DEVELOPMENT OF ETHANOL GEL COOK STOVE

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Abstract
As a result of ongoing global oil price hikes, forest depletion, and rising electricity bills, there has been an increasing interest in using more available alternative energy for cooking in recent years. This has sparked interest in the fabrication of an ethanol-powered clean cook stove as an alternative to fossil fuels and fuel wood. The ethanol clean cook stove is a wickless stove, made up of a galvanized steel combustion chamber, a seat pot made of mild steel iron rod, an air inlet section with a choke adjustment, and a mild steel plate frame. The construction approach involved folding and welding. The fabricated ethanol clean cook stove was tested using the produced banana ethanol gel, cassava ethanol gel, and the purchased biofuel gel. The results of the cold, hot, and simmer tests performed show that the biofuel gel has the following thermal efficiency: 45.31%, 59.56%, and 38%; the thermal efficiency of the banana ethanol gel is 55.3%, 61.44%, and 32.03%; while that of the cassava ethanol gel is 51.03%, 60.04%, and 32.2%, respectively. The boiling water test conducted when the ethanol cook stove was still cold (cold test) using the biofuel, banana, and cassava ethanol gels takes 13.11 minutes, 13.23 minutes, and 13.23 minutes, respectively, for one (1) litre of water to be boiled. Whereas boiling one (1) litre of water when the ethanol cook stove is warmed (hot test) takes 11.25 minutes, 11.15 minutes, and 12.31 minutes, respectively. The fabricated ethanol cook stove was compared with kerosene, LPG, and electric stoves. The results show that the fabricated ethanol cook stove takes longer to boil a litre of water, and kerosene produces more carbon soot than banana and cassava ethanol gels. An optimal thermal efficiency of 61.44% was achieved after testing the fabricated stove using the water boiling test. One litre of the biofuel gel, banana ethanol gel, and cassava ethanol gel used for the boiling test analysis resulted in boiling times that varied slightly under two (2) minutes. The experiment proved that the stove was appropriate for domestic use. Each part was modeled in 3D using Solid Works CAD software and then analyzed (simulated) using Ansys software. The result revealed that the loaded frame had an extreme stress of 1.24E+06 Pa, which is less than the yield strength of the materials of 2.5E+08 MPa, indicating that the design is secure. Although both ethanol gels and kerosene fuels produce a blue flame, it was discovered that ethanol gel burns cleanly and emits neither smoke nor odor when extinguished. The blue flame output makes the stove a more user-friendly and energy-efficient device. As a result, the ethanol clean cook stove serves as a renewable energy product, which would remain relevant as long as the world strives to solve fossil fuel depletion and concerns about greenhouse gas emissions.

Keywords: Ethanol gel, cook-stove, biofuel, banana gel, water

Introduction

The primary source of energy for home needs including lighting, space heating, and cooking as such, each day, cook stoves are used to burn almost two billion kilos of biomass, including wood, charcoal, dung, and crop leftovers (World Health Organization, 2022; Rehfuess *et al*., 2011). The primary activity (cooking) is typically performed indoors in small spaces, exposing the user for an extended period of time to pollutants from incomplete combustion. Together with increasing greenhouse gas (GHG) emissions that have an adverse impact on the environment, these emissions have a significant negative impact on human health (World Health Organization, 2022). Besides endangering the health of users, the inefficient combustion and heat transfer of biomass cook stoves wastes too much fuel, depleting forests and lengthening time required to find suitable fuel, habitat destruction, biodiversity loss, and aridity are all consequences of deforestation. The bio

sequestration of air and carbon dioxide is also negatively impacted.

In many developing nations, household energy consumption particularly that used for cooking constitutes a significant portion of total energy use. The primary energy source in rural parts of tropical and subtropical nations like Nigeria is still wood. Large sections of forest are destroyed as a result of the increasing use of firewood for cooking, posing serious ecological, economic, and societal issues. More than 2.5 billion people cook their food over open flames with firewood or plant remains, according to Stumpf (2006). The fumes from the open fire not only pollute the environment but also endanger the users' health. With a variety of health-damaging chemicals (formaldehyde, acetaldehyde, acrolein, polycyclic aromatic hydrocarbon, benzene, etc.) and minute soot particles that can get deep within the lungs, such inefficient cooking stoves and technologies produce high levels of home air pollution. Women and young children, who spend the majority of their time close to the domestic fireplace, are particularly exposed. According to Zwick (2011), open fire is the main cause of indoor pollution that results in twice as many deaths from lung illness each year.

In order to enhance both fuel usage and air quality, it is necessary to phase out outdated, inefficient cook stoves with more modern models that burn cleaner fuel. The most popular fuel, paraffin, has been shown to present significant hazards when used in typical, easily accessible cookers, according to studies by (Makonese *et al*., 2012; Bradnum, 2007; Gevart *et al*., 2014). When this happens, the fuel cans conflagrate at a rate high enough to raise the temperature to approximately 30seconds and above 4000C in a typical low-income home. This method results in the destruction of about 100,000 homes annually (Lioyd, 2006).

Given this context, it is clear that the introduction of effective and clean burning ethanol cook stove will have significant potential to help society and the environment. The development of ethanol clean cook stove will make it simple to control the flame and produce output comparable to that of LPG and kerosene burners now in use. The stove is anticipated to be extremely suitable for a normal rural household, safe to use, and inexpensive to operate when compared to more traditional options. As a result, the study is focused on the development of an ethanol-clean cook stove for household use. The goal of this research was to create a clean cook stove that runs on ethanol. When compared to the cooking effects of conventional fuels like kerosene and charcoal, the performance of the designed stove will be evaluated using metrics like burning rate, specific fuel consumption /calorific value, thermal efficiency, and cooking time.

