NIPES

Journal of Energy Technology and Environment

Journal homepage: www.nipesjournals.org.ng

# Development of Biogas Burner Stove from Aluminum Alloy Scraps

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**Article information**

*Article History*
Received 7 April 2022
Revised 28 April 2022
Accepted 4 May 2012
Available online 13 June 2022

*Keywords*:
*Aluminum alloy scrap, Flame transmission, Biogas burner stove, Biogas digester*

https://doi.org/10.37933/nipes.e/4.2.2022.3

**https://nipesjournals.org.ng**


**Abstract**

*Waste associated with scraps from aluminum alloy cans and containers are on the increase with low recycling capacity in Nigeria. Equally too, sustainable utilization of methane (from biogas) generated from bio-waste for household cooking and heating applications is gaining greater attention currently, due to environmental concerns from fossil fuel. Recycling of these wastes would reduce environmental pollution arising from them. In this work, a single aluminum burner biogas stove was designed, developed and its performance was evaluated using biogas generated from a mobile 200 liters' biogas digester plant at the Federal University of Petroleum Resources Effurun, Nigeria. The aluminum alloy biogas burner was manufactured using sand casting method. The thermal analysis were conducted for the biogas burner stove. The biogas digester plant was operated with the co-digestion of cattle dung and poultry droppings as feed stock in the ratio 1:2 and water substrate ratio of 1:0.5. The system operated at a retention time of 30 days. The performance of the burner was analyzed and evaluated. An average of 3.10 seconds flame transmission time for the burner port-holes with burner stove efficiency of 50%, were recorded. Also, an average of 0.24 $m^3$ /min methane from biogas boiled about 1 litres of $H_2O$ in approximately 8.5 minutes*

## 1. Introduction

The need for recycling of scraps from metals such as aluminum cans are on the increase as a results of economic and environmental benefits. Environmental pollution from solid waste, scraps, and Carbon (IV) oxide emission from utilization of fossil fuel are matters of concern round the world. Reduction on the effect of carbon emission globally has necessitated the search for alternative sources of fuel and energy [1].

The advancement in harnessing and utilization of biogas has steered the development of biogas appliances for household applications, heating and electricity generation world-wide [2]. Bio-waste generation, biogas stove designs and applications using various ferrous metals materials with emphasis on cost consideration, availability, heat treatment and functionality have been researched [3-5]. Biogas burners are designed to meet low pressure gas generated from bio-waste [6-7]. The combustion efficiency of biogas depends on its Calorific value. Good combustion efficiency depends appropriately on the $O_2$ and $CO_2$ contents in the final combustion mixture [8].

Some researchers also had worked on biogas burner stove development and efficiency consideration. For example, Vianney et al[9] conducted a review on biogas applications used in

Sub-Saharan Africa. Likewise, Orhorhoro et al[10] designed and constructed an improved biogas fuel from medium carbon steel material and they obtained an average efficiency of biogas stove to be 56.89 %. Itodo et al[11] also reported the performance of a biogas stove developed by them and found that the efficiency of the stove for boiling water, cooking rice and beans were 20%, 56% and 53%, respectively. Relatedly, biogas stove developed by Kurchania et al[12] for energy needs had a thermal efficiency of 60.01% and the emission of $CO_2$ during combustion was measured approximately between 150 and 180 ppm [13, 14]. Equally too, Hira[2] developed a multi criteria decision making (MCDM) methodology based on Analytical Hierarchy Process (AHP) to evaluate biomass energy alternative and they observed that AHP model was able to determine and rank the best cooking stove alternative in Sindh.

Furthermore, several materials such as mild steel, brass, etc had been employed in the development of biogas burner and stove. However, from literature, it has been observed that limited attention has been given to the application of scrapped Aluminum alloy cans and containers as suitable materials for the fabrication of biogas burner. The application of scrapped Aluminum cans and containers would help in solid waste reduction and environmental management. Hence this work seeks to design, develop and simulate Aluminum alloy scraps biogas burner stove

## 2. Methodology

In attempt to recycle aluminum alloy scraps and to utilize the biogas produced for domestic proposes, a biogas burner was developed at the Laboratory and workshop, in the Department of Mechanical Engineering, Federal University of Petroleum Resources Effurun, Delta State, Nigeria. Some parameters were considered during the design stage of the work, namely; air requirement for complete combustion, injector orifice, flame port, etc [10]. The computation and analysis of each required component were done in line with the procedure suggested by [6].

