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# Simulation and Analysis of Fresnel lens Solar Furnace for Aluminium Can Recycling in Nigeria

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**Abstract**

This study examined the solar furnace potentials in the six geo-political zones in Nigeria. The simulation of a Fresnel lens solar furnace for aluminium beverage can recycling have been done. For the simulation, a 1000mm diameter spot Fresnel lens for solar radiation concentration was used. Software tools such as TracePro and SolidWorks were utilized for the simulation study. Radiations from the sun are converged to a point by the Fresnel lens. Solar radiation concentration by the Fresnel lens was simulated in TracePro, and then the resultant heat flux was used in SolidWorks to determine the temperatures attainable and the thermal stress produced by the solar intensities. The solar insolation used for this analysis is limited to the average solar insolation in the six geo-political zones of Nigeria, as obtained from The Global Solar Atlas solar resource map of Nigeria which details the average daily and yearly solar insolation from 1994-2018 (Solargis, 2020). The analysis shows that for a 1000mm diameter fresnel lens, 312.83W/m$^2$ minimum solar radiation is required to raise the temperature of aluminium to 1006.171℃ which is above the pouring temperature (750°C) of aluminium. A fresnel lens of bigger diameter will be required in Southern Nigeria to attain the same heat intensity that a fresnel lens of smaller diameter will attain in Northern Nigeria. The heat flux at the focal point is directly proportional to the diameter of the Fresnel lens i.e. the bigger the Fresnel lens diameter the higher/hotter the heat flux at the focus.

**Keywords:** Aluminium cans, Focal point, Focal diameter, Fresnel lens, Heat flux, Solar furnace, Recycling, Solar radiation.

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## 1. Introduction

Solar energy refers to energy from the sun, it reaches the earth in form of radiation (ultra-violet, visible, infrared radiation etc.). Rani and Fareen (2018) estimated that about 99.9% of the energy flow on the earth's surface is due to incoming solar radiation, the rest is from geothermal, gravitational (tidal) and nuclear sources.
Nigeria is blessed with abundant solar resources in the six geo-political zones. These abundant solar resources have been underutilized. The majority of recycling furnaces are driven by fossil fuel, coal, charcoal, or electricity obtained from either of the aforementioned sources. Given the growing threat posed by climate change activities in Nigeria and other areas of the world, this is not sustainable. In light of this, the current study explores the potential for Fresnel lens solar furnaces in Nigeria.

A Fresnel lens is a component which focuses light onto a single point or a line. There are two types of solar-concentrating fresnel lenses; one is the Spot Fresnel lens and the other is the Linear Fresnel lens. The spot Fresnel lens focuses the light onto a spot on the object and the linear Fresnel lens focuses light onto an entire line on the object (Rajkrishna, 2016). Solar radiation is concentrated by reflection or refraction through mirrors or lenses. The mirrors can be plane, called heliostats, or parabolic; the lenses can be simple lenses or Fresnel lenses (FL) (Gaurav and Karale, 2012). In a lens, the refraction phenomenon is produced on the surface, while the bulk material between the two surfaces doesn't have any influence on 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 (Gaurav and Karale, 2012). The spot Fresnel lens can be used to generate the heat needed to melt the aluminium beverage cans. This is achieved when solar radiation (infrared) from the sun is collected over a large area and then concentrated in a small area called the focal point of the Fresnel lens. The reacting furnace will be composed of a chamber functioning to guide the concentrated sunlight into the furnace, and a thermal insulation and crucible is placed at the Fresnel lens' focal point. Modern Fresnel lenses are mostly made of plastic. Traditional transparent plastic material can withstand reasonably long exposure to sunlight with very small degradation. Ultraviolet (UV) radiation absorbed by plastic can cause a slight loss in transmission and strength. However, this has been mitigated in modern plastic material, such as plexiglass, which is also called polymethyl methacrylate (PMMA). PMMA is the ideal commercially available material for the current application due to its high transparency and flexible strength (Valmiki et al., 2011).

According to Katarína (2014), aluminium is one of the most used metals in the world. It is characterized by a low melting point, which facilitates its processing and recycling. After their use, aluminium cans are suitable to be recycled, which makes them very beneficial to the environment as a secondary raw material. With a tonne of aluminium, more than 60,000 cans of beverages can be produced. The use of 1 ton of recycled aluminium saves 4 tons of bauxite and 700 kg of crude oil. The recycling of aluminium in comparison to the production of aluminium from ore saves 95% of energy. A recycled aluminium can saves enough energy to run a television for three hours. There are also environmental advantages. By recycling it is possible to reduce air pollution by 95% and water by 97% in comparison to the production of aluminium from the ore. Recycling lets also reduce greenhouse gas emissions by 95%. By recovering aluminium cans, people reduce the amount of waste in the natural environment and landfills (Katarína, 2014).

Aluminium beverage cans constitute a percentage of solid waste in Nigeria. Aluminium recycling is one of the most profitable businesses in Nigeria and the world at large. Its popularity can be attributed to the fact that it takes a lesser amount of energy to recycle aluminium scrap when compared to the energy required to get aluminium from its ore. It is, therefore, necessary to harness the available source of energy that will encourage and support the productivity of small and medium enterprises involved in the aluminium recycling business in Nigeria (Chukwudi and Ogunedo, 2017).

Fresnel lens concentrated solar thermal energy has been used for several thermal applications such as material heat treatment, cooking, water desalination, power generation, solar furnace applications etc. Notable of these works are:

Markus (2011), designed a 3D Solar Sinter (Solar powered 3D printer) which he used to print 3D objects with sand and sunlight alone. In his experiment sunlight and sand were used as raw energy and material to produce glass objects using a 3D printing process that combines natural energy and material with high-tech production technology.