Anil *et al.* (2007) developed a low concentration ethanol stove intended for usage in rural India. The study proposes an alternative to an ethanol stove that burns a mixture of 50% ethanol and water. The stove has an output that is similar to kerosene and LPG stoves, and it has an easy-to-adjust flame. The stove has undergone field testing, and the results indicate that it is both safe to use and ideal for a normal rural household. Peter (2013), investigated the use of bioethanol gel in cook stoves as a substitute for conventional biomass. In comparison to existing cook stoves that use the same gel fuel, he assessed the combustion behavior of bio ethanol gel in terms of fuel efficiency, interior emissions, and heat transfer. How the physical and chemical characteristics of gel fuel affected the combustions was investigated. Philip *et al.* (2016) worked on the local bio ethanol: An alternative fuel and key for a Safer Cooking. The study focuses on the burning of bio-ethanol in cook stoves as a substitute for conventional biomass. The researchers were able to use bio ethanol, a locally produced substance in the area, as fuel for a newly developed stove. The researchers advise modifying the stove's design and materials, by using cooking utensils with a thin texture and new building materials, to improve the stove's performance and achieve a normalized fire output. They recommended choosing a tank that is definitely clean inside; otherwise, the fuel may flow with contaminants due to particles. Dioha *et al.* (2012) conducted research comparing the performance of cook stoves using ethanol and kerosene fuels.

The study compared the merit and demerit of domestic cooking fuels such ethanol, LPG, and kerosene. To establish the boiling time for a given volume of water, a straight forward water boiling test was conducted. According to the findings, kerosene fuel boils water more quickly than ethanol fuel. The usage of ethanol gel cook stoves as a more accessible alternative cooking energy source was investigated by Okusanya *et al.* (2019). There were variations in cooking times and specific fuel usage of around one minute and twenty grams per liter, respectively, between cooking tests conducted with a gel stove and a kerosene stove. The values of PM and CO from the cook stove were 0.022 mg/m^3 and 6.57 ppm, respectively. They concluded that because ethanol gel makes up for its lack of heating value with efficiency, it can be a better clean cooking fuel for residential use. Megan *et al.* (2018) studied the ethanol Clean Cook stove intervention and prospective scale-up in Ethiopia.

The study exemplifies the difficulties in promoting a new fuel for domestic cooking, as well as the numerous challenges and implementation stumbling blocks. They came to the conclusion that ethanol exhibits some potential for scaling up and commercialization as a household fuel in Addis

Ababa, but it may also call for the stabilization of the ethanol supply, the expansion of a citywide distribution network, fuel and stove that is reasonably priced. Palanisamy *et al.* (2023) studied the evolutions in gaseous and liquid fuel cook stove technology.

Materials and Methods
Design Criteria and Consideration
Design considerations for ethanol gel cook stoves fall into three categories: social, developmental, and ecological. The concept uses the air/fuel combustion mechanism to ignite gel fuel and produce a blue flame for cooking. While designing the stove, some of the ISO performance standards for stoves taken into account include efficiency, emissions, Safety, affordability, accessibility and Effects on livelihood. The material selection will be based on factors such as cost, workability, strength/fatigue resistance, heat resistance, wear and corrosion resistance, and aesthetics (Baqui et al., 2008). The flowchart of the ethanol clean cook stove fabrication processes is
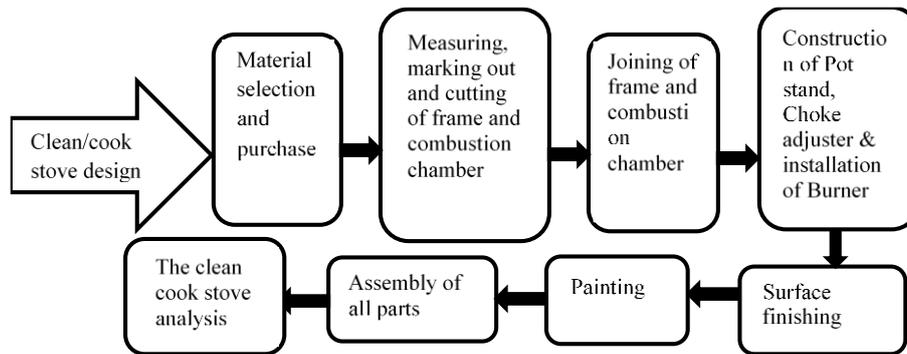
Height of the combustion chamber $L_{cc} = 100$ mm; ; internal radius of combustion chamber, $r_1 = 80$ mm; external radius of the combustion chamber, r_2; 95 mm; height of the clean stove, Hsb 200 mm; height of pot seat chamber, Hps = 40 mm and measured external temperature of combustion chamber, $T_0 = 31^O$C

(i) Combustion chamber design
The combustion chamber is kept in place to the member frame by a 10 mm iron rod drilled and bolted to the frame and have a cylindrical shape made from a 0.8 mm galvanized plate. It is 100mm high and 80mm in radius. The formula for calculating cylinder volume was used because of its cylindrical shape as shown in Equation 1.

$$V = \pi r^2 h \qquad (1)$$
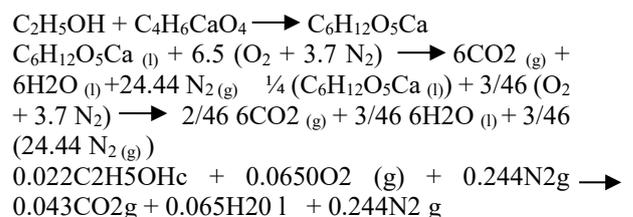
$$V = 3.142 \, (80)^2 \times 100 = 2 \text{ litres}$$

(ii) Combustion air requirement
One litre of bioethanol sample was used in the

Figure 1: The flowchart of the clean ethanol cook stove fabrication processes

showed in Figure 1.