The sequence of design process for the development of a single burner made from scrapped aluminum alloys, entails the followings;

i. Generation of Biogas from cow-dung, poultry droppings

ii. Purification and storage of Biogas

iii. Design of Burner and Cooker (CAD)

iv. Sorting and Preparation of Aluminum wastes

v. Casting of Burner head (Foundry process)

vi. Fabrication of stove frame

viii. Assembly of parts

ix. Testing and evaluation

### *2.1. Materials*

The materials employed for the fabrication of the biogas single burner and the biogas generated, were Aluminum alloy scraps which were obtained from waste cans and containers (figure 1), and a modified 200 liters bio-disgester mobile plant developed by [15], respectively, at the Mechanical Engineering workshop, Federal University of Petroleum Resources Effurun, Delta State, Nigeria. The Biogas digester was made from mild steel with 2 mm thickness. It has a volume of 200 liters for anaerobic digestion. The generated biogas was cleaned to remove the associated impurities. A desulphuriser was employed to manage the hydrogen sulfide ($H_2S$) in the gas while activated carbon was introduced, to absorb the carbon dioxide ($CO_2$) present. The gas was dried using silica gel and collected in a tyretube ready for testing on the fabricated aluminum burner stove.

Fig 1. Crushed Aluminum alloy waste cans and Containers

*2.1.1 Materials Used for Aluminum Burner*

The following were the materials used for the development of the aluminum biogas burner stove [2]:

i. Gas regulator or control
ii. Aluminum sheet: employed for the covering/wrapping of the skeletal framework
iii. Four (4) set of rubber stands
iv. Copper pipe: connect the gas regulator and the gas inlet hose from the gas collector tank.
v. Angle iron: four (4) pairs of angle iron was used for the skeletal frame work
vi. Galvanized pipe: used to connect the Aluminum burner to the gas regulator
vii. Aluminum inside cover: designed to cover the burner head area
viii. Pin: used to join the Aluminum sheet together
ix. Two flat bar: used for the inside the cooker
x. Aluminum burner: this was fabricated using sand casting foundry process

*2.2. Methods*

The biogas stove was intended to meet basic requirements, such as ease of cleaning, repair, improve combustion properties, safety, and ergonomics. Some mathematical expressions were adopted from [10, 13] for the design of some components. It includes the followings

*2.2.1 Air requirement for complete Combustion*

Air (Oxygen) requirement for complete combustion of the methane could be expressed in equation 1, [10, 13];

$$CH_4 + 2O_2 \rightarrow CO_2(g) + 2H_2O \quad (1)$$

*2.2.2 Gas Flow Design*

From Bernoulli's theorem, the pressure of gas in the pipe/hose could be expressed in equation 2 [6] as;

$$\frac{p}{\rho} + \frac{v^2}{2g} - f(\text{losses}) = \text{constant} \qquad (2)$$

where,
P = Gas pressure ($Nm^{-2}$)
P = gas density ($kgm^{-3}$)
V = the gas velocity ($ms^{-1}$)
g = 9.81 $ms^{-2}$
f = energy losses due to friction

*2.2.3 Injector Orifice and Venturi Design*

The flow rate Q, at the injector orifice could be expressed as [6]:

$$Q = 0.0467\, C_d\, A_0 \sqrt{\frac{p}{s}} \qquad (3)$$

Where,
Q = flow rate ($m^3h^{-1}$)
$A_0$ = area of orifice ($mm^2$)
p = presure before orifice (mbar)
s = specific gravity of gas
$C_d$ = coefficient of orifice discharge; it accounts for the vena contractor and friction losses.