Wang et al., (2018), in a bid to overcome the problem of sun-tracking systems of solar concentrators which are expensive, sensitive to operational costs, and complications in optical design. Their work presented a fixed-focus Fresnel lens solar concentrator (FFFSC) using polar-axis tracking which allows the Fresnel lens to concentrate sunlight to a fixed small heat-receiving area and the receiver remained fixed in location and rotation. Experimental research was conducted to obtain the optical characteristics of the FFFSC for different solar times, tracking errors, and periodical adjustment errors. It was found that the maximum values of the relative optical efficiency loss ($\eta_{\text{re-opt, loss}}$) and minimum value of the optical efficiency ($\eta_{\text{opt}}$) of the FFFSC for different solar times are 1.87% and 71.61%, respectively. The mean value and maximum value of the local concentration ratio of the solar flux on the receiver are more than 86.64 and 1319.43, respectively.

Barbara et al., (2017) published a work titled "Advancing Solar Sintering for Building a Base on the Moon" which is a product of the Project RegoLight. They used the Fresnel lens as the concentrated thermal energy collector to build a 3D solar printer or solar sintering machine for the creation of habits during space travel. Solar sintering is a unique AM (Additive Manufacturing) technique which uses only the sun and sand as building materials to produce building elements; making it an ideal way of constructing future habitats on the moon.

Hatakeyama et al., (2016) used a Fresnel lens to produce silicon from volcanic ash. The Silicon was prepared from Shirasu (Japan) volcanic ash using a solar furnace. The solar furnace was composed of two parts; a Fresnel lens made of PMMA (polymethylmethacrylate) and reacting furnace. A Fresnel lens was used to concentrate sunlight onto the reacting furnace where the sample was put on. The sample was made from silica and silicon carbide formed using Shirasu volcanic ash and placed in the carbon crucible inside the reacting furnace. By using the light of the sun concentrated with a Fresnel lens, the sample was irradiated for 3.5 hours and the furnace was left until it cooled down to room temperature. Both irradiating and cooling processes were done under an argon atmosphere. After the experiment, the sample was evaluated by X-ray diffraction. The sample was found to have produced the Si component.

Sandip et al., (2020) in their work "Design of Solar Furnace Using Fresnel Lens", designed a solar furnace for aluminium can melting. The solar energy is concentrated using a Fresnel lens, the setup was made of a swing arm type mechanism where the Fresnel lens will be placed inside a rectangular frame to which arms of length which is equal to the 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 a T-shape, to which two pairs of elevating screws are placed which will be set to match the azimuth angle. Single-axis horizontal axis tracking mechanisms were employed. The chamber was covered to prevent airflow and cover the crucible with thermal insulation material. About 800$^o$C was obtained, and 100 grams of aluminium was melted in about 19 minutes considering all losses. The power developed by the Fresnel lens was 0.087KW.

## 2.0 Material and Methods

For this simulation study, TracePro will be used for ray tracing to determine the heat intensity at the focus, while SolidWorks will be used to conduct thermal analysis using the heat intensity at the focal point since TracePro does not conduct thermal analysis.

### 3.1 Fresnel Lens and Grid Source Modelling

For accuracy and ease of analysis, the standard fresnel lens in TracePro will be used. The fresnel lens menu item opens a modeless dialogue box that allows users to specify a Fresnel lens based on the material and the object and image distances. The dialogue box allows you to enter: Ring width or lines/unit length, Thickness of the substrate, Radius of the lens substrate, Material catalogue, name, and design wavelength, Object distance, Image distance, Origin or location of the centre of the part, and Rotation angles specifying the orientation. TracePro interprets an object or image distance equal to zero as an infinite distance.

The ring width specifies the width of the individual rings in the Fresnel lens, while the lines/unit length specifies the inverse of the ring width: the number of rings per unit length. You can specify either one of these quantities, and the other will be updated. The object and image distances specify point-to-point imaging. After entering all the data for the Fresnel lens, TracePro will build a Fresnel lens with conical facets that provide the requested imaging. The facet angles will be chosen so that light from a point on the left side of the lens at a distance equal to the object distance is imaged optimally into a point at a distance equal to the image distance on the right side of the lens, for the selected material and wavelength.

The grid boundary was set to annular and the grid pattern circular since the shape of the sun is circular. The unit of the source was set at radiometric instead of photometry since we are studying Irradiance (the intensity of light in watts per square meter) and not Illuminance (measuring visible light that is weighted according to the sensitivity of the human eye in Lux) and the lens material selected was PMMA (Polymethyl methacrylate).

#### a. Energy Supplied by a Fresnel Lens

The maximum energy intensity at the focal point of a Fresnel lens according to Demirtas and ¨Ozcan (2020). is calculated by the formulae:

$$\text{Incident Energy on Fresnel lens} = \text{Area of Fresnel lens x Intensity of radiation} \quad (3.1)$$

$$\text{Incident Energy on Fresnel lens } Q_{in} = \eta_0 I_b A_{lens} \quad (3.2)$$

Where

$\eta_0$ = Optical efficiency of Fresnel lens

$I_b$ = solar beam radiation (W/m$^2$) and

$A_{lens}$ = area of the Fresnel lens (m$^2$).

$$\text{Energy Intensity at Focal Point} = \frac{\text{Incident Energy on Fresnel lens(W)}}{\text{Area of Focal Point}} \quad (3.3)$$

## 3.2 Energy Required to Melt One Aluminium Beverage Can

### i. Required solar heat estimation

a. Useful heat $Q_{req}$ required to cause melting, b. Focal heat loss $Q_{loss}$: Heat lost from the lens' focal area due to convection and radiation. It is calculated based on the desired focal properties like material, diameter, temperature and ambient conditions (Bergman et al. 2011).