Material Selection
Material selection was based on factors such as cost, workability, strength or fatigue resistance, heat resistance, wear and corrosion resistance, and aesthetics. To ensure the best quality of the ethanol-clean cook stove as well as to meet design criteria, the best materials were carefully chosen. The materials used for the fabrication of the stove are galvanized steel plate, mild steel plate, iron rod and angle iron.

Design Analysis and Calculation
The data gathered was analyzed and computed through the applications of principles lying behind the bio ethanol clean stove such as the formulas governing the ethanol combustion, thermodynamic concepts and principles of chemical balancing to arrive at the needed air fuel ratio and heating value to calculate the heat in the process. Based on the choice of a domestic-size stove, the following parameters were selected for the design:

experiment. Bioethanol has a chemical formula of C_2H_5OH and a molecular mass of 46. Assumed 100% theoretical air, then the oxygen molecular mass is 32 and nitrogen is 28.

(iii) Chemical balance
Ethanol (C_2H_5OH) is the gel fuel's main ingredient and Calcium acetate ($C_4H_6CaO_4$) is a thickening agent used to make the fuel pour like gel. The fuel's chemical composition and combustion reaction are:

$C_2H_5OH + C_4H_6CaO_4 \longrightarrow C_6H_{12}O_5Ca$

$C_6H_{12}O_5Ca_{(l)} + 6.5 \, (O_2 + 3.7 \, N_2) \longrightarrow 6CO2_{(g)} + 6H_2O_{(l)} + 24.44 \, N_{2(g)}$ ¼ ($C_6H_{12}O_5Ca_{(l)}$) + 3/46 (O_2 + 3.7 N_2) $\longrightarrow$ 2/46 $6CO2_{(g)}$ + 3/46 $6H_2O_{(l)}$ + 3/46 (24.44 $N_{2(g)}$)

$0.022C2H5OHc + 0.0650O2_{(g)} + 0.244N2g \longrightarrow 0.043CO2g + 0.065H20 \, l + 0.244N2 \, g$

(iv) Stoichiometric air fuel ratio
The stoichiometric air fuel ratio was determined with the use of Equation 2.

Table 1: Enthalpy of formation for various substances at 25°C and 1atm

Substances	Formula	Enthalpy of formation (h°f (kglkmol)
Nitrogen	$Na_{(g)}$	0
Oxygen	$O_{2\ (g)}$	0
Water Vapour	$H_2O_{(g)}$	-241820
Water	$H_2O_{(l)}$	-285830
Carbon dioxide	$CO_{2\ (g)}$	-393520
Ethanol	$C_2H_2OH_{(g)}$	-235310
Ethanol	$C_2H_2OH_{(l)}$	-277690

Source: From JANAF, Thermochemical Tables (Midland, MI: Dow Chemical Co., 1971); Selected Values of Chemical Thermodynamic Properties, NBS Technical Note 270-3, 1968; and API Research Project 44 (Carnegie Press, 1953).

$$\left(\frac{A}{F}\right) Steieh = \frac{Molecular\ mass\ of\ air}{Molecular\ mass\ of\ fuel} \qquad (2)$$

$$\left(\frac{A}{F}\right) Steieh = \frac{20}{100} \times 9 + 9 = 1.8 + 9 = 10.8\ kg\ of\ fuel$$

$$\frac{\frac{(A)}{F} Steieh}{\frac{(A)}{F} Actual} = \frac{9}{10.8} = 0.833$$

Since 0.833 < 1, it means the mixture of the gel fuel and air is a lean mixture. There is therefore likelihood of complete combustion.

(v) Heating value of the bioethanol clean stove
The heating value of the ethanol clean stove can be determined by the standard enthalpy of formation Equation 3.

$$H_V = \sum h^o\ (Products\text{-} \sum h^o\ (Reactants) \qquad (3)$$

Table 1 depict the enthalpy of formation for various substances at 25°C and 1atm.

(vi) Conceptual design of the ethanol cook clean stove
The computer aided design (CAD) model for the ethanol cook clean stove was developed using Solid Works application software. Figure 2 depicts the isometric, orthographic, and exploded view of the ethanol-clean cook stove.

Fabrication Processes
The member frame, the air inlet section, the pot stand, the combustion chamber, the choke adjuster, and so on are among the component parts. Below is a breakdown of some of the components' functions.

(i) Combustion chamber: combustion chamber is made from a galvanize steel plate in form of a cylindrical bowl for housing the ethanol gel and space where combustion take place

(ii) The choke adjuster: the choke adjuster regulates the flow of air into the combustion chamber. When the user finished cooking, the adjuster also puts out the fire. The chamber is completely sealed at this point to keep outside air from entering the combustion chamber.

(iii) The frame of the stove: the frame is made from two (2) inch angle iron and serves as supports for the canisters, pot stand and the whole structure.

