Beam down Solar concentrator using spot Fresnel Lens

Ruchira Nirale, Alumina, MIT College of Engineering, ruchira.nirale@gmail.com Sanjay N. Havaldar, Associate Professor, MITWPU School of Engineering, sanjay.havaldar@mitwpu.edu.in

Abstract A majority of the world's current electrical power is generated from fossil fuels such as coal, oil and natural gas. These traditional energy sources face a number of challenges including depletion, rising prices and growing environmental concerns. As a result of these, renewable energy sources such as solar, biomass, geothermal, hydroelectric and wind power generation have emerged as potential alternatives in power sector. Solar energy being abundantly available in the nature can be harnessed using various means for electricity generation. One concern with using solar energy is that it is a dilute source of energy. Concentrating solar technologies are being used in a number of applications to convert the dilute source into concentrated energy. Fresnel lenses are used to concentrate solar beam radiations on heat receivers or absorbers for steam generation which can be further utilized in electricity generation. In this pilot project, we aim to design a downward beam concentrator which focuses beam solar radiations on a receiver which houses a helical coil heat exchanger. Water is converted to steam as temperatures at the receiver reaches approximately 240°C. This steam can be further used for various domestic (indoor heating, cooking, etc.), industrial process (chemical process, pre-treatment processes, heating of ovens, etc.) or power generation applications.

Keywords — Solar energy, Fresnel lens, downward beam concentrator, helical coil heat exchanger, steam.

I. INTRODUCTION

Changing lifestyle with technological advancements has led to an exponential increase in the demand for electricity and natural gas both of which are a derivatives of fossil fuels. With rising demand, the reserves of such natural resources have depleted over the years leading the world towards an energy crisis. It has been anticipated that oil will run out in 53 years, natural gas in 54, and coal in 110[1]. We have managed to deplete these fossil fuels, which have their origins somewhere between 541 and 66 million years ago, in less than 200 years since we started using them.

Alternatives like solar, wind, tidal, biogas have emerged out of which solar energy is most freely and abundantly available in the nature. Technologies like photovoltaic and thermal concentrator systems have successfully been able to utilize solar energy for power generation. On the contrary to the photovoltaic panels which require a large collecting surface areas, Fresnel lens and circular/parabolic reflector technology requires much less area. We are still unsure of the effectiveness and longevity of these technologies.

To investigate for the same, we have made one such effort using a point focusing spot Fresnel lens to concentrate solar heat over a small collector surface which further conducts this heat into a heat exchanger to produce steam. Our objective is to develop such a system which is capable of generating steam in shortest possible time and which is also cheap and compact. As there is no external high grade energy input, the system is perpetual.

The steam generated can be utilized for different applications like process heating, atomization of fuel for combustion, power generation and humidification or other domestic applications.

II. MATERIALS AND METHODS

The type of concentrator used in this system is Fresnel lens. Fresnel lens is a compact conventional lens with large aperture and short focal length with reduced mass and volume [2]. The working is simple: given that, the refractive power of a lens remains same, removing as much of the optical material as possible while still maintaining the surface a curvature.

A helical coil heat exchanger is used due to its compact and simple design. Heat exchanger is a tin container (outer container) with another inner container and a layer of thermal insulator-foam in between. The inner container is filled with working fluid in the heat exchanger- engine oil.

The container is covered with a lid of mild steel with a cylindrical copper fin attached to it. The fin is 50mmDx100mm in dimension. One end of the fin is exposed to the sun radiations at the focal point. This surface is called as the collector surface. The other end if fin in immersed in the working fluid. A copper tube of 3mm diameter is wound around the fin in which water is circulated. Copper is selected because of its excellent

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thermal conductivity; it has the second least specific heat which raises its temperature quickly and drives the heat transfer by temperature difference.

The solar heat received at the collector surface is conducted through the fin and consequently to the water in the copper coil. Remaining heat is taken up and stored in the oil and some is lost during the process.