$$Q_{est} = Q_{req} + Q_{loss} \tag{3.4}$$

Where $Q_{est}$ is the estimated required heat energy, $Q_{loss}$ is net heat loss and $Q_{req}$ is useful energy transferred

### ii. Energy Required to Melt Aluminium

$Q_{req}$ The useful heat energy required to raise the temperature of aluminium (solid) through its melting point temperature (660℃) to its required pouring temperature (750℃) (Owolabi et al., 2020), is determined by:

$$Q_{req} = Q_1 + Q_2 + Q_3 \tag{3.5}$$

Where

$Q_1$ = Heat is required to raise the temperature of solid aluminium from room temperature (25℃) to its melting temperature.

$$Q_1 = \mathrm{m}\, C_s\, (T_m - T_r) \tag{3.6}$$

Where m = Mass of aluminium

$C_s$= Specific heat capacity of aluminium (Solid)

$T_m$ = Melting point temperature of aluminium

$T_r$ = Room temperature.

$Q_2$ = Heat required to change solid aluminium to molten aluminium metal

$$Q_2 = \mathrm{mL} \tag{3.7}$$

Where m = Mass of aluminium

L = latent heat of fusion of aluminium

$Q_3$ = Heat is required to raise the temperature of molten aluminium from its melting point to the required pouring temperature (750℃) (Owolabi et al., 2020)

$$Q_3 = \mathrm{m}\, C_m\, (T_p - T_m) \tag{3.8}$$

Where $C_m$ = Specific heat capacity of molten aluminium

$T_p$ = Pouring temperature of aluminium

$T_m$ = Melting point temperature of aluminium

In this study, one aluminium beverage can will be considered.
The mass of one 375ml aluminium beverage can = 15grams (Average)
Latent heat of fusion L = 396KJ/kg (Kaufman, 2016)
Specific heat capacity of solid aluminium = 0.9KJ/kg.K (Kaufman, 2016)
Specific heat capacity of molten aluminium = 1.18KJ/Kg.K. (Kaufman, 2016)
Mass of aluminium = 0.015kg
Melting Point temperature of Aluminum $T_m$= 660℃
Ambient temperature $T_r$ =25℃
Pouring temperature of aluminium $T_p$ = 750℃

$$Q_1 = \mathrm{m}\, C_s\, (T_m - T_r) \tag{3.9}$$

$$Q_2 = \mathrm{mL} \tag{3.10}$$

$$Q_3 = \mathrm{m}\, C_m\, (T_p - T_m) \tag{3.11}$$

Therefore total heat

$$Q_{req} = Q_1 + Q_2 + Q_3 \quad = \mathrm{m}\, C_s\, (T_m - T_r) + \mathrm{mL} + \mathrm{m}\, C_m\, (T_p - T_m) \tag{3.12}$$

### iii. Net heat loss

The net heat loss is the sum of heat lost due to conduction, convection and radiation to the surrounding. (Bergman et al. 2011).

The net heat loss is

$$Q_{loss} = Q_{cond} + Q_{rad} + Q_{conv} \tag{3.13}$$

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

$$Q_{cond} = \frac{\mathrm{KA}(T_r - T_p)\,.\mathrm{t}}{\mathrm{dx}} \tag{3.14}$$

Where A = surface area of heat flow
$(T_r - T_p)$ = temperature difference between the two surfaces
dx = thickness of the body in the direction of flow
K = thermal conductivity of the material W $m^{-1}$ $k^{-1}$

$$Q_{conv} = hA(t_1 - t_2) \tag{3.15}$$

Where h = co-efficient of convective heat transfer
A = area of surface
$(t_1 - t_2)$ = temperature difference between the fluid and the surface.

$$Q_{rad} = \delta A T^4 \tag{3.16}$$
$$Q_{rad} = \delta A(T_p^4 - T_r^4) \tag{3.17}$$

Where A = radiation area of black body
δ = Stefan Boltzmann constant
T = absolute temperature

## 3.0 Results and Discussions

In TracePro modelling, the Monte Carlo method is used to simulate the scattering and diffraction of light, and to sample the distributions of rays emanating from light sources. Light moves in discrete directions that can be precisely modelled by ray tracing in the absence of scattering and diffraction processes. On the other hand, light that scatters from a surface disperses continuously. In theory, one could calculate the exact propagation of light by cascading this distribution with the distribution produced by the subsequent surface, and so on, up until the irradiance in the light field is so low that it can be disregarded.

## 4.1 Test and Applications

The Global Solar Atlas (an online map-based application that provides information on solar resources globally) published a Solar resource map of Nigeria which details the average daily and yearly solar insolation from 1994-2018 (Solargis, 2020) as depicted in table 4.1. This data will be used as reference data to simulate the practicability of fresnel lens solar furnaces in the six geo-political zones in Nigeria.