Using locally accessible materials, the stove combustion chamber or canister was fabricated with 0.8 mm galvanize steel plate into a cylindrical bowl solid member frame through folding and welding to server as fuel container. The two (2) canisters are made to seat on 1mm mild steel rectangular plate and welded to the frame of the stove. The canisters are held into position by two (2) pieces of bents 10 mm
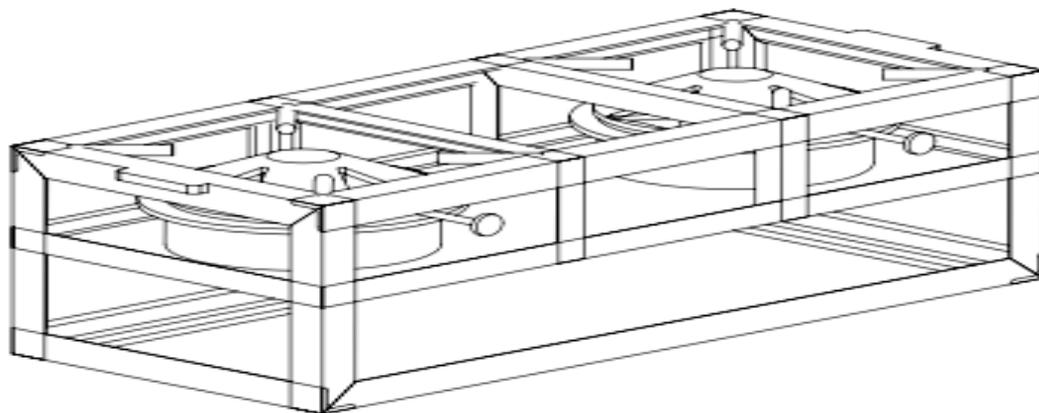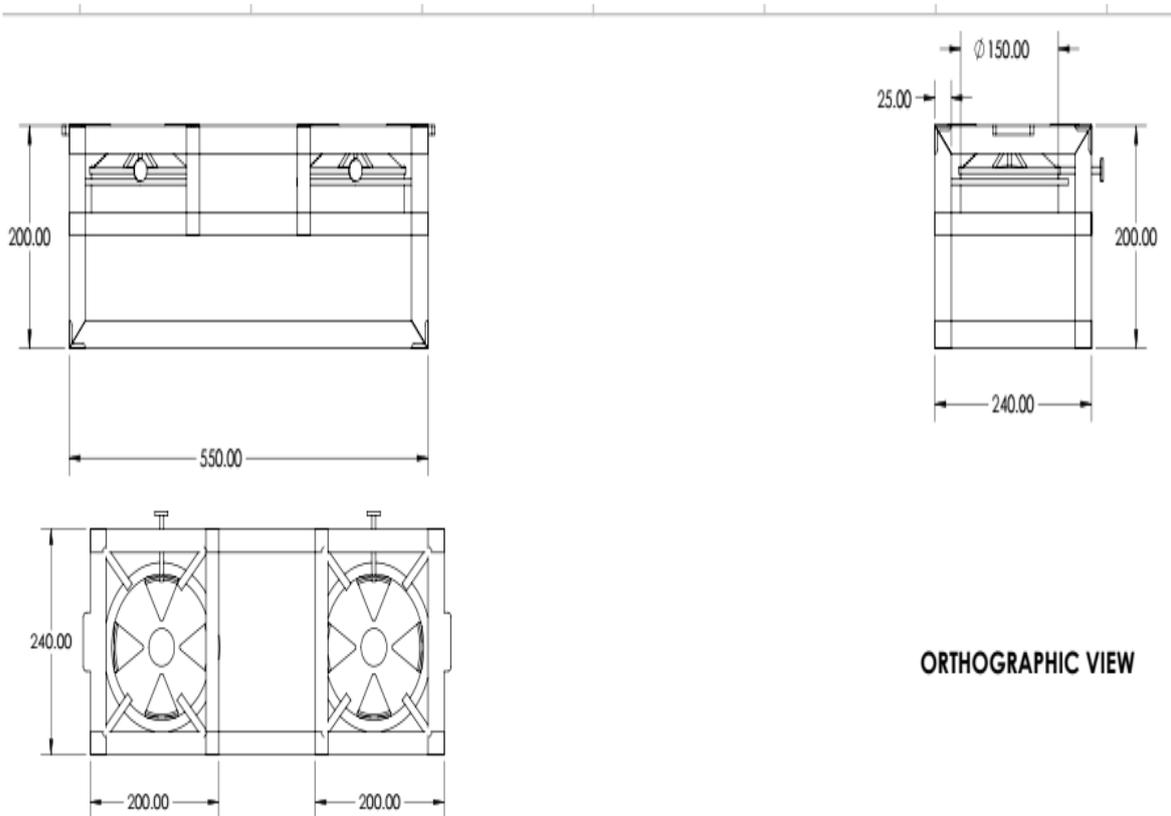

Figure 2a: Isometric view

Figure 2b: Orthographic view

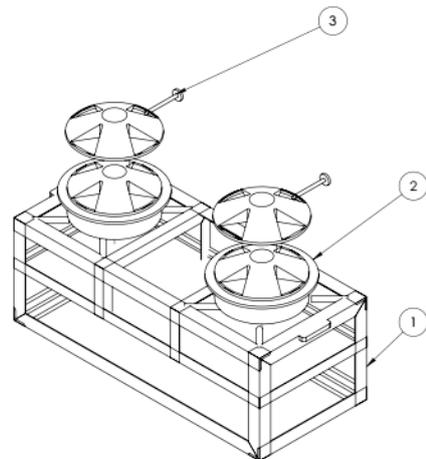| ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Welded frame	steel	1
2	Cannister	Stainless steel	2
3	Cannister control	Stainless steel	2

