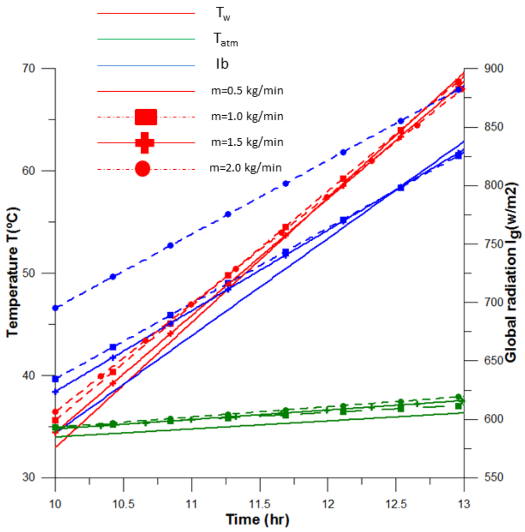

Figure 8.Temperature vs. time.

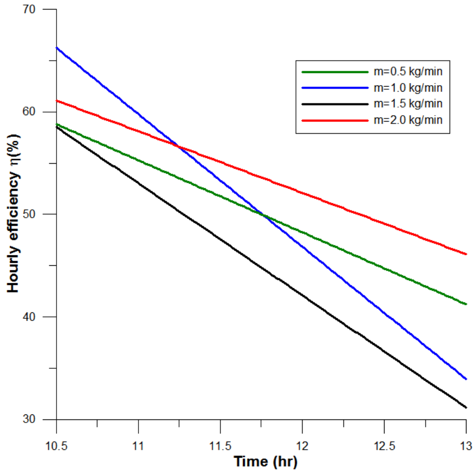

Figure 9.Hourly efficiency vs. time.

Maximum temperature achieved by the evacuated tube collector is 69 ºC as shown in Fig. 8. Fig. 9 shows variation of hourly efficiency with time, from result it is found that hourly efficiency decrease as time increase. Fig. 10 shows heat losses from evacuated tube, it is found that heat loss increase as time increases and maximum at the afternoon. Maximum average efficiency achieved using evacuated tube collector is 53.34 % at 0.5 kg/min mass flow rate as shown in Fig. 11.

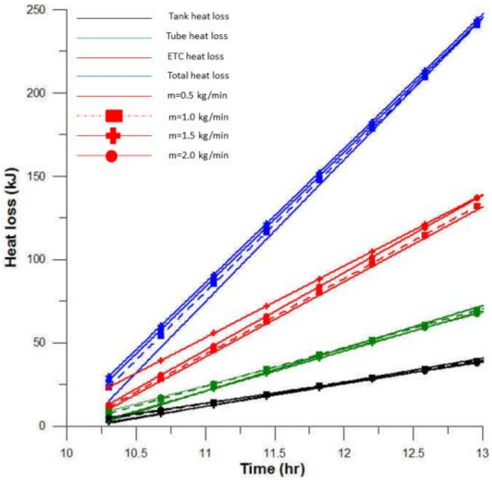

Figure 10 Heat loss vs. time.

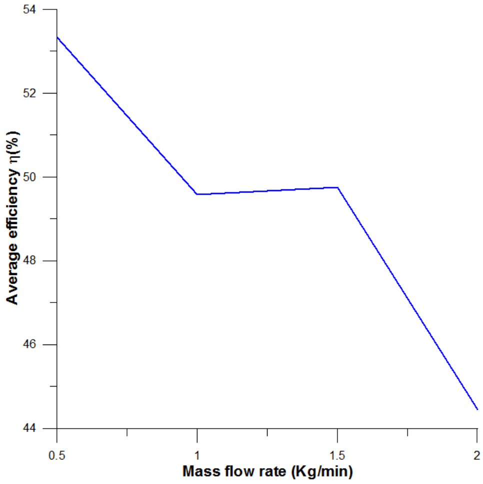

Figure 11 Average efficiency vs. mass flow rate.

4 CONCLUSION

The major conclusions drawn from the study are as follows:

- The efficiency of evacuated tube collector was found to be in the range of 44–53% at different flow rates.
- Due to the presence of Fresnel lens, the efficiency was increased to a range of 10–17% at different flow rates. The maximum efficiency of Fresnel lens collector was obtained as 67.05% at a mass flow rate of 1 kg/min.
- Four calculation results are under different mass flow rate showing that the flow rate dose not impact on performance of solar collector, rather, it depend mainly on the intensity of solar radiation.
- The convective and radiation heat losses increased with the rise in water temperature which led to a decrease in efficiency at elevated temperatures. When the water temperature was raised from 38 ºC to 74 ºC, the heat losses increased from 25.56 kJ to 299.73 kJ in Fresnel lens collector.

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