4.1.1 Experiment condition
Fresnel lens Diameter = 1000mm
Fresnel lens Focal Length = 1029mm
Atmospheric Temperature = 27°C

## 4.2 Solar-Ray Tracing Using TracePro

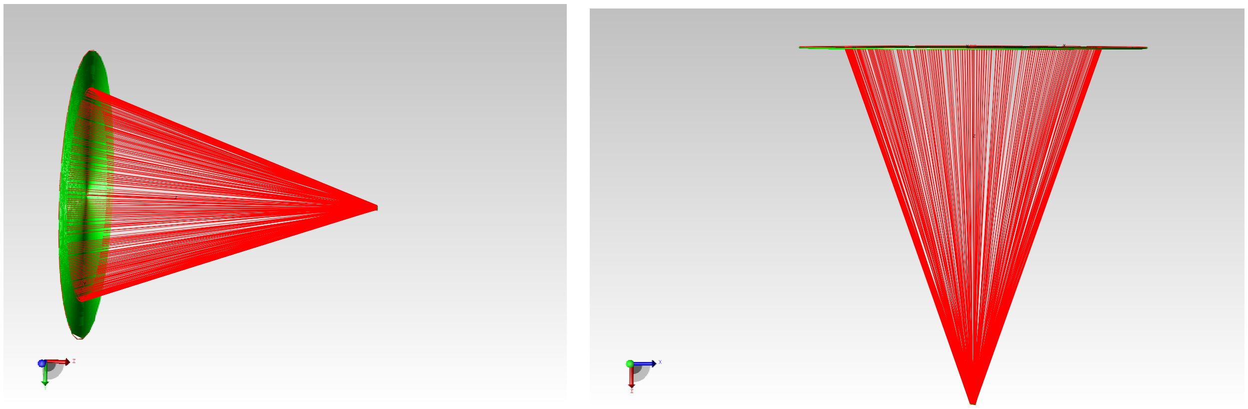
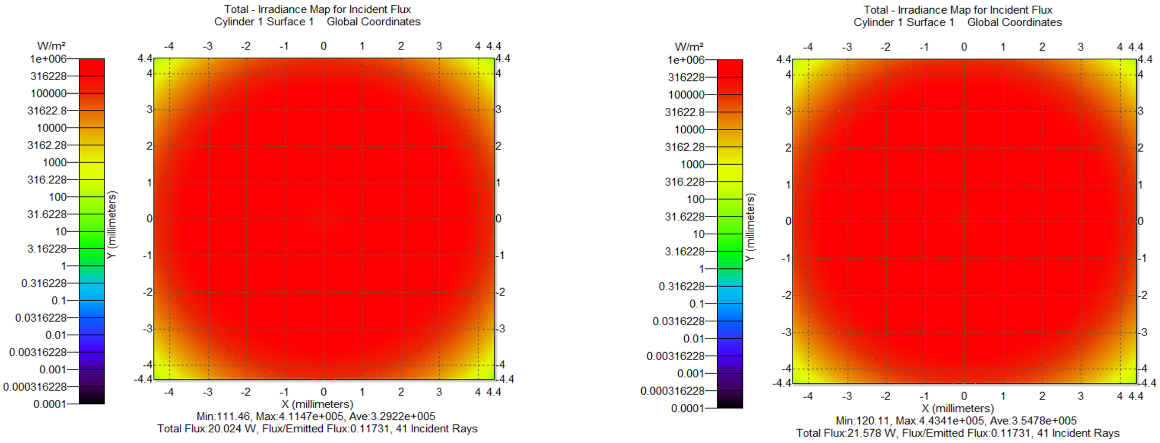
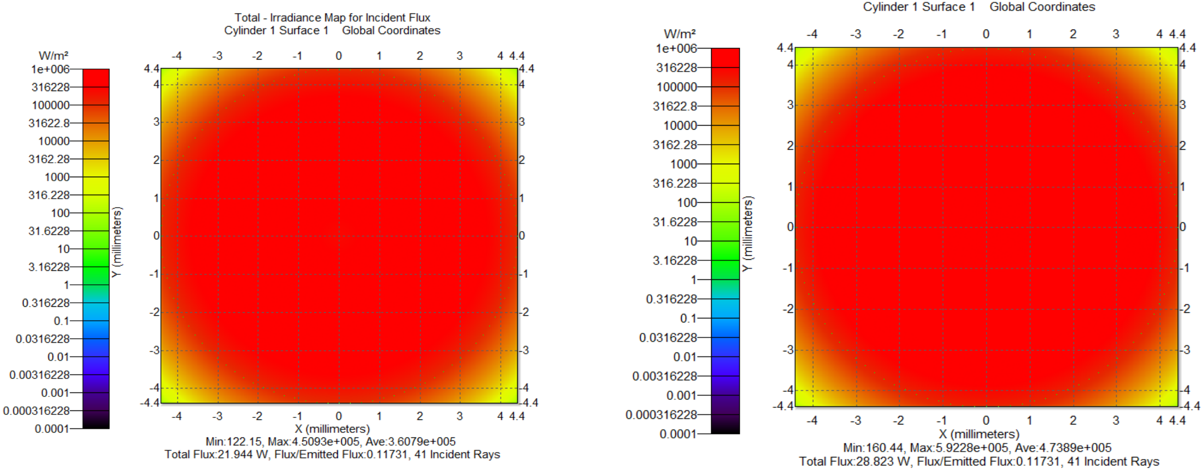