Figure 2c: Exploded view

Figure 2: Conceptual Design of the Developed Clean Cook Stove

rod, made to pass through the drilled holes on the plate and bolted to the frame. The subsection of "design analysis" above specifies the dimensions of the combustion chamber. The stove's design eliminates the need for a wick in order to create combustion. Thus, it is not necessary to include a wick adjuster knob to regulate heat output. To regulate the flow of air into the combustion chamber, a choke adjuster was introduced to puts out the fire when the stove is no longer in use. The chamber is completely sealed at this point to keep outside air from entering the combustion chamber. The choke adjusters are made with 10 mm iron rod handle welded to two (2) curved overlapping open and close 1 mm mild steel plate, screwed with nuts. The frame top and stand were fabricated into a rectangular shape of size 540 mm × 240 mm using 2 inches angle irons of gauge 1 mm thickness. Measured, cut and welded to size as specified in the design drawing. The height of the frame is 80 mm and doubles as a
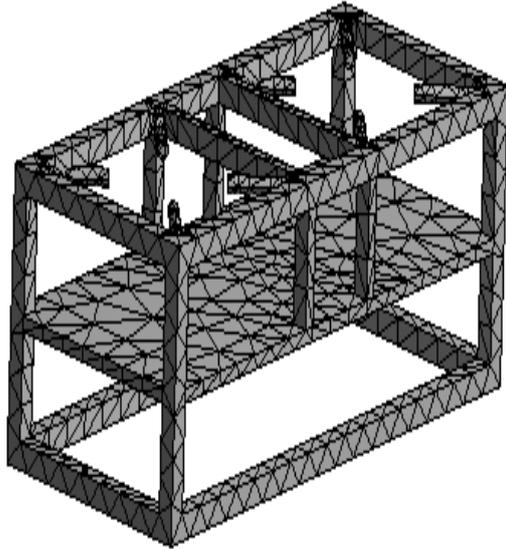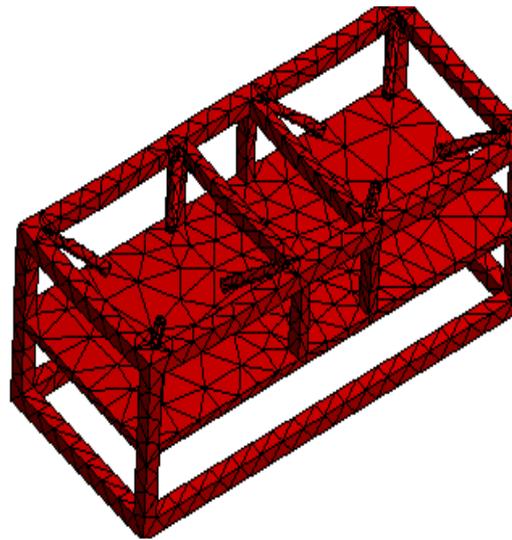
Plate 1a: Mesh Model

Plate 1b: FOS of the Frame

seat for the pot stand and housing for the two (2) chambers. After fabricating the frame, canisters and choke adjusted through, measuring, cutting, drilling, and welding processes. The ethanol cook stove was cleaned and welded joints areas body filled and grinded after drying with angle iron. The stove and the canisters were painted with black paint and the canisters coupled to the frame with bolt and knot.

Performance Evaluation of the Developed Ethanol Clean Stove
The ethanol-clean stove is distinguished by its even distribution of low environmental impact emissions with good quality, straightforward design, simple operation, and continuous operation. The performance evaluation of the developed clean cook stove was carried out using biofuel, banana and cassava ethanol gel under the identical test conditions using the water boiling test. The cold start test, the hot start test, and the simmer test are the three stages of the water boiling test. One (1) liter of water was boiled in a kettle and it temperature and time required to boil, and the quantity of fuel used were measured in the cold start test. Following the cold start test, the hot start test starts with the still-warm stove and one (1) liter of fresh room-temperature water. The simmer test, which is carried out after the hot start test, gauges how much fuel is required to sustain a boil for 30 minutes. With the exception of the simmering test, which required maintaining water at a constant temperature of 99° or even 100° for roughly 30 minutes, all tests were performed with the air opening of the stove fully open. Plate 1a and Plate 1b shows the mesh and FOS solid work analysis of the fabricated ethanol-clean

Plate 1c: Fabricated ethanol cook stove

Plate 1d: Fabricated ethanol cook stove during test

Plate 1: Developed Ethanol Clean Cook Stove

cook stoves used for the experiment. Plate 1c and Plate 1d depicts the view of the fabricated ethanol-clean cook stove and the view under test.

Results and Discussion
Cold test on the fabricated ethanol cook stove using bio fuel gel, banana ethanol gel and cassava ethanol gel
The performance evaluation of the fabricated ethanol cook stove for the cold test evaluation using biofuel gel, banana ethanol gel and cassava ethanol gel is shown in Table 2. The boiling time for one (1) litre of water using the purchased biofuel gel, produced banana ethanol gel, and produced cassava ethanol gel are 13 minutes 7seconds, 13 minutes 14 seconds, and 13 minutes 14 seconds respectively.

Hot test on the fabricated ethanol cook stove using bio fuel gel, banana ethanol gel and cassava ethanol gel
The performance evaluation of the fabricated ethanol cook stove for the hot test evaluation using biofuel gel, banana ethanol gel and cassava ethanol gel is shown in Table 3. The boiling time for one (1) litre of water using the purchased biofuel gel, produced banana ethanol gel, and produced cassava

ethanol gel are 11 minutes 15seconds, 11 minutes 9 seconds, and 12 minutes 19 seconds respectively.

Simmer test on the fabricated ethanol cook stove using bio fuel gel, banana ethanol gel and cassava ethanol gel
Table 4 shows the performance evaluation result of the fabricated ethanol cook stove for the simmer test evaluation using biofuel gel, banana ethanol gel and cassava ethanol gel. Plate 2 depicts the biofuel gel, banana ethanol gel and cassava ethanol gel used on the fabricated ethanol-clean cook stove to carried out the test.

