Fresnel Lens Technology for Distillation of Water with LDR Sensor Based Tracking System

Joji Johnson and Arjun Srinivas
1 Department of Mechanical Engineering, SRM Institute of Science and Technology, Kattankulathur, Chennai, Tamil Nadu, India, Pin: 603203.

E-mail: jojij@srmist.edu.in, arjunsrinivas2@gmail.com

Abstract. Fresnel lens reduces the amount of material required compared to a conventional lens. By employing this technology to two of the ubiquitous resources available almost everywhere – sunlight and brine water - we produce steam. Focused sunlight by sun tracking was used to boil water from a copper tube while a spiral piping is used as a condenser. With LDR sensors and a high torque servo motor, the solar irradiance was maximised. This was done using ‘Adruino Uno’ micro controller coded to use real time data obtained from the LDR sensors. The apparatus was tested on sunny, partially cloudy and cloudy days in manually set to North – South direction manually. The amount of water distilled was proportional to the solar irradiance and were highest, mediocre and lowest respectively for three sample days of varying solar albedo. Though black paint on copper boiler helped to increase distilled water productivity, loss in heat from the system was evident. An average of 1.6 litres of water was produced per day by the system with boiler volume 3.18 litres and rectangular Fresnel lens of size 345 x 345 mm. Heat loss from system may be further controlled by larger aperture lens and selective insulation of copper duct. Addition of baffle for heating and fins at condenser may increase heat transfer rate.

1. Introduction
The sun has been a staple source of energy for many years and technological advancements help in new methods of harnessing the same. Fresnel lens technology is an attractive method of water purification in small scale while scaling up at a reasonable cost can help increase efficiency. This will help mitigate one of the most pressing issues, scarcity of potable water. Though there has been considerable development in water purification technology such as RO systems, such systems need reliable supply of fresh water and have high rejection rate. Fresnel technology application for water purification will be a better choice in regions around the globe receiving adequate sunshine [1]. In India, the daily average solar irradiation ranges between 4 and 7 kWh/ sq. meter which brings great potential in the country. Fresnel lens combined with solar still was used for desalination. The volume of condensate collected from Fresnel lens system was directly proportional to the volume of salt water inside the solar still [2]. An increase in mass flow rate of fluid inside the boiler, increased the heat transfer coefficient but resulted in lower collector efficiency factor and higher heat loss factor, with an overall system efficiency of 51% [3]. Fresnel lens system generated low pressure steam with a temperature range of 100 to 200°C and the refracting type Fresnel lens has a lifespan five years more than the reflecting type [4]. Comparison of different types of cavity receiver shows that the triangular cavity gives the best thermal performance [5]. Theoretical calculation for Fresnel lens spot intensity has inferred that a boiler with better heat conductivity is required to maximize efficiency but with
considerable heat losses. Steel pipe showed poor heat transfer characteristics [6]. The optical assessment of two axis point focus system when compared to single axis line focus system showed lower yearly performances than the north configuration because of the cosine effect. Also, the optical efficiency varied about 20-25%, while the power block efficiency variation was as high as 50%. The point focus systems have little efficiency advantages compared to parabolic trough technologies, while significant compared to Linear Fresnel Collectors [7]. Tracking system designed as a ‘closed – loop’ control based active tracking system, employing Light Dependent Resistor (LDR) sensors as the inputs of the system. The strategy utilizes a digital logic design of the sensors implemented in a pseudo-azimuthal system to simply rotate around the primary (north-south) axis and the secondary (east-west) axis. The tracking system increased the efficiency of electrical energy by 44.89% compared to the fixed flat-plate system [8]. By studying the parameters of Fresnel lens size, its focal point, boiler and condenser types and the solar tracking mechanisms, an efficient Fresnel lens system can be designed and a cost effective solution to the drinking water problem can be achieved.

2. Design and Construction of Fresnel lens Boiler
The system was initially designed using solidworks software having the sub components - Fresnel lens, boiler, water reservoir and tracking system, according to the design specifications as in figure 1. The framework of system is made from wood to reduce the weight of Fresnel lens tracking system thereby enabling the use of a lower capacity servo-motor. Height between boiler and lens was optimised according to focal length of Fresnel lens for maximum efficiency. A slot in the leg made space for servo motor and a stand helped to maintain water level in boiler by adjusting water level in auxiliary tank.