*2.2.4 Burner and Frame ports*

The flame-port diameter could be expressed as [10, 11, 17];

$$\frac{A_p}{A_o} = (r+1)(r+d)\sqrt{\frac{[F(2+C_F)]}{dC_{dp}}} \qquad (4)$$

Where,
D = diameter of frame port
r = Ratio of entrained -jet fluid
$A_p$ = Area of burner port ($mm^2$)
$A_o$ = Area of Injector orifice ($mm^2$)
$C_{dp}$ = Discharge coefficient of burner ports
$C_F$ = Frictional-loss Coefficient

*2.2.5 Biogas Burner Power, the cooking/boiling rate (Cr), rate of biogas consumption (Q), and efficiency of burner (η)*

i. The power could be expressed as [10, 17];

$$P = \frac{M_f . L}{t} \qquad (5)$$

where,

$P$ = Biogas burner power (W)
$M_f$ = Mass of fuel consumed (kg)
$L$ = Latent heat of evaporated
$t$ = time (min)

ii. The cooking/boiling rate (Cr), biogas consumption rate (Q), and burner efficiency (η) were determined from equations 6-8, respectively [10, 11, 17].

$$C_r = \frac{\text{quantity}}{\text{time taken (min)}} \quad (6)$$

$$Q\left(\frac{m^3}{h}\right) = \sqrt[c]{\frac{\delta p d^3}{\rho L}} \quad (7)$$

Where Q = quantity of flow $m^3/h$
c = pipe pressure drop
$\delta p$ = change in pressure drop
d = Hose diameter
$\rho$ = air density
L = distance between manometers

$$\eta = \frac{C_r}{Q} \times 100\% \quad (8)$$

*2.3 Foundry Process of Aluminum Burner*

The impurities were separated from the aluminum scrap during the sorting and preparation for sandcasting foundry process. Aluminum scraps such as waste cans and containers were sorted and prepared for the foundry process. The furnace was used to liquefy the aluminum scraps above the melting temperature to obtain molten aluminum alloy, which was poured into the prepared designed mold and allow to solidify to obtain the required aluminum burner.

*2.3.1 Materials and Procedures used for the foundry process*

The materials used are as follows;

i. Furnace
ii. Mold Box
iii. Mold sand
iv. Ramming stick
v. Runner (rod)
vi. Parting powder/Separation chemical
vii. Water
viii. Foam
ix. Pattern

The procedure for the foundry process adopted for the design of the Aluminum gas burner is listed below;

i. Preparation of the sand mold by mixing appropriately to produce fine grains
ii. Insert the pattern into the mold box

iii. The ramming stick is used to prepare the sand to create compactness/tightness within the box. This continue until the shape is formed on the mold sand
iv. Desired shape obtained on the mold sand, the pattern is removed from the mold box
v. The separating powder chemical (ash) is applied to the surface of the shape formed on the mold sand. The two molds are allowed to dry up before casting is carried out.
vi. Before casting, the two molds are placed on top of each other. The molten Aluminum metal is poured into the set mold and allowed to solidify for about an hour (1 hour).
vii. After solification, de-molding and finishing processes were done.

*2.4 Design of the Burner Stove*

Solid works version 2016 software was used to design and model the aluminum alloy burner stove and its properties simulated. The 2 and 3-dimensional drawings of assembly of the biogas burner stove are shown in figures 2 to 4.