Boiling time of the fabricated ethanol cook stove, kerosene stove, LPG stove and electric stove
The time taken to boil 1 liter of water using the fabricated ethanol cook stove, Kerosene stove, LPG stove and electric stove are recorded and shown in Table 5. The boiling time for one (1) litre of water on the fabricated ethanol, kerosene, LPG, and electric stove are 16 minutes 10seconds, 13 minutes 20 seconds, 5 minutes 47 seconds and 8minutes 12 seconds respectively. Figure 3 depict the boiling time on different stove type.

Table 3: Water boiling test for 1 litre of water (cold test) using biofuel gel, banana ethanol gel and cassava ethanol gel

Time (min)	Biofuel gel			Banana Ethanol gel			Cassava ethanol gel		
	Temperature T_C (°C)	Mass of water evaporated (g)	Mass of fuel consumed (g)	Temperature T_C (°C)	Mass of water evaporated (g)	Mass of fuel consumed (g)	Temperature T_C (°C)	Mass of water evaporated (g)	Mass of fuel consumed (g)
0	36.2	-	-	36.2	-	-	36.2	-	-
2	40.5	2.90	4.99	44.5	2.20	3.70	47.8	2.22	4.10
4	53.2	3.40	5.57	56.6	2.50	4.25	55.0	2.53	4.66
6	64.1	3.90	6.44	66.2	2.90	5.10	62.4	2.91	5.53
8	74.8	4.25	7.05	75.8	3.55	5.74	73.8	3.60	6.04
10	84.3	4.86	7.62	85.2	3.96	6..19	84.0	4.00	6..71
12	94.5	5.20	8.06	94.6	4.30	6.40	94.2	4.32	7.15
14	100.0	5.92	8.47	100.0	5.09	6.72	100.0	5.06	7.56
Total	**-**	**30.43**	**48.2**	**-**	**24.5**	**38.1**	**-**	**24.64**	**41.75**

Table 4: Water Boiling Test for 1 litre of water (simmer test) on the fabricated ethanol cook stove using bio fuel gel, banana ethanol gel and cassava ethanol gel

Time (min)	Biofuel gel		Banana Ethanol gel		Cassava ethanol gel	
	Mass of Water Evaporated (g)	Mass of Fuel Consumed (g)	Mass of Water Evaporated (g)	Mass of Fuel Consumed (g)	Mass of Water Evaporated (g)	Mass of Fuel Consumed (g)
00	-	-	-	-	-	-
05	41.40	22.65	42.15	24.54	41.75	24.50
10	53.57	24.01	54.54	24.60	54.02	24.30
15	51.93	24.32	52.96	27.00	52.46	26.50
20	55.11	24.23	56.20	21.00	55.67	20.87
25	50.66	24.92	51.66	23.40	51.17	23.00
30	52.58	24.75	53.61	24.60	53.11	24.10
Total	**305.25**	**120.56**	**311.12**	**145.14**	**308.18**	**143.27**

Comparative water boiling time for the fabricated ethanol cook stove and Kerosene stove
Time taken to boil different quantity of water using the fabricated ethanol cook stove and kerosene stove was evaluated. Figure 4 shows that kerosene stove boils faster than the fabricated ethanol stove.

Figure 4 depict the boiling time for the fabricated ethanol cook stove and kerosene stove.

Comparative soot formation for the banana ethanol gel, cassava ethanol gel, bio fuel gel, and kerosene fuel
The carbon weight from the flame produced by the fuel used (banana ethanol gel, cassava ethanol gel, bio fuel gel, and kerosene fuel) is shown in Figure 5.

Determination of thermal efficiency on the fabricated ethanol clean cook stove using bio fuel gel
By monitoring the rate of water loss and fuel use, the efficiency was ascended. Whether or not the kettle was covered with a lid and how much water was in it had little effect on how quickly the water was lost when boiling. The diameter of the kettle made a

negligible difference. The thermal efficiency of the stove was calculated using Equation 4. Thermal efficiency is determined using the common law of heat transfer, which states that heat loss equals heat gain.

$$\eta = \frac{M_w C_p(\theta_b - \theta_i) + M_p C_p(\theta_b - \theta_i) + M_e L}{M_f B_f} \times 100\% \qquad (4)$$

M_w is mass of water boiled, C_p is specific het capacity of pot, θ_b is boiling point temperature, θ_i is initial temperature , M_e is mass of water evaporated, L is latent heat of evaporation, M_f is mass of fuel consumed, B_f is calorific value of fuel, and η is thermal efficiency.

Calculation of thermal efficiency for cold test
From Table 2;

Burning Rate (BR) $= \frac{M_f}{t} = \frac{48.2}{13.11} = 3.68 \ g/min$

Stove Fuel Consumption $(SFC) = \frac{M_f}{V} = \frac{48.2}{1} = 48.2 \ g/litre$

Table 5: Boiling time of 1litre of water on the fabricated ethanol cook stove, kerosene stove, LPG stove, and electric stove

Time (min)	Fabricated ethanol cook stove Temperature T_C (°C)	Kerosine stove Temperature T_C (°C)	LPG stove Temperature T_C (°C)	Electric stove Temperature T_C (°C)
0	36.2	36.2	36.2	36.2
2	40.8	38.3	54.0	44.0
4	47.7	49.9	78.2	63.8
6	53.6	61.9	98.7	80.9
8	58.8	73.5	-	97.8
10	65.5	83.6	-	-
12	76.8	95.8	-	-
14	88.1	97.5	-	-
6	100.0	-	-	-

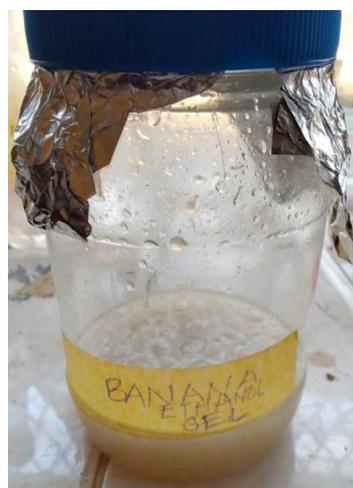|		
Plate 2a: Bio fuel Gel	**Plate 2b:** Banana ethanol gel	**Plate 2c:** Cassava ethanol gel