Figure 4.1: Ray trace to the focal point of the Fresnel lens using TracePro



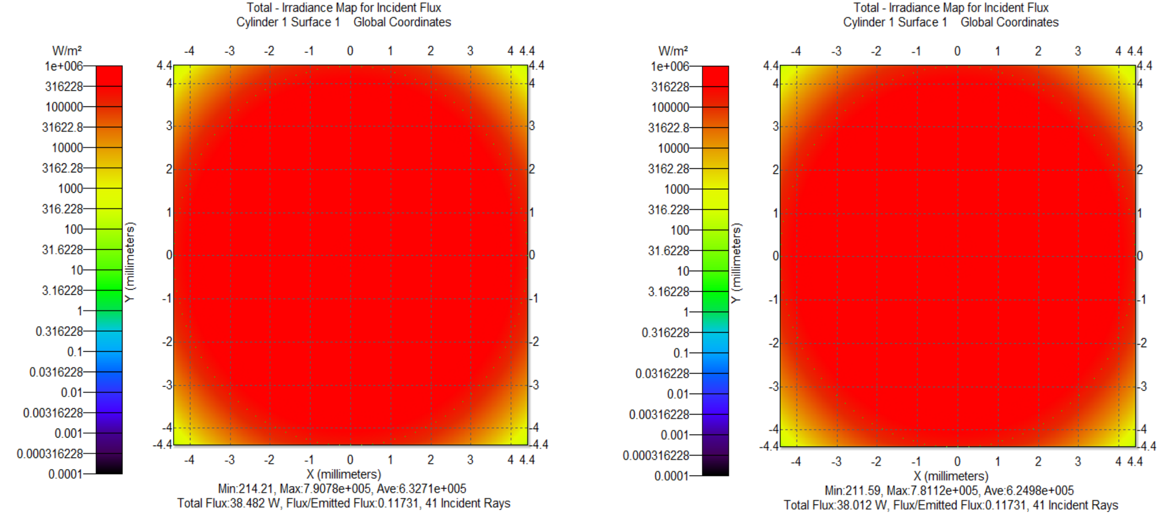
(a) At 217.33W/m$^2$ Insolation

(b) At 234.2W/m$^2$ Insolation



(c) At 238.17W/m$^2$ Insolation

(d) At 312.83 W/m$^2$ Insolation



(e) At 412.57 W/m$^2$ Insolation

(f) At 417.67W/m$^2$ Insolation

Figure 4.2: Irradiance Map of incident rays at the focus of a Fresnel lens using the insolation for the six geo-political zones in Nigeria

The solar ray convergence was simulated using TracePro Expert – 7.3.4. The simulated rays traced to the focal point are displayed in figure 4.1. The grid boundary was set to annular and the grid pattern circular since the shape of the sun is circular. The unit of the source was set at radiometric instead of photometry since the study is on irradiance (the intensity of light in watts per square meter) and not luminance (measuring visible light that is weighted according to the sensitivity of the human eye in Lux) and the lens material selected was PMMA (Polymethyl methacrylate). The solar radiation was set at 312.83 W/m$^2$, 417.67 W/m$^2$, 412.57 W/m$^2$, 234.2 W/m$^2$, 217.33 W/m$^2$, and 238.17 W/m$^2$.

Table 4.1: Solar Insolation in Six Geo-Political Zones in Nigeria. (Solargis, 2020)

| S/N | Zones | DNI (Direct Normal Irradiation) (W/m²) | Air temp (°C) |
|---|---|---|---|
| 1 | North Central | 312.83 | 27.31666667 |
| 2 | North East | 417.67 | 27.15 |
| 3 | North West | 412.57 | 27.21428571 |
| 4 | South East | 234.2 | 26.66 |
| 5 | South South | 217.33 | 26.3 |
| 6 | South West | 238.17 | 26.13333333 |

The irradiance map for the incident rays at the focal point is displayed in figure 4.2, it shows the energy distribution at the focal point for 312.83 W/m$^2$, 417.67 W/m$^2$, 412.57 W/m$^2$, 234.2 W/m$^2$, 217.33 W/m$^2$, and 238.17 W/m$^2$. The minimum and maximum solar irradiance at the focal point are also displayed. The heat intensity is highest towards the centre as depicted by the bright red circle between -7.5 to 7.5 in figure 4.2, the solar irradiance drops outwards as depicted by the orange region.

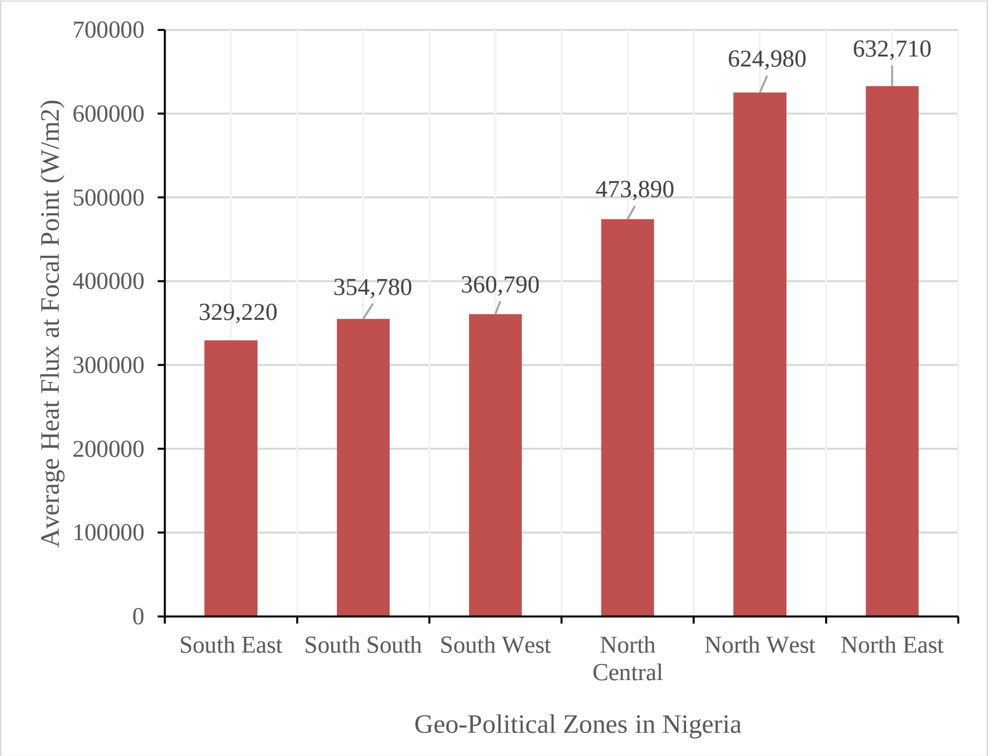


Figure 4.3: The Average Irradiance at the Focus Area for the Solar Irradiance for each Geo-Political Zones.