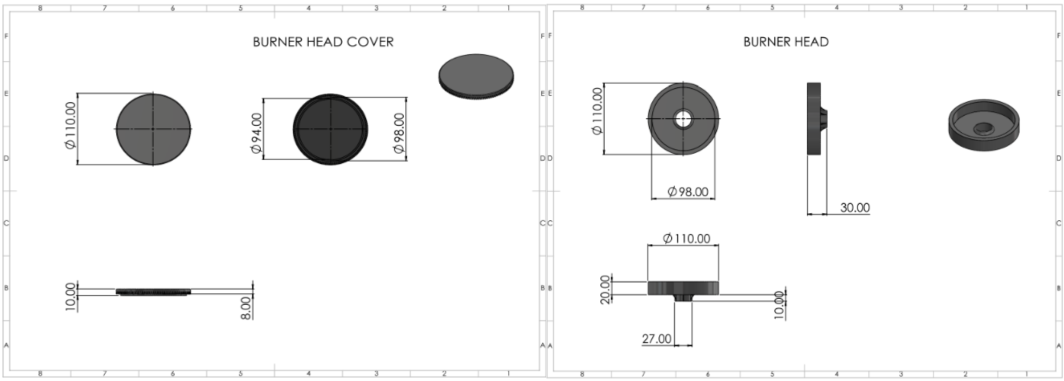



Fig 2. Burner Head Cover Drawings

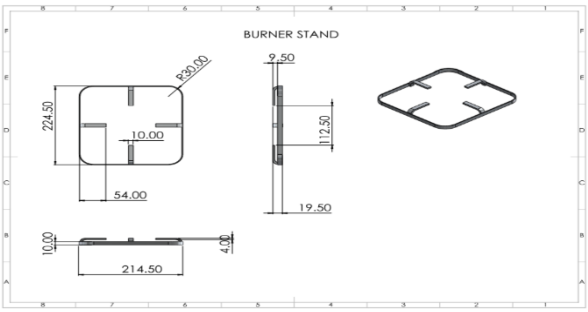



Fig 3. Burner Top Stand 2-Dimensionl Drawings

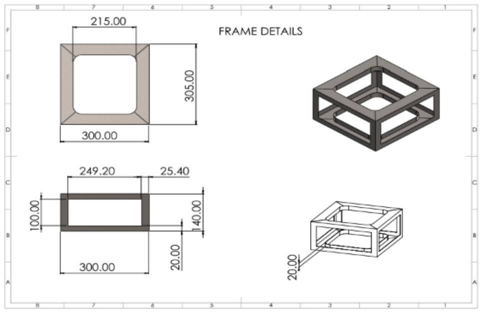



Fig 4 Biogas Stove Frame Drawing

## 3. Results and Discussion

*3.1 Performance Evaluation of burner*

The biogas burner fabricated with the scrapped aluminum alloy is depicted in figure 5, its dimension presented in table 1 and the setup shown in figure 6. During the testing of the burner, the stove was used to heat up four sets of one litre of water from ambient temperature to about 98˚C, and the time taken were recorded (table 2). From table 2, the performance of the burner was analyzed and evaluated. An average of 3.10 seconds flame transmission time for the burner port-holes with burner stove efficiency of 50%, were recorded. Also, an average of 0.24 $m^3$ /min methane from biogas boiled about 1 litres of water ($H_2O$) in approximately 8.5 minutes.

Fig 5: Actual Picture of the Fabricated Biogas Burner/Stove with Aluminum alloy Scraps

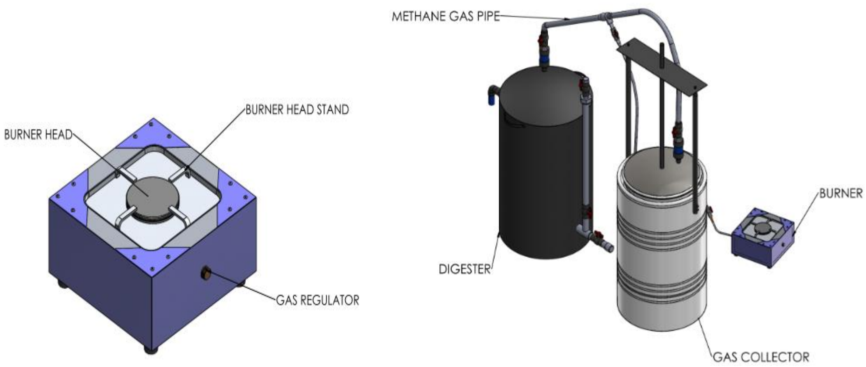



Fig. 6: Biogas Digester and Stove System Setup

Table 1. Dimension of Fabricated Aluminum Biogas Stove

| Parameter | Dimension (mm) |
|---|---|
| Pot above Burner | 30 |
| Diameter of ports | 4.5 |
| Height of frame | 140 |
| Diameter of frame | 300 |

Table 2. Performance Evaluation of the Biogas burner Stove

| Parameter | Water | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | Average |
| Qty. of water (litre) | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| Time / Duration (mins) | 8.5 | 8.00 | 8.80 | 8.50 | 8.50 |
| Time for all jets to ignite (secs) | 3.10 | 2.95 | 3.20 | 3.00 | 3.10 |
| Cooking/boiling rate $C_R$ (litre/min) | 0.12 | 0.13 | 0.11 | 0.12 | 0.12 |
| Biogas consumption rate Q ($m^3$/min) | 0.24 | 0.25 | 0.24 | 0.24 | 0.24 |
| Efficiency of Burner (%) | 50 | | | | |