Plate 2: Fabricated ethanol gel cook stove, bio fuel gel, banana ethanol gel, and cassava Gel
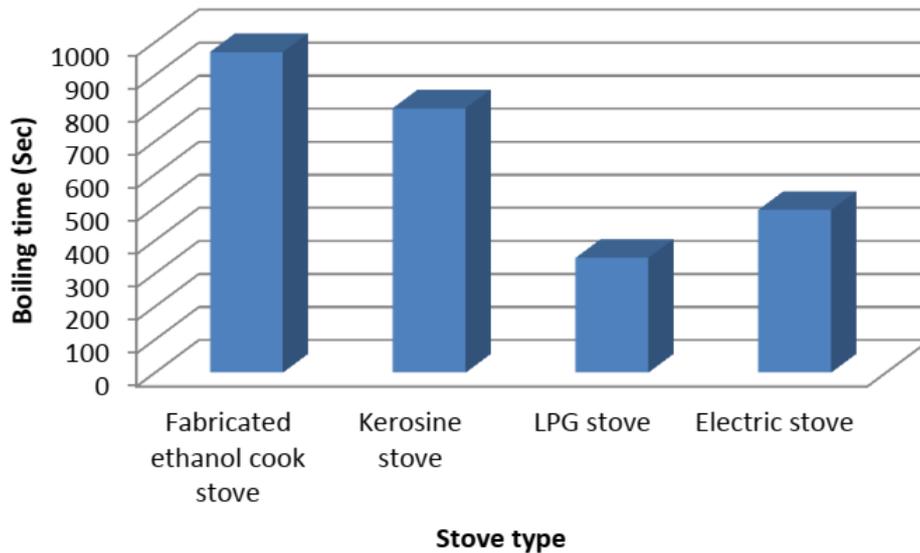
Figure 3: Boiling Time on different stove type

$Water\ loss\ (WL) = \frac{M_e}{t_{avg}} = \frac{30.43}{13.11} = 0.0387\ g/sec$

$Total\ power\ supplied\ by\ the\ fuel\ to\ water\ (P) =$
$(M_w C_w \Delta\theta)_{Water} + (M_k C_k \Delta\theta)_{kettle} + Water\ loss\ \times L =$
$\frac{937.3 \times 4.2 \times 63.8}{13.11\ \times 60 \times 1000} + \frac{390.5 \times 0.5 \times 63.8}{13.11\ \times 60 \times 1000} +$
$0.0387 \times 2.261 =$
$0.4196\ kW\ Stove\ Power\ (SP) = Burning\ rate\ (BR) \times$
$Net\ calorific\ value\ of\ the\ ethanol\ gel\ (B)$
Take B = 15.1kJ/g (Lioyd and Visage, 2011),
BR = 3.68 g/min

$Therefore, Stove\ power\ = \frac{3.68}{60} \times 15.1 = 0.9261\ kW$

Thermal Efficiency ɳ $= \frac{Total\ Power\ Supplied}{Stove\ power} \times 100\% =$
$\frac{0.4196}{0.9261} \times 100\% = 45.31\%$

Calculation of thermal efficiency for hot test
From Table 3;
Burning Rate (BR) $= \frac{M_f}{t} = \frac{35.70}{11.25} = 3.2\ g/min$

$Stove\ Fuel\ Consumption\ (SFC) = \frac{M_f}{V}$
$= \frac{35.7}{1} = 35.7\ g/litre$

$Water\ loss\ (WL) = \frac{M_e}{t_{avg}} = \frac{34.94}{11.25} = 0.0518 g/sec$

$Total\ power\ supplied\ by\ the\ fuel\ to\ water\ (P) =$
$(M_w C_w \Delta\theta)_{Water} + (M_k C_k \Delta\theta)_{kettle} + Water\ loss\ \times$
$L = \frac{937.3 \times 4.2 \times 59.2}{11.25\ \times 60 \times 1000} + \frac{390.5 \times 0.5 \times 59.2}{11.25\ \times 60 \times 1000} +$
$0.0518 \times 2.261 = 0.47954\ kW$

$Stove\ power\ = \frac{3.2}{60} \times 15.1 = 0.8053 kW$

Thermal Efficiency ɳ $=$
$\frac{Total\ Power\ Supplied}{Stove\ power} \times 100\% =$
$\frac{0.47954}{0.8053} \times 100\% = 59.56\%$

Calculation of thermal efficiency simmer test
From Table 4;

$Stove\ Fuel\ Consumption\ (SFC) = \frac{M_f}{V} = \frac{120.56}{1} =$
$120.56\ g/litre$

$Water\ loss\ (WL) = \frac{M_e}{t} = \frac{305.25}{30} = 0.170\ g/sec$

$Total\ power\ supplied\ by\ the\ fuel\ to\ water\ (P) =$
$(M_w C_w \Delta\theta)_{Water} + (M_k C_k \Delta\theta)_{kettle} + Water\ los =$
$\frac{937.3 \times 4.2 \times 0}{30\ \times 60 \times 1000} + \frac{390.5 \times 0.5 \times 0}{30\ \times 60 \times 1000} + 0.170 \times 2.261$
$= 0.3844$

$Stove\ power\ = \frac{4.02}{60} \times 15.1 = 1.0117\ kW$

Thermal Efficiency ɳ $= \frac{Total\ Power\ Supplied}{Stove\ power} \times 100\% =$
$\frac{0.3844}{1.0117} \times 100\% = 38\%$

