

Design of Solar Furnace Using Fresnel Lens

Sandip M S¹, Nihan Pasha K M², P Harinath Reddy³, Manu S⁴, Mukesh Kumar M P⁵

Assistant Professor, Department of Mechanical Engineering, NIEIT, Mysore, Karnataka, India¹

Students, Department of Mechanical Engineering, NIEIT, Mysore, Karnataka, India^{2,3,4,5}

ABSTRACT: Solar energy is abundant over the surface of the earth. This solar energy is a renewable energy which can replace fossil fuels in many ways. One the way of using solar energy is for foundry and casting application. The use of infrared wavelength of electromagnetic spectrum for melting metals is the purpose of the project. The solar energy is concentrated using a Fresnel lens and directing it over the metal results in heating and eventually melting. On an average Mysore receives 5.45kWh/m²/day of solar irradiance. For better performance we are using a horizontal type solar tracking mechanisms for better working and efficiency.

KEYWORDS: Solar irradiance, Horizontal tracking mechanisms, Thermal analysis.

I. INTRODUCTION

The solar energy is abundant over the surface of the earth. The solar energy consists of broad spectrum of electromagnetic waves such as UV, infrared, the seven colours light etc., in these waves the photons of the right wavelength are used for solar electric generation. Other waves such as UV, X rays are used for medical purpose, and in this project we are using infrared light which carries heat with it is used. The infrared light is concentrated using the Fresnel lens and pointed on the metals for melting it. The temperature which would be obtained is dependent on the following factors which are Weather, Size of lens and Thermal insulation. The Fresnel lens is oriented towards the sun for optimal operation by using a horizontal axis tracking mechanisms. The temperature that would be obtained in our setup would be around 800C which is enough to melt metals like aluminium, zinc, tin etc. our project will help the small scale industries by reducing the working cost and also removing risk of fire.

II. LITERATURE SURVEY

1. Hyunjin Lee, et.al., evaluated that optical performance of a solar furnace in the KIER (Korea Institute of Energy Research) by measuring the highly concentrated solar flux with the flux mapping method. They presented and analysed optical performance in terms of concentrated solar flux distribution and power distribution. They investigated concentration ratio, stagnation temperature, total power, and concentration accuracy with help of a modelling code based on the ray tracing method and thereby compared with other solar furnaces. They also discussed flux changes by shutter opening angles and by position adjustment of reflector facets. In the course of flux analysis, they provided a better understanding of reference flux measurement for calibration, reflectivity measurement with a portable reflectometer, shadowing area consideration for effective irradiation, as well as accuracy and repeatability of flux measurements. The results in the study helped proper utilization of a solar furnace by facilitating comparison between flux measurements at different conditions and flux estimation during operation.
2. D. Laplaze, et.al., showed that the high intensity of solar radiation, obtained with the Odeillo (France) solar furnace facilities, could be used to vaporize graphite in inert gas atmosphere to produce fullerenes. After a short survey of the possible mechanisms of formation of these molecules, they reported some results in agreement with the proposed model and discussed the possibilities of increasing the fullerene yield which reached 20%.
3. Jarosh.S., proposed that an improved technique had been proposed based on Carlson's et al. modelling that could be used to estimate the reflectivity of the heliostat-concentrator system, the tracking errors and mirror imperfections in a lumped parameter for simulating the performance of a solar furnace as measured by a calorimeter.
4. D. Jafrancesco, et.al., summarised the optical design of a concentration system for a solar furnace was studied, proposing several possible solutions. The foreseen use of those solar furnace was to test components and methodologies for solar applications. The analysis assessed and compared the optical performances of several possible configurations. The possibility of employing in a solar furnace an array of off-axis mirrors as primary optics was examined comparing simulations with various diameters and different configurations. In particular, the paper compares

spherical mirrors, parabolic mirrors with axis inclined with respect to the heliostat rays and a paraboloid with axis parallel to the rays arriving from the heliostat. It proposed an optimal solution, with spherical mirrors on a spherical envelope, which is compared to the heliostat-axis paraboloid. Considering realisation tolerances, mirrors positioning, mirrors pointing and solar divergence effects they equivalently concentrate the sunlight on the receiver.