*3.2 Thermal Simulation of Aluminum Biogas Stove*

Solid works software was used to simulate the heat/thermal distribution in the biogas stove. The thermal analysis shows the temperature distribution from the aluminum burner head to the entire stove. The units used for the analysis are presented in table 3. The stove model with its mesh formation and volumetric properties are shown in figures 7 and 8, respectively. The material properties of the Aluminum used for the fabrication of the biogas burner stove is presented in figure 9. Aluminum LM25 Alloy with thermal conductivity of 170W/(m.K), specific heat of 1000J/(kg.K) and Mass density of 2700kg/m$^3$ was selected in the modelling of the stove since it properties are close to the fabricated stove. The results for the thermal loading, analysis, with minimum and maximum temperature distribution in the biogas stove are presented in figures 10 to 13.

Table 3: Biogas Stove Model Units

| | |
|---|---|
| **Unit system:** | SI (MKS) |
| **Length/Displacement** | mm |
| **Temperature** | Kelvin |
| **Angular velocity** | Rad/sec |
| **Pressure/Stress** | N/m^2 |

**Mesh Information**

| | |
|---|---|
| **Mesher Used:** | Standard mesh |
| **Jacobian points** | 4 Points |
| **Element Size** | 18.4709 mm |
| **Tolerance** | 0.923547 mm |

**Mesh Information - Details**

| | |
|---|---|
| **Total Nodes** | 22105 |
| **Total Elements** | 11098 |
| **Maximum Aspect Ratio** | 66.878 |
| **% of elements with Aspect Ratio < 3** | 16.1 |
| **% of elements with Aspect Ratio > 10** | 61.9 |

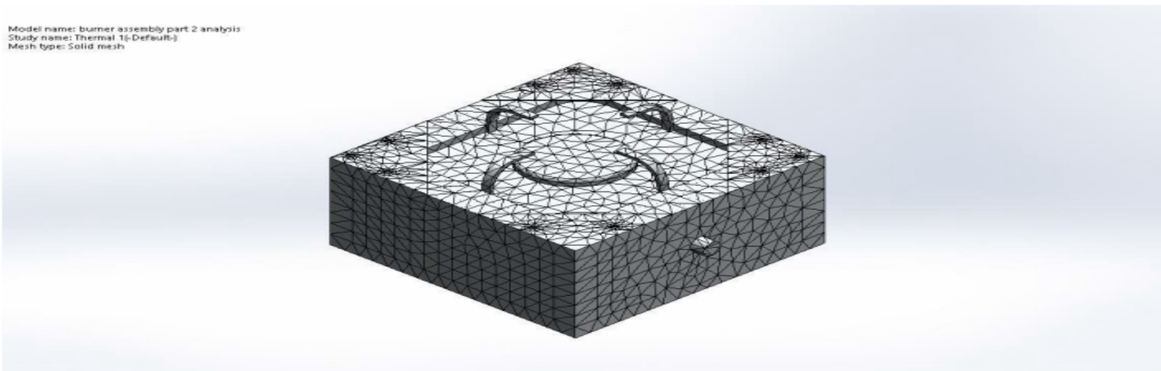
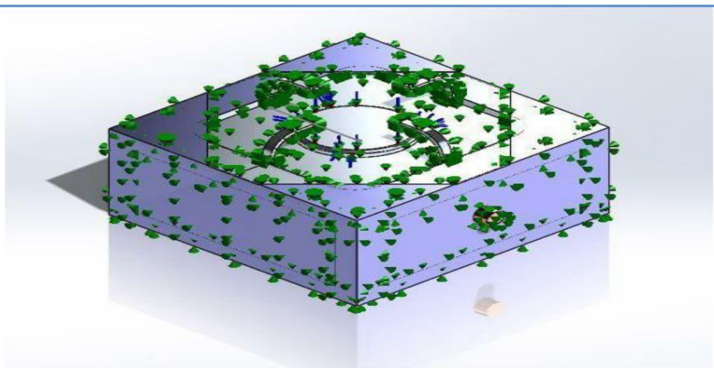