One end of the coil is connected to the water supply and the other end is the outlet from which steam is released. The water is supplied using a water dispenser which is placed at a height in order to get enough pressure head. Then, the water flow is regulated using a flow regulating valve. Thermocouples are placed at four different points to take temperature readings, at collector surface, oil, water inlet and outlet.

The lid of the heat exchanger is made of mild steel with a fin sized hole in it threaded internally to accommodate the externally threaded copper fin.

Thickness of insulation - 35mm

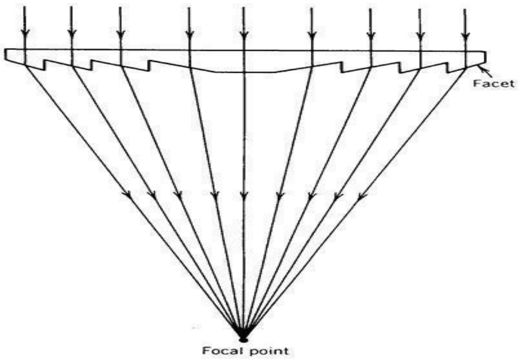

Fig. 2 Fig. Fresnel lens concentrating light rays at focal point

III. Design Calculations

Design Analysis and Calculations

Design of heat exchanger:

Diameter of outer container -180mm Diameter of inner container - 110mm

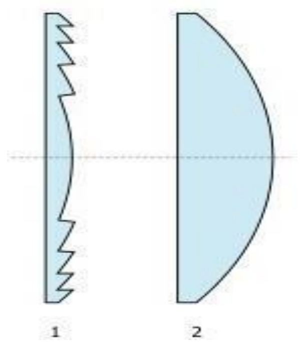

Fig. 1. Cross section of a spherical Fresnel lens.

2. Cross section of a conventional spherical plano-convex lens of equivalent power

Amount of oil to be accommodated is arbitrarily taken as 1*l* Accordingly, **fin$_{vol}$ = vol. of inner container – 1*l***

Therefore, fin dimensions are

Diameter of the fin - 50mm

Length of the fin - 100mm

Fin is attached to the lid of thickness 8mm Therefore, available length of fin = 90mm

Coil dimensions are

Diameter of coil = Diameter of fin + 2 x outer radius of tube

= 50+2 x 1.5

= 53mm No. of turns = length of fin/d No. of turns = 90/3 =30

Length of tube = circumference of coil x 30+ 62 x 2 +allowance (A) =1.714+ A

Volume accommodated in the coil,

$$V = \pi r^2 \times L\, m^3$$
$$= \pi 0.0015^2 \times 1.714$$
$$= 1.211555 \times 10^{-5}\, m^3$$

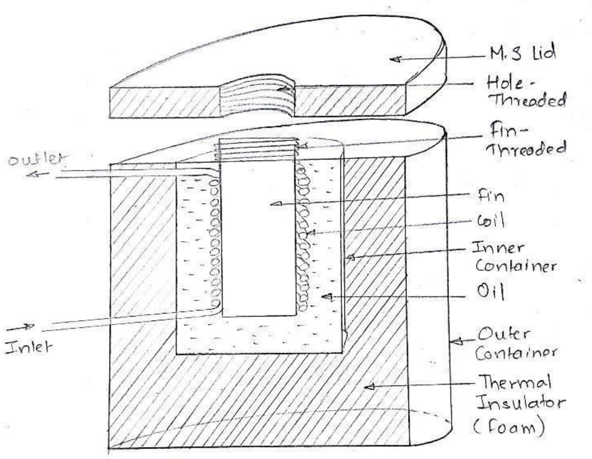

Fig.3 Cross section of the heat exchanger

Analysis:

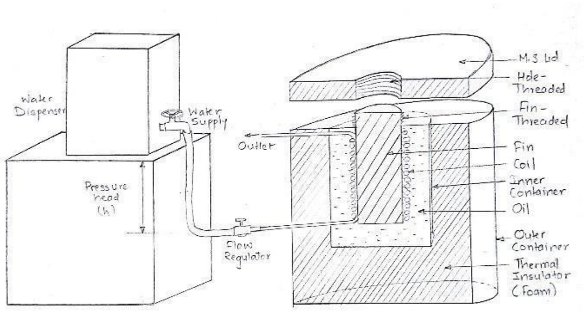

Fig.4 Pressure head obtained by placing water dispenser at a required height

Calculations

If we take solar beam radiations at a particular place to be 243 W/m^2,

Then heat received through the Fresnel lens

We will measure temperatures at 4 places in the setup: T_1= Temperature at the collector surface T_2= Temperature of oil

$\dot{Q} = 243xArea\ of\ the\ lens$
$= 243 \times 0.68 \times 0.94$
$= 155.3256$ W

T_3= Temperature at inlet (water) T_4= Temperature at outlet (steam)

$Q_1 = \sigma\varepsilon(T_{1i}^4 - T_{1f}^4)$

Suffices $_i$ & $_f$ represent initial and final Heat gain by the

collector surface

Heat gain by the oil

$\dot{Q}_2 = \dot{m}C_p(T_{2i} - T_{2f})$

Heat utilized by the water

$\dot{Q}_3 = \dot{m}_w C_p(T_4 - T_3)$

Heat loss

$Q_l = Q_1 - Q_2 - Q_3$

The pressure head required can be calculated as follows

$$h = \frac{v^2}{2g} m$$

Pressure head is converted into velocity head.

$\dot{V}$

$\dot{V} = \frac{m}{\rho} m^3/s$

$\because T_4 =$

55°C $from\ expt\ result$

Where, v=velocity, which can be calculated from volume flow rate ( )

And,

The area of lens that we used is 68cm x 94cm This heat

is then received at the collector and conducted through the copper fin

$\therefore \dot{Q}_1 = 155.3256\ W$

The experiment conducted for 2 hours,

$Q_1 = \dot{Q}_1 \times 2 \times 60 \times 60$
$= \mathbf{1118344.32}\ J$

Heat taken up by the oil is,

$Q_2 = m_o \times 1.67^{[3]} \times (62 - 20)$
$= 70.14 m_o\ W$

$\because T_2 = 62°C \quad from\ expt.result$

$m = \rho \times v = 890 \times 10^{-3} kg$
$= 0.89 kg$

$\because \rho = 890 \frac{kg}{m^3}$ [4]

$\therefore Q_2 = 0.89 \times 70.14 = \mathbf{62.4246}\ J$

$\dot{Q}_3 = \dot{m}_w \times 4190 \times (T_4 - T_3) W$

$Q_3 = 0.01211555 \times 4190 \times (55 - 18)$
$= \mathbf{1878.2737}$ J

$\because T_3 = 18°C \quad from\ expt\ result$

$\because m = V \times \rho = 1.211555 \times 10^{-5} \times 1000 = 0.01211555\ kg$

$Q_l = Q_1 - Q_2 - Q_3$
$= 1118344.32 - 62.4246 - 1878.2737$
$= \mathbf{1116403.622}\ J$

IV. Results and Discussion

The design of this experiment is based on a single parameter *i.e.* temperature, specifically of steam. Heat flow in the heat exchanger is controlled and channelized by suitable modifications to enable maximum utilization of heat received at the collector surface and ultimately generating steam within shortest possible time.

Adequate time was given to heat the fin before water supply was given. It turned out that setup time required was much more than expected which was approximately 45 minutes. But when the water was passed, it was heated within no time.

Although, results didn't turn out to be satisfactory and the temperature of oil and water at the end of the experiment was recorded to be 62°C and 55°C respectively.

V. Conclusion

The immediate inference from the results is that due to difference between specific heats of water (4.19) and oil (1.88- average), oil heats up faster causing a temperature difference; and this facilitates heat transfer from oil to water.

The steam generated by this apparatus is enough to cater to small needs of power using micro-turbine at domestic level. The output is obtained by investing least or no amount of input energy using readily available materials and hence, this implies that the apparatus is simple and cheap.

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