2.1. Fresnel lens
Fresnel lenses are made from optical grade acrylic, have many concentric ridges that create small prisms, reducing the overall material requirement. The continuous surface of a normal lens is divided into a number of surfaces of same curvature with stepwise discontinuities between them. The Fresnel lens chosen has dimensions 345*345mm, Focal length 350 mm and made of Polymethyl methacrylate (PMMA). The maximum energy intensity at focal point on the boiler surface is calculated by the formulae:

\[
\text{Energy Intensity at Focal Point} = \frac{\text{Incident Energy on Fresnel lens} \times \text{Intensity of radiation}}{\text{Area of Focal Point}}
\]

2.2. Boiler
The Boiler is made out of copper due to its high thermal conductivity to obtain highest thermal efficiency. It was coated with black paint to mitigate reflectivity of shiny copper. Steel wool filled inside boiler helped improve convection rate. The boiler contains a water inlet and two outlet one for releasing of steam and the other for hot water. The cylindrical boiler have dimensions of 0.09 m diameter, 0.5 m height giving a volume of 3.18 Litre. The boiler was designed for a maximum allowable working pressure (MAWP) of 2.857 MPa.

2.3. Condenser
Condensation of steam generated in boiler is done by a copper coil. The heat from steam will be absorbed by copper coil and transferred to the air around it. The copper is coiled in spiral manner rather than keeping it straight to increase area for convection and facilitate movement of condensed water out.

2.4. Solar Tracking
The tracking mechanism is designed in such a way that the concentrator is always perpendicular to the rays of the sun. This helps to keep the incident sunlight in focus. Two LDRs and a servo motor are used for tracking and it is seen that both LDRs have same intensity of light incidence. The control unit which is an Arduino UNO microprocessor takes feedback from the LDRs and gives input to the servo motor based on the stored code so that it rotates and maintains the correct alignment of the Fresnel
lens with respect to incident sunlight. Single axis tracking tracks the concentrator with respect to sun only from East to West whereas dual axis solar trackers tracks the concentrator in both the axis providing both North-South and East-West movement. As the North-South movement only covers 23° in six months and vice versa in the remaining half year, this is not a big movement and tracking it isn't viable. This can alternatively be set manually every three days. Thus we have employed a single axis East-West solar tracking system for the Fresnel lens. This system on a clear sunny day automatically tracks the sun using real time data and can even adjust itself to provide optimum focus on cloudy days.

2.4.1. Servomotor (MG995). It is a high speed, high torque variant metal geared servo motor with the ability to move 12 kg/cm precisely along the axes with 180° rotation with 90° rotation in each direction. It also holds good response and holding power. The servo motor is sturdy enough to hold the large Fresnel lens in place even in slightly windy conditions of wind speeds up to 12km/hr without slippage of the metallic gear.

2.4.2. Arduino Uno. It is a micro controller board based on ATmega328P and has 14 digital input and output pins. The coding input is passed via a USB and is stored inside the micro controller. A reset button is present to reset the operation from starting sequence was also supported.

2.4.3. LDR Sensor Module. Two LDR sensor modules are used by mounting them to either ends of the Fresnel lens and connected to the analogue pins of the Arduino board. As the light intensity varies the resistance across the LDR will also vary and the rate of sensitivity can be adjusted with the potentiometer knob included in the module. These sensors provide real time data to the Arduino and this data is utilised in the code to make adjustments to the servo motor rotation based on light intensity difference between the two sensors.

2.4.4. Battery. Three batteries, each having 3.7 V, 2500 mAh, Li-ion rechargeable are assembled in series and a voltage regulator is used to regulate the supply voltage separately to the Arduino Uno board and the servo motor. These Li-ion batteries can last. For up to a week of continuous operation before recharging is needed.

2.4.5. Solar Tracking Software Working. The code (APPENDIX A) is written based on light intensity on the two LDR sensors placed on Fresnel lens frame ends, there is an error that we are inputting and considering as 5 units (between the two LDR sensor input - light intensity). If the absolute value of the difference between the two LDR’s is less than or equal to error input pre-set at 5, then the servo motor holds the same position. If the difference is greater than error, then the servo motor rotates to the

**Figure 1.** CAD Model of the system.  
**Figure 2.** Experimental Setup.
respective direction based on which LDR has greater intensity. This error of 5 is taken as it’s really
difficult to consider a point where there will be equal light intensity on both the LDR’s. Factors like a
shadow or sensor potential and output of readings may not be precise to the dot, hence the error value
of 5 units and less is considered for fixing the position of Fresnel lens.