Fig 7. Mesh information for Biogas stove



Model name: BURNER

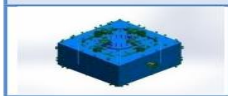
| | Treated As | | Volumetric Properties | |
|---|---|---|---|---|
|  | Solid Body | | Mass:2.88159 kg<br>Volume:0.00106725 m^3<br>Density:2700 kg/m^3<br>Weight:28.2395 N | |

Fig. 8: Biogas Model with Volumetric Properties

## Material Properties

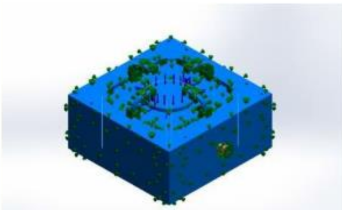
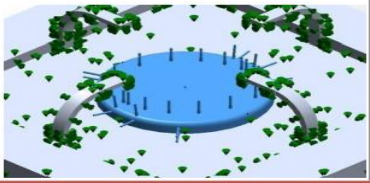
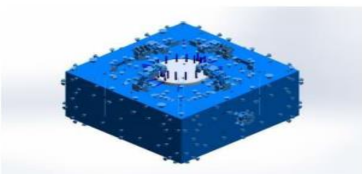
| Model Reference | Properties |
|---|---|
|  | Name: **Aluminum Alloy Grade LM 25**<br>Model type: **Linear Elastic Isotropic**<br>Thermal conductivity: **170 W/(m.K)**<br>Specific heat: **1000 J/(kg.K)**<br>Mass density: **2700 kg/m^3** |

Fig 9. Material Properties for Biogas Stove

## Thermal Loads

| Load name | Load Image | Load Details |
|---|---|---|
| Temperature-1 |  | **Entities:** 4 face(s)<br>**Temperature:** **2200 Kelvin** |
| Convection-1 |  | **Entities:** 72 face(s)<br>**Convection Coefficient:** 62 W/(m^2.K)<br>**Bulk Ambient Temperature:** 298 Kelvin |