5. D. Hernandez, et.al., proposed that a solar furnace experimental setup which was used to measure melting and freezing temperatures between 2000 and 3000^oC. The solar furnace was coupled to a self-crucible device inside a rotating reactor. Cavities with a depth/aperture ratio of 1.0–1.5 were obtained, with apparent emissivity's from 0.87 to 0.98. With the current setup, freezing plateaus lasted a few seconds. Four refractory oxides (HfO₂, Y₂ O₃, Al₂ O₃, and Ho₂ O₃) were studied. Preliminary radiance temperature measurements obtained with two radiation thermometers operating in two different spectral ranges were presented. Typically, the reproducibility of the temperature measurements ranged from 5 to 50^oC, depending on the material and on the spectral range of the radiation thermometer.

6Y. T. CHEN, et.al., put forth that in the architecture of the first prototype, 25 mirrors, each with a dimension of 40x40cm, are arranged into five rows and five columns to form a total reflective area of 4 m. The design of the essential part of the first prototype heliostat would be discussed in those paper, which consists of two primary elements; a rotation–elevation system for tracking a mirror support frame which carries 25 mirror facets, and a separate two-axis tracking system for compensating (each second) off-axis aberrations of 24 slave facets relative to the central mirror, which was fixed in the mirror frame. The rotation–elevation system consists of a pedestal supporting a rotational tracking mechanism carrying a U-shaped arm and a second tracking system for tracking a moving frame in elevation. The moving frame carries a central stationary (relative to the frame) mirror, called a master mirror. Slave mirrors were arrayed in five rows and five columns, and eight stepper motors drive the outer four rows and columns relative to the master mirror via a computer programme implementing newly proposed formulas to eliminate the first-order aberration. With a second stage concentrator comprising a small aperture size parabolic mirror (diameter of 60 cm), a cost-effective high temperature solar furnace was constructed. In our experiment, the highest furnace temperature of 3400^oC had been recorded through the melting of pure tungsten wires.

7. M. Beschi, et.al., addressed that the temperature control problem in a solar furnace. In particular, two control strategies for the disturbances rejection (represented by the variation of the input energy provided by the Sun, mainly because of passing clouds and the solar daily cycle) were proposed, based on a two-degrees-of-freedom scheme. The first one was based on generalized predictive control, where a nonlinear model was employed for free response prediction while a linearized model was used for the computation of the forced response. Amplitude and slew-rate constraints on both the control variable and the output of the system were taken into account. The second one was a constrained control strategy where both the process input and output constraints were taken into account explicitly. In both cases an adaptation of the most significant process parameter was performed. Simulation and experimental results show the effectiveness of the methodologies.

8. G.P. Rodriguez, et.al., suggested that the concentration of solar energy provided the possibility to get power densities high enough to produce surface modifications of materials, with low environmental impact. The paper discussed the possibilities of surface hardening steel by means of concentrated solar energy. Surface treatments had been made by using the solar furnace of the Platafoma Solar in Almeria (Spain), which consists of a group of heliostats and a parabolic mirror. The surface transformation hardening treatment was performed on a 40CrMo4 steel. The paper presented the microstructural changes and the hardness values obtained after the solar treatment in a superficial zone. According to the power density applied on the sample, the hardened zone varied between 1 and 10 mm deep and the treatment time was less than 30 s.

9. Xinglong Ma, et.al., presented a novel method approaches to simplify refractions on prisms to get the ideal shape of the Fresnel lens. A simplification was about to use one refraction on the upper surface to replace the two refractions on the upper and the lower surfaces. A differential equation that describes the ideal shape of Fresnel lens had been derived out. It showed that the particular solution of the differential equation was a bunch of confocal curves. Especially, the ideal curves were closing to their basic circle when total refracted angle less was than 30°, which made it reasonable to use the basic circle as the profile of Fresnel lens. Then a Fresnel lens was designed with considering material and manufacturing technology. Then an analysis on the focal length change during the tilt incidence was mainly carried via simulation and experiment. It was found that the effective tilt incident angle could be enhanced from 7° to 32° by lifting up the position of the receiver and adding a simple mirror secondary reflector. The experimental result showed that the Fresnel solar concentrator was working efficiently during the time from about 10:00 to 14:30 a day. The steady output temperatures are 125 °C, 150 °C and 170 °C, with collection efficiencies are about 0.53, 0.48 and 0.44. It can well satisfy mid-temperature solar thermal application.