3. Energy analysis of the system
Steady state energy balance for the Boiler is

\[ Q_{in} = Q_u + Q_l \]

where \( Q_{in} \) is the incident solar radiation (W) \( Q_u \) is useful energy transferred to water to generate steam
in the boiler (W) and \( Q_l \) is net heat loss from the boiler (W).

The incident solar radiation is the total energy from the sun concentrated by the Fresnel lens that is
focused on the boiler is

\[ Q_{in} = \eta_0 I_b A_{Lens} \]

where \( \eta_0 \) is the Optical efficiency of Fresnel lens, \( I_b \) is solar beam radiation (W/m²) and \( A_{Lens} \) is area of
the Fresnel lens (m²).

The useful energy transferred to water to generate steam in the boiler is

\[ Q_u = m_w C_p (100 - T_{win}) + m_w L_w \]

where \( m_w \) is the mass of distilled water (kg), \( C_p \) is the specific heat of water (kJ/kg K), \( T_{win} \) is the
temperature of water at boiler inlet (°C) and \( L_w \) is the Latent heat of vaporisation of water (kJ/kg).

The net heat loss from the boiler is the sum of heat lost due to conduction, convection and radiation
to the surrounding at ambient temperature. The net heat loss is

\[ Q_l = Q_{cond} + Q_{rad} + Q_{conv} \]

where \( Q_{cond} \) is conduction heat loss (W), \( Q_{rad} \) is radiation heat loss (W) and \( Q_{conv} \) is convection heat
loss (W).

The thermal efficiency of the system is

\[ \eta_{th} = \frac{Q_u}{Q_{in}} = \frac{[m_w C_p (100 - T_{win}) + m_w L_w]}{\eta_0 I_b A_{Lens}} \]

4. Experimentation
Testing was carried for three different atmospheric lighting conditions sunny, cloudy and partially
cloudy days to ascertain the proper working of the tracking system. The system was set manually for
South tilt (azimuth angle) in the morning and the East – West tracking of the sun was done by the
tracking system. The tracking system was able to effectively track the sun in all three atmospheric
conditions.

The wooden frame housed the Fresnel lens, boiler and tracking motor; making the whole system
light weight and cheap. The sun tracked Fresnel lens concentrates and focuses sun light onto the
boiler. The incident sun light and its solar irradiance is multiplied through the Fresnel lens at the focal
point on the surface of the copper boiler. The black painted surface improves absorptivity and reduces
reflectivity hence the copper material is able to conduct the incident heat across its surface and into the
boiler. Convection takes place within the boiler and the stainless-steel wool with which the boiler is
filled enhances the surface area in contact with the water inside the boiler from the boiler sides and
walls. The level of water inside the boiler is maintained in between half or three quarters level by
adjusting the water level inside the auxiliary tank which is also placed on the wooden base at slightly
raised in height. Once the boiler is sufficiently filled the valve from the auxiliary tank is closed. The
experimental setup is shown in figure 2. The water in the boiler gains temperature in proportion to
time and eventually attains boiling temperature. The water vapour that rises is passed through the
spiral copper condenser and condense as distilled water and is pure and free of impurities. This water
can be further mineralised and used for consumption.

5. Observation and Results
On a cloudy day the solar irradiance is the least. The clouds moved very slowly and were covering the
sun for the majority of time. On a partially cloudy day the solar irradiance is better than that of a
cloudy day but not as high as that of a clear sunny day. There was constant movement of the clouds and the wind conditions were highest on this day with wind speeds close to 12 km/hr. On a clear sunny day, the water production was maximum.

Thermocouple collected temperature data from three testing points namely; focus point on boiler surface, boiler side walls and the water temperature inside the boiler. There is a noticeable delay to attain the system operating temperature for the water to begin boiling and vaporising. This delay which was recorded to be 105 minutes on a cloudy day, 90 minutes on a partially cloudy day and 75 minutes on a sunny day. Increasing the Fresnel lens size of reduces the delay time. The variation of temperature at the focal point and boiler water temperature with time is shown in figure 3 and figure 4 respectively.