The average heat flux at the focus area for each geo-political region is displayed in figure 4.3. It shows the average heat flux obtainable for North Central, North East, North West, South East, South-South, South West with solar radiation set at 312.83 W/m$^2$, 417.67 W/m$^2$, 412.57 W/m$^2$, 234.2 W/m$^2$, 217.33 W/m$^2$, and 238.17 W/m$^2$ respectively.

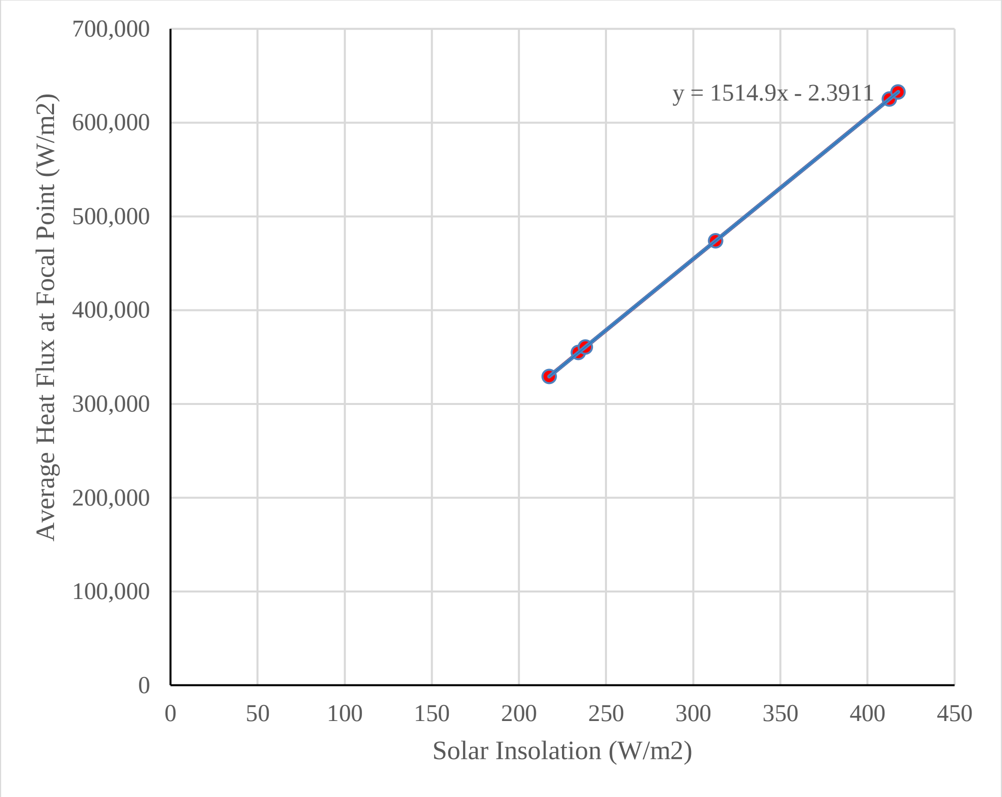


Figure 4.4: Graph of Solar Insolation (W/m$^2$) against Average Heat Flux at Focal Point (W/m$^2$) for each geo-political zone.

$$y = 1514.9x - 2.3911 \tag{4.1}$$

Where y = Average Heat Flux at Focal Point (W/m$^2$)

$\boldsymbol{x}$ = Solar Insolation (W/m$^2$)

Figure 4.4 displays the relationship between solar insolation (W/m$^2$) against average heat flux at the focal point (W/m$^2$). It shows that there is a linear relation between solar insolation (W/m$^2$) against average heat flux at the focal point (W/m$^2$). Thus the higher the solar insolation or radiation the higher the heat flux at the focal area and the higher the obtainable temperature.

## 4.3 Steady State Thermal Analysis of Aluminium Beverage Can Using Solidworks2017

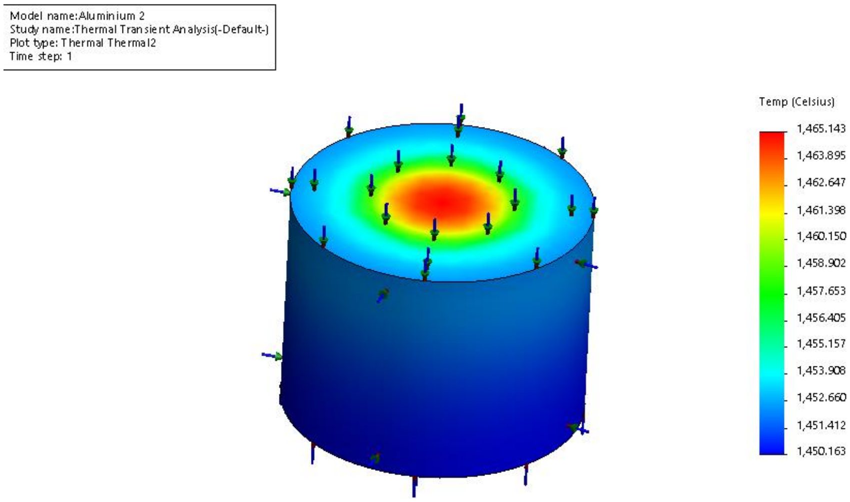


Figure 4.5: Steady state thermal analysis of average heat flux in North Eastern Nigeria

The average heat flux at the focus gotten at different solar intensities from TracePro was used to conduct a transient thermal analysis on an aluminium material (Al 3004) to determine the maximum temperature attainable by the solar intensities on the aluminium material. From the ray trace simulated in TracePro the focal spot diameter is about 9.6mm, so an equivalent heat intensity was applied to and an aluminium material of 20mm diameter and a thickness of 20mm, then simulated using SolidWorks thermal simulation to determine the maximum temperature at a steady state, since TracePro cannot provide that information. Figure 4.5 shows the temperature distribution of the aluminium medium when subjected to a heat flux of 632,710W/m$^2$. Figure 4.6 displays the steady state maximum temperature obtainable by solar radiations for the six geo-political zones in Nigeria.