10. Alzahrani.M, et.al., put forth that recycling optical devices and materials for solar concentrator devices was a relatively unstudied area but one which was likely to grow in importance as they progressed towards an increasingly sustainable and minimum waste environment. As such, considerations into major optical flaws were required. Here, they had investigated the durability of a cracked Silicon on Glass (SOG) Fresnel lens incorporated as the primary optical component in a concentrated photovoltaic (CPV) application. Optical and electrical characterisations of the flawed glass had been conducted to show the effect on the performance. The optical characterisation had shown a drop of 3.2% in optical efficiency. As well, I-V and power curves of cracked and non-cracked Fresnel lens were compared to shows a drop of 3.2% in short circuit current (I_{sc}) and power. The results had confirmed that the power loss was directly related to only the area of the primary optic flawed, which had been calculated through as a percentage of geometrical loss (a form of shadowing) which was estimated to be 2.7% of the concentrator area. From the results, they could confirm that although the performance had slightly declined for the significantly flawed Fresnel lens, there were no other detrimental optical effects. The durability of such optics still needs to be tested, but from those results, they recommend that similarly critically flawed optics could be utilised, likely in non-demanding singular CPV units where < 5% loss was acceptable.

III. IMPORTANT FINDING

The environmental pollution and exhaustion of fossil fuel has cause the world to shift towards renewable energy. Also the resistance by the people has also been influence. The exhaust fumes and the particulate matter which are let out of the furnaces has very bad effect on human and nature health. Most of the furnaces use fossil fuel such as coal for heating purpose. These leads to large carbon foot print. Small scale industries need large setups with heavy energy consumption for furnaces. The solar energy is very abundant over the surface of the earth, which could be used for melting metals. This solar furnace will be very helpful for small scale industries and also cop up environment while being economical in terms of fuel.

IV. CONSTRUCTION

The setup will be made of a swing arm type mechanisms where the Fresnel lens will be placed inside a rectangular frame to which arms of length which is equal to focal length of the lens. The arms will be holding the crucible within which metals will be placed for melting. The swing action would be executed by a stepper motor which is controlled by solar tracking electronics. The whole setup would be placed on two legs of T-shape, to which two pairs of elevating screw are placed which will be set to match azimuth angle.

V. DESIGN CHALLENGES

The main challenge was to make the Fresnel lens point in the most optimal way towards the sun so that maximum sun rays concentrate without loses. The method involved to solve the problem is by using a solar tracking mechanisms, but considering the budget of the project many considerations were taken in like the type of tracking, single axis or dual axis and whether to use GPS. And finally the conclusion made was to use single axis horizontal axis tracking mechanisms, which oriented the lens towards the sun by considering the axis of elevation of the sun and the azimuthal angle would be taken care of by using elevation screw. The next challenge was the size and efficiency of solar concentration, which is solved by insulating the chamber to prevent air flow and cover the crucial with thermal insulation material.

VI. CALCULATIONS

1) Torque generated due to weight of the set up:

a) Mass of individual components at 730mm from the shaft are

Mass of frame=0.192kg

Mass of crucible =0.239kg

Mass of insulation box=0.5kg

Mass of hollow pyramid frustum=1kg

Mass of metal to be melted=0.1kg

The total mass =0.192kg+0.239kg+0.5kg+0.1kg+1kg=2.031kg==2.1kg

b) Mass of lens frame at 225mm from the shaft = 1.59kg

Total Torque= [(Total Mass of Frame Setup) x (Distance from Centre of Shaft) + (Total Mass of Lens Frame) x (Distance from Centre Of Shaft)] x (Acceleration Due To Gravity)



$$T = [(2.1\text{kg}) \times (0.73\text{m}) + (1.59\text{kg}/2) \times (0.225\text{m})] \times 9.81\text{ms}^{-2}$$

$$T = 16.784\text{Nm} = 17\text{Nm}$$

2) Calculations regarding gears:

Driver gear:

- Pitch circle dia=40mm
- Number of teeth=20
- Module=1
- Pressure angle=20°
- Width of gears=10mm
- Hardness ≤187HB
- Torque of stepper motor=1Nm
- Torque in driver=1Nm

Driven gear

- Required Torque for driven gear =17Nm
- Radius of the driven gear is

$$\frac{\text{Torque of driver}}{\text{Torque of driven}} = \frac{\text{radius of driver}}{\text{radius of driven}}$$

$$\frac{1\text{Nm}}{17\text{Nm}} = \frac{2\text{cm}}{R}$$

$$R = 34\text{cm}$$

- Radius of the driven gear=340mm
- Angle of sector of driven gear=75°
- Arc length of the sector of driven gear=445mm
- Number of teeth on driven gear=76
- Module of the driven gear=1