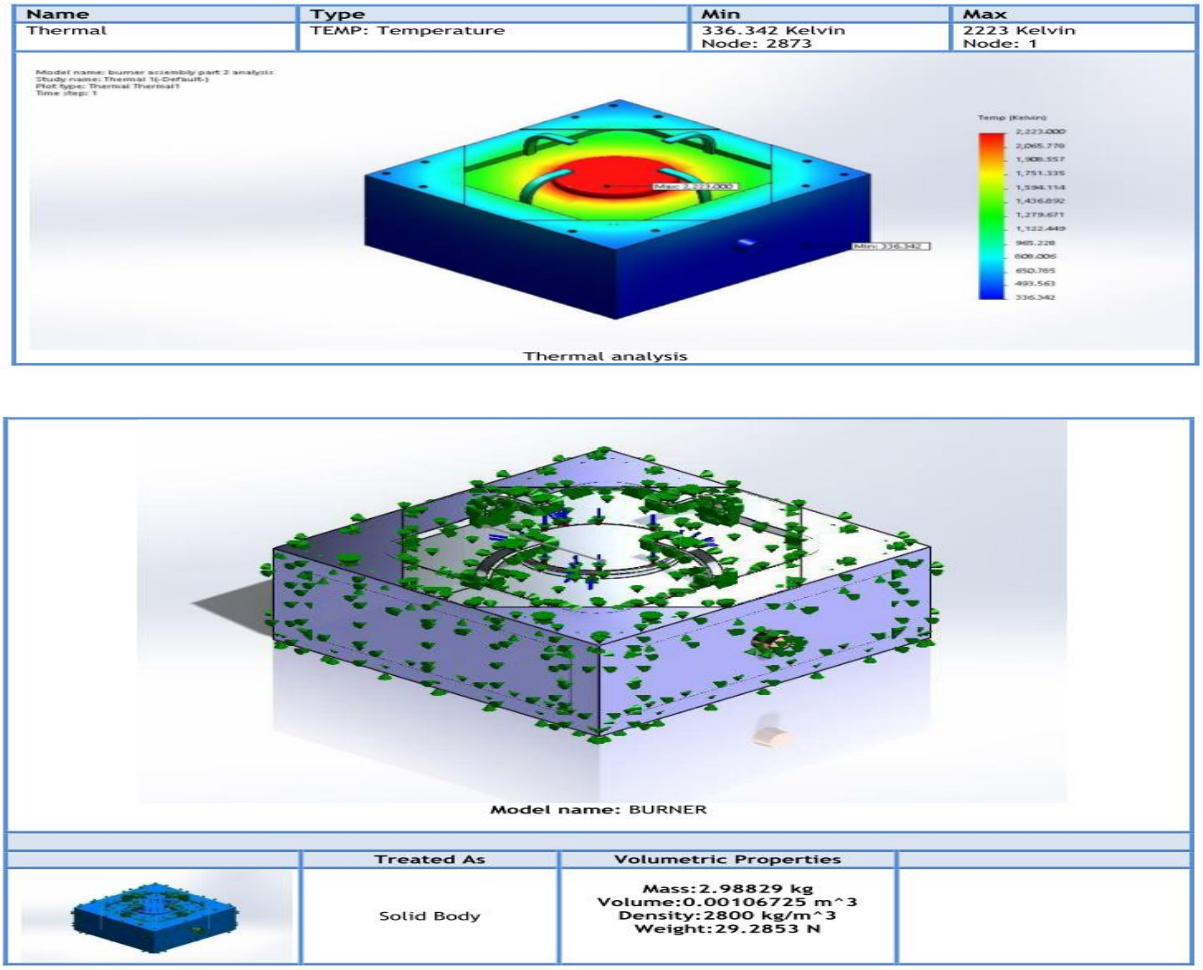



Fig 10. Thermal Loads

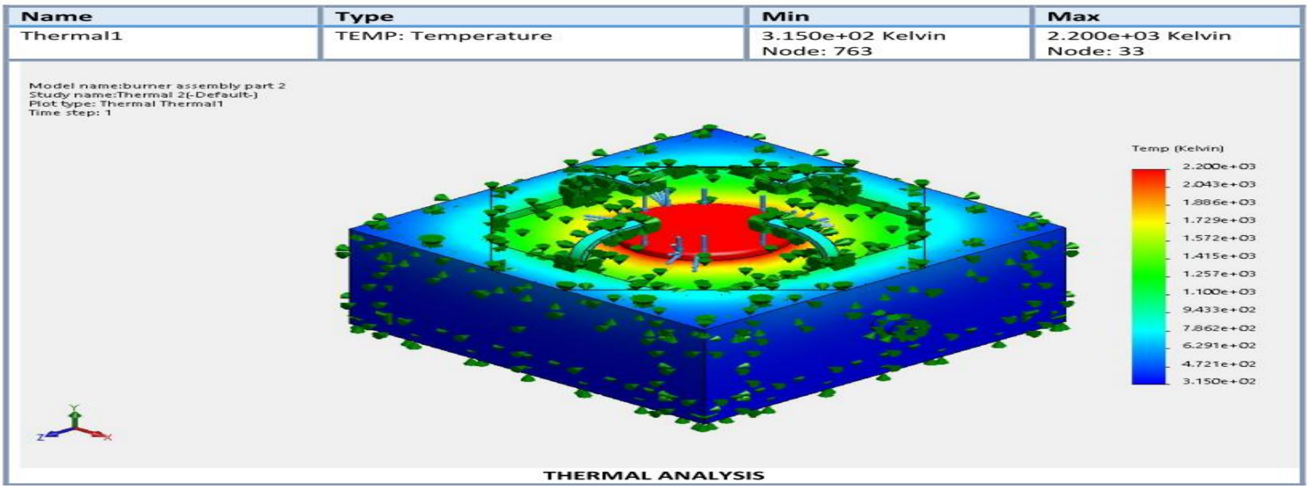



Figure 11. Thermal Analysis of Biogas Stove with Aluminum Burner

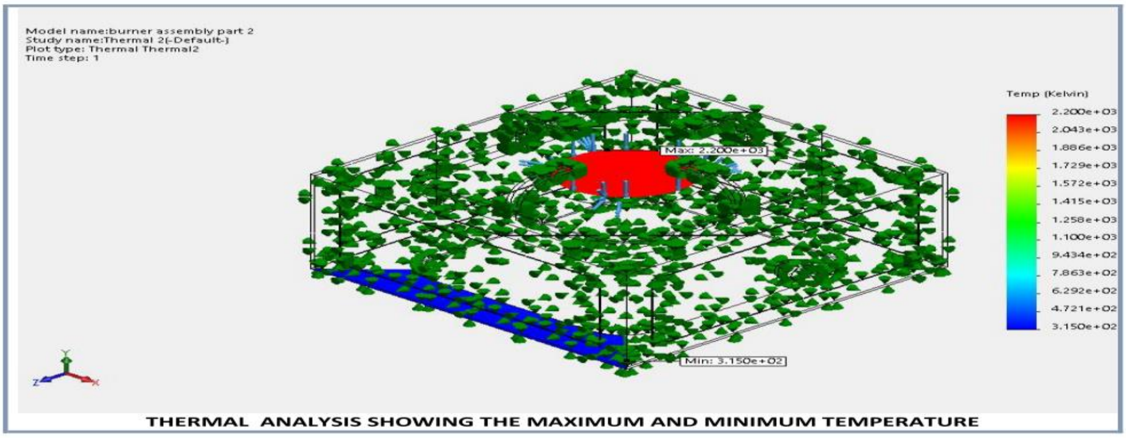



Figure 12. Thermal Analysis Showing the maximum and Minimum Temperature

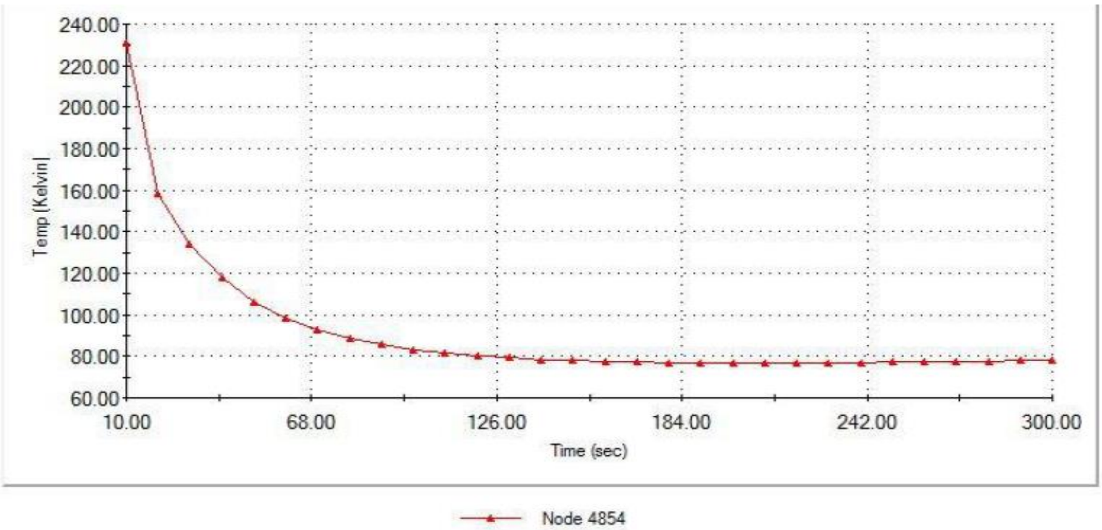



Figure 13. Transient Response of the Model

The graph in figure 13 shows the transient response of the system as heat is distributed from the source (highest temperature) through to where the heat is less felt (lowest temperature) with respect to time. And from the plot, temperature decreases as the time increases.

## 4. Conclusion

In this work, a biogas burner was fabricated from aluminum alloy scraps, for the utilization of methane obtained from bio-waste. Performance evaluation was conducted on the biogas burner. And the study shows that the stove could boil 1 litre of $H_2O$ in 8.5 minutes. The biogas consumption rate for the water heating was 0.24 $m^3$/min. The burner efficiency was approximately 50%. The thermal analysis revealed that the aluminum alloy burner obtained from scrap cans and containers could be a suitable material for the fabrication of biogas stove.

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