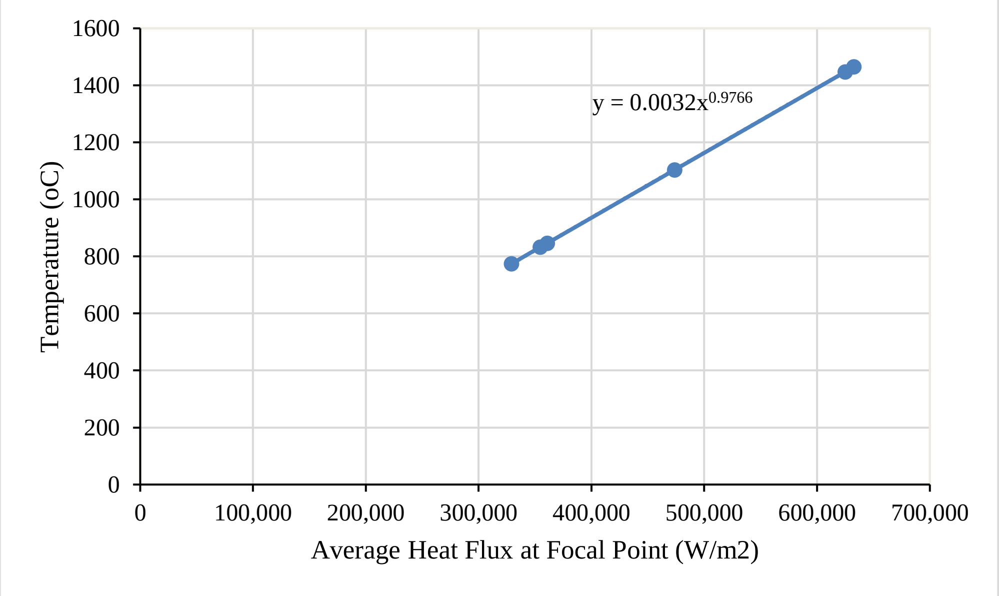


Figure 4.6: Maximum Temperature at the Focus Area for the Solar Irradiance for each Geo-Political Zones

### 4.4 Transient Thermal Analysis of Aluminium Beverage Can be Using Solidworks 2017

The average heat flux at the focus gotten at different solar intensities from TracePro was used to conduct a transient thermal analysis on an aluminium material (Al 3004) to determine the transient temperatures of the solar intensities and the time taken to get to the steady state temperature. 1200sec at 6 steps (200sec each step) was considered during the analysis, a convection coefficient of 25 W/m.k for still air was used, the initial temperature of the model was placed at 27ºC and the ambient bulk temperature of convection was placed at 27ºC.

Figure 4.7 shows that the temperatures obtained in Southeast, Southsouth, and Southwest with average solar intensities of 234.2 W/m$^2$, 217.33 W/m$^2$, and 238.17 W/m$^2$ with a Fresnel lens diameter of 1000mm won't be sufficient to melt aluminium medium because losses by conduction and radiation will further drop the effective temperature, thus it does not get to the pouring temperature of aluminium. However, the same average solar intensity of Southeast, South-south and Southwest can melt an aluminium beverage can if the diameter of the Fresnel lens is increased. The resultant temperature for North-central, Northwest and Northeast shows good prospects for the prevailing design. This shows that for the same heat requirement a bigger Fresnel lens will be required in SE, SS and SW to attain the temperature that a small Fresnel lens will attain in NC, NW, and NE.

Figure 4.7 shows the graph of the transient thermal analysis. It depicts how the temperature of the medium increased with time until it got to its steady-state temperature for each geo-political zone. The Northeast has the highest temperature at 1341.743℃ for an average solar irradiation of 417.67 W/m$^2$, while the Southeast had a temperature of 700.496℃ for an average solar irradiation of 217.33W/m$^2$. Also, figure 4.7 shows that the rate of temperature increase drops drastically with time. This indicates that the thermal conductivity of aluminium (Al 3004) decreases with an increase in temperature.