Heat required calculations

1.Specification of Fresnel lens used

- Length=850mm
- Width=450mm
- Area =length*width
- A=850mmx450mm=3825mm²=0.3825m²
- Solar irradiance in Mysore=5.45KW/m²/day

Therefore, the heat or power generated by our Fresnel lens is

$$P = \frac{5.45 \times 1000\text{KW}/\text{m}^2/\text{day} \times 3600\text{s} \times 0.3825\text{m}^2}{24\text{h} \times 60\text{min} \times 60\text{sec}}$$

$$P = 86.859\text{W} = 0.087\text{KW}$$

2.The heat required to melt 100grams of aluminium is

- Latent heat of fusion L =396KJ/kg
- Specific heat C_v=0.9KJ/kgK
- Mass of aluminium=0.1kg
- Initial temperature=25°C
- Final temperature=660°C
- Q=mC_vΔT +mL Joules
- Q=0.1x0.9x(660-25) + 0.1x396x10³
- Q=96,496 J=96.5 KJ

Therefore, the heat required is 96.5KJoulesfor 100grams of aluminium

The power of Fresnel lens is P=0.087KW

Therefore, the time required is,

$$\text{Time} = \frac{\text{Heat energy required}}{\text{Power of lens}} = \frac{96.5}{0.087} = 1,105.74\text{sec} = 18.42\text{min}$$

Therefore, time required to melt 100grams of aluminium is 19minutes when the setup give maximum efficiencyLosses like heat loss, weather condition and damage to lens may cause the time required to increase.

VII. MATERIAL SELECTION

Materials used in our solar furnace project are

- Fresnel lens
Focal length = 73 cm
Spot size = 1 cm
Length = 82 cm
Width = 48 cm
Weight = 70 grams
- Wooden frame
- Crucible:- Material: Silicon carbide, Capacity: 200 ml, Max temperature: 1500 °c
- 2 Bearings: - Model: 6200ZZ, Outer diameter: 30mm, Inner diameter: 10mm, Width: 9mm
- Arduino uno Microcontroller
- Mild steel square hollow section pipe - Dimensions: 20 x 20 x 2 mm
- Fire clay brick.
- Single axis solar tracker which we have used consists of the following components
LDR (light dependent resistor)
Arduino Uno
Stepper motor