![Figure 3. Temperature at focal point vs time.](image)

![Figure 4. Boiler water temperature vs time.](image)

Figure 5 gives the plot of Time vs Amount of distilled water produced per hour. It is observed that there is no water production in the first hour as this time is need for the system to obtain its operating temperature. Also the amount of water produced was directly proportional to the incident radiation and was maximum at the mid noon (12 – 1 PM). The total amount of water collected on was 1450 ml on cloudy day, 1650 ml on partially cloudy day and 1750 ml on sunny day.

![Figure 5. Amount of distilled water produced per hour vs time.](image)

The tracking system worked efficiently, tracking the sun in all environmental conditions, which is evident from the system output. However during cloudy days, due to irregular shading by clouds, the
tracking system used up a lot of current for constant readjustments. So the energy efficiency of tracking system is greatly reduced during cloudy days.

6. Conclusion
A low cost small-scale water purification system by distillation using Fresnel lens technology was designed, developed and manufactured. A novel and cheap LDR based solar tracking system was developed and integrated into the system. This solar tracking and the coding developed can be carried forward and applied for a large variety of thermal systems that utilise solar irradiation through means of various types of solar collectors. The code developed is given in Appendix 1. The prototype model with a boiler of 3.18 litres and Fresnel lens of 345 x 345 mm gave an average output of 1.6 litres of distilled water. A scaled up system of the model developed can be utilised for household roof-top applications to produce distilled water which can be mineralised and used for drinking purpose.

Future advancements
Scope for future work on the system includes,
1. A copper boiler high amount of thermal losses due to its high thermal conductivity and black coated surface enhanced the radiation loss. Losses from boiler can be reduced by using evacuated glass tube or by means of insulation cover around the boiler excluding the area of line of focus.
2. The time taken to attain the initial boiling temperature can be reduced by increasing the size of the Fresnel lens and enhancing heat transfer into the boiler.
3. Rate of production of condensed water can be increased by using a heat exchanger at the exit of the boiler.
4. Increasing the pressure inside the boiler can facilitate higher rate of steam production. A pressurized chamber can replace the current boiler for better output.
5. Implementing code-correction in solar tracking system to stabilise the system on a cloudy day. On a cloudy day when the clouds come in front of the sun the intensity of the light that hits the LDR sensors changes more often which will lead to a huge correction rate in the tracking which is actually unnecessary; these huge changes can be constrained by modifying the code which will restrict huge movements of the tracking system.
6. Photovoltaic cells can be integrated into the system to recharge the battery source for tracking system, making the system autonomous.

7. References
[1] Kuriakose J Tharamuttama and Keong Ng 2017 Design and development of an automatic solar tracker Energy Procedia 143 629-34
[2] Kritchman E.M Friensem A and Yekuteli A.A. 1979 Efficient Fresnel lens for Solar Concentration Solar Energy 22 Pages 119-23
[3] Wua G Zhenga G XinglongMaa CagriKutlub and YuehongSub 2017 Experimental investigation of a multi-stage humidification-dehumidification desalination system heated directly by a cylindrical Fresnel lens solar concentrator Energy Conversion and Management 241-51
[4] Udawant R.R Mohite K.C. and Takwale M.G. 2016 Study of Performance of Fresnel Lens Solar Concentrator International Journal of Energy Engineering p-ISSN: 2163-1891
[5] Xie W.T Wang R.Z. and Dai Y 2011 Evaluation of a pre-heating system for solar desalination system with linear Fresnel lens Renewable and Sustainable Energy Reviews 2588-606
[6] Mahmoud M.S. and Mohamed AAES 2011 Utilization of Fresnel Lens Solar Collector for Water heating for Desalination by Humidification – Dehumidification Process Fifteenth International Water Technology Conference IWTC 15 1-12
[7] Rinaldi F. Binotti , M Giodori A and Manzolini , G. 2013 Comparison of linear and point focus collectors in solar power plants SolarPACES 1491-500
[8] Chaowanan J Preecha K Sompol K and Himananto W 2020 A low-cost dual-axis solar tracking
system based on digital logic design: Design and Implementation Sustainable Energy Technologies and Assessments 1-24