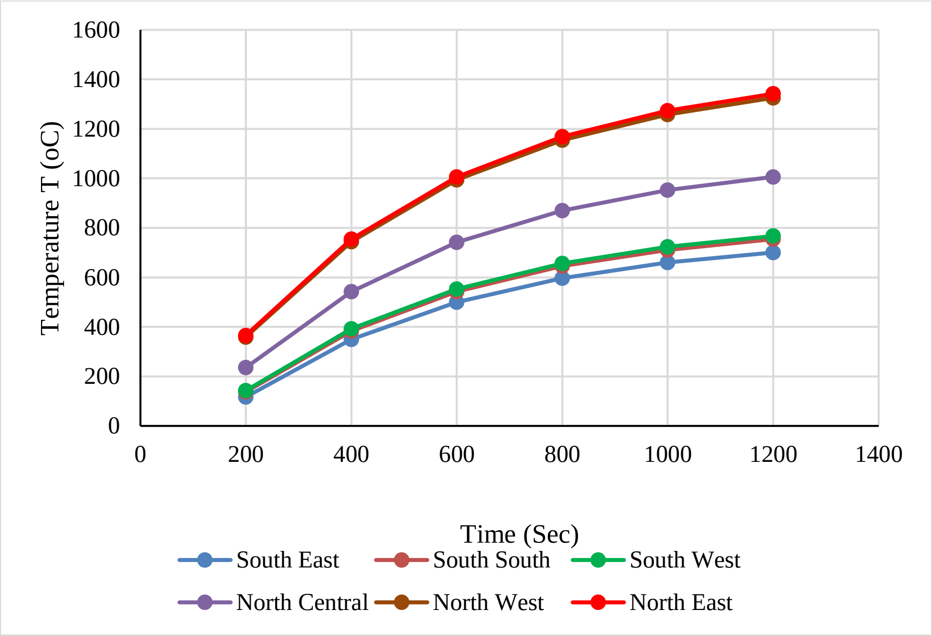


Figure 4.7: Graph of temperature (Celsius) against time (sec) for different geo-political zones

## 4.5 Von Mises Stress

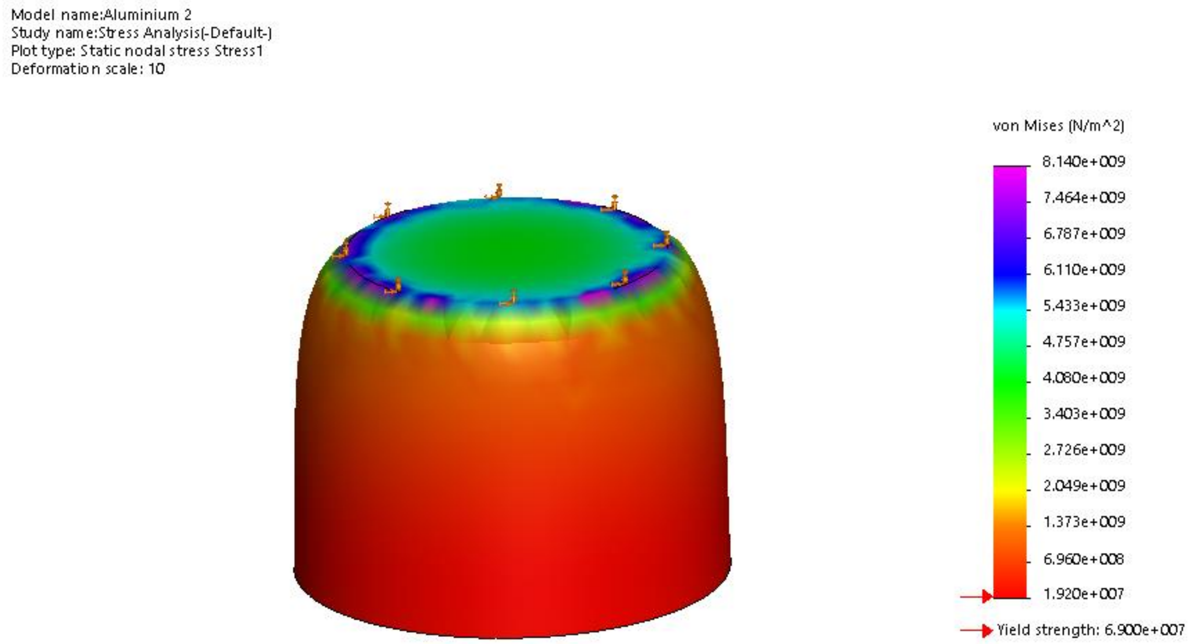


Figure 4.8: Von Mises stress

Von Mises stress is a value used to determine if a given material will yield or fracture. It is mostly used for ductile materials, such as metals. The von Mises yield criterion states that if the von Mises stress of a material under load is equal to or greater than the yield limit of the same material under simple tension then the material will yield. The simulation shows that after step 2 (400sec) after the ray incident, the stress at every point of the aluminium medium exceeded the yield strength of the material which is about 6.9 x $10^7$N/$m^2$ as shown in figure 4.8. Thus the material structure failed after 400sec, thereby further confirming that the material will melt at an average irradiance of $632,710W/m^2$

## 4.0. Conclusion

In recent years, the energy crisis and global warming have pushed scientists to search for alternative energy sources and alternative methods, to overcome the problems of depleting energy resources and climate change. There is huge potential for solar thermal applications due to the abundant solar energy resources in Nigeria.

This work is on the use of a fresnel lens solar furnace for aluminium can recycling in Nigeria, From the analysis and simulations done. The following conclusions are made from the study;

- The analysis shows that, for a 1000mm diameter fresnel lens, 312.83W/m2 minimum solar radiation is required to raise the temperature of aluminium to 1006.171℃ which is above the pouring temperature (750℃) of aluminium.
- A fresnel lens of bigger diameter will be required in Southern Nigeria to attain the same heat intensity that a fresnel lens of smaller diameter will attain in Northern Nigeria.
- The fresnel lens diameter is directly proportional to the size of the focal point i.e. the bigger the Fresnel lens diameter the bigger the focal point size.
- The heat flux at the focal point is directly proportional to the diameter of the Fresnel lens i.e. the bigger the Fresnel lens diameter the higher/hotter the heat flux at the focus.

## 5.0 Recommendation

The following are recommended for improved operation and better utilization of fresnel lens solar furnaces in Nigeria.

- As the menace of global warming is on the rise. It is recommended that Fresnel lens solar furnaces should be employed in aluminium can recycling, especially in Northern Nigeria where higher heat intensity can be achieved at a lower cost.
- Research should be conducted on the production of the Fresnel lens locally, due to the difficulty of importing the Fresnel lens.

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