VIII. FINAL ASSEMBLED MODEL

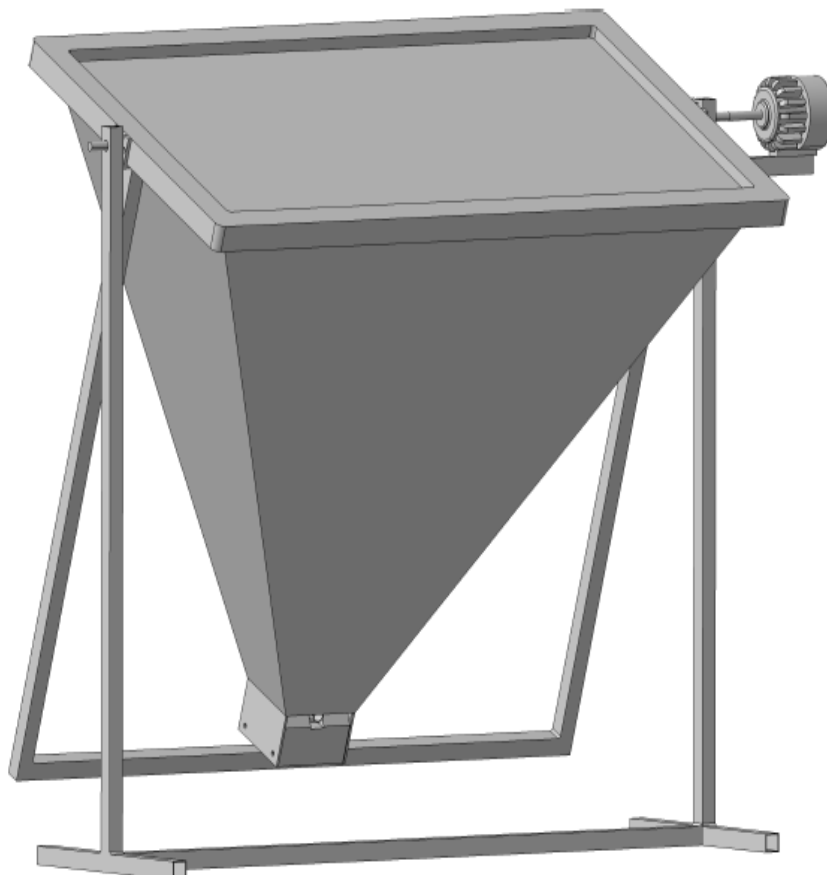


Fig. 1 Assembled view of solar furnace

IX. STEADY-STATE THERMAL ANALYSIS

Temperature distribution of insulation box and crucible is shown below which is done using Ansys 2020 R1 student version.

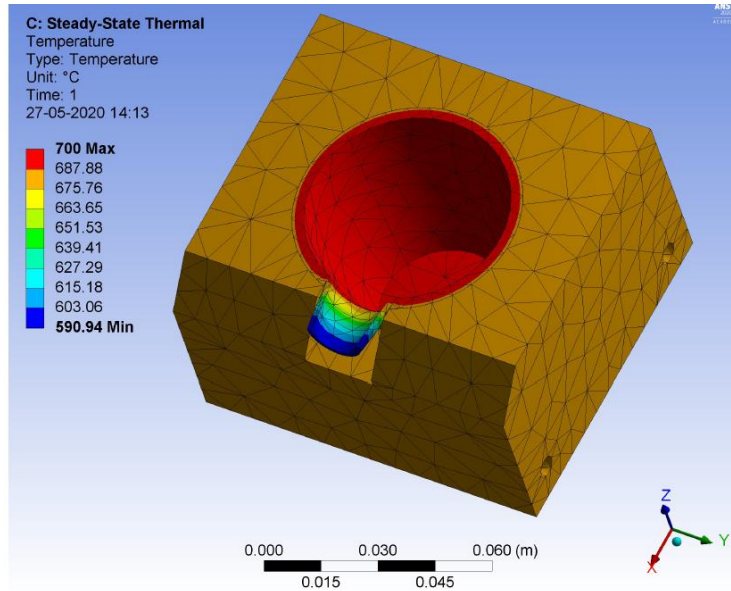


Fig.2 Temperature distribution

The total heat flux of the insulation box and crucible is shown below which is done using Ansys 2020 R1 student version.

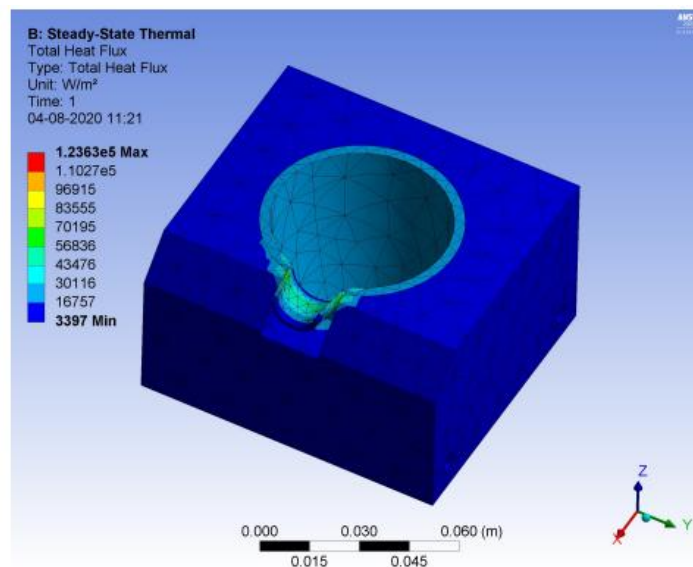


Fig3. Total heat flux

X. RESULT AND DISCUSSION

Considering the temperature obtained is 800C the following results were obtained

The heat energy required to melt 100grams of aluminium is=96.5 KJ

The power of Fresnel lens is P=0.087KW

The time required for melting 100grams of aluminium considering all the losses is=19minutes.

XI. CONCLUSION

The solar furnace has a basic setup which can be economical and environmental friendly. With the world moving towards renewable energy solar furnace will play a big role. The temperature attained can be further pushed to higher temperature by better and bigger lens with improved efficiency. The metals which can be melting depends on the size of Fresnel lens and the weather condition, therefore by using bigger equipment metals like iron with melting temperature of 1538C can be done hence widening of its application through the industries.

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