Determination of thermal efficiency on the fabricated ethanol clean cook stove using banana ethanol gel
Calculation of thermal efficiency for cold test
From Table 2;

Burning Rate (BR) $= \frac{M_f}{t} = \frac{38.1}{13.23} = 2.89 g/min$

$Stove\ Fuel\ Consumption\ (SFC) = \frac{M_f}{V} = \frac{38.1}{1} =$
$38.1 g/litre$

$Water\ loss\ (WL) = \frac{M_e}{t_{avg}} = \frac{24.5}{13.23} = 1.85 g/min =$
$\frac{1.85}{60} = 0.031 g/sec$

$Total\ power\ supplied\ by\ the\ fuel\ to\ water\ (P) =$
$(M_w C_w \Delta\theta)_{Water} + (M_k C_k \Delta\theta)_{kettle} +$
$Water\ loss\ \times L = \frac{937.3 \times 4.2 \times 63.8}{13.23\ \times 60 \times 1000} +$
$\frac{390.5 \times 0.5 \times 63.8}{13.23\ \times 60 \times 1000} + 0.031 \times 2.261 = 0.4022$
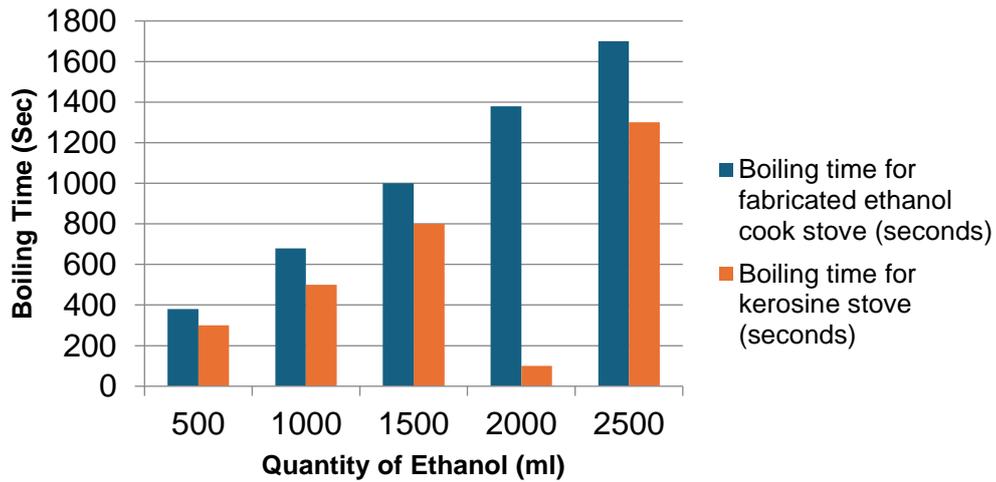$Stove\ power\ = \frac{2.89}{60} \times 15.1 = 0.7273 kW$

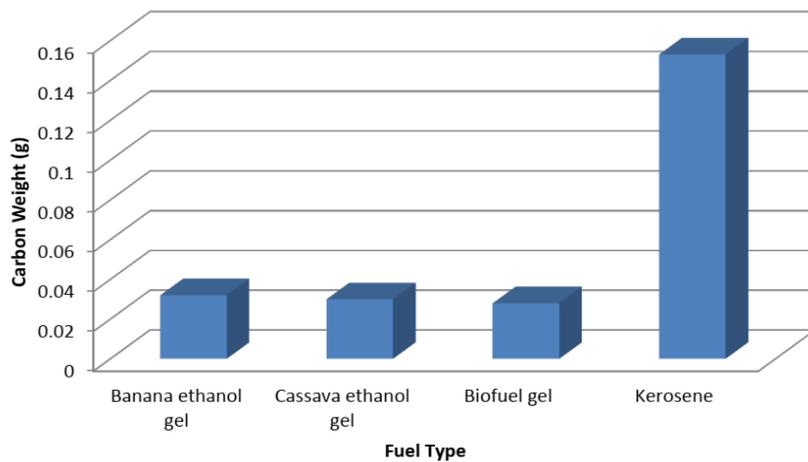**Figure 4**: Boiling time for the fabricated ethanol cook stove and kerosene stove

Figure 5: Comparative soot formation for the banana ethanol gel, cassava ethanol gel, bio fuel gel, and kerosene fuel

Thermal Efficiency $\eta = \frac{Total\ Power\ Supplied}{Stove\ power} \times 100\% = \frac{0.4022}{0.7273} \times 100\% = 55.3\%$

Calculation of thermal efficiency for hot test
From Table 3;

Burning Rate (BR) $= \frac{M_f}{t} = \frac{32.9}{11.15} = 2.95 g/min$

$Stove\ Fuel\ Consumption\ (SFC) = \frac{M_f}{V} = \frac{32.9}{1} = 32.9 g/litre$

$Water\ loss\ (WL) = \frac{M_e}{t_{avg}} = \frac{27.5}{11.25} = 2.444 g/$
$min = \frac{2.444}{60} = 0.0407 g/sec$

$Total\ power\ supplied\ by\ the\ fuel\ to\ water\ (P) =$
$(M_w C_w \Delta\theta)_{Water} + (M_k C_k \Delta\theta)_{kettle} +$
$Water\ loss \times L = \frac{937.3 \times 4.2 \times 59.2}{11.15 \times 60 \times 1000} +$
$\frac{390.5 \times 0.5 \times 59.2}{11.15 \times 60 \times 1000} + 0.0407 \times 2.261 = 0.45614 kW$

$Stove\ power\ = \frac{2.95}{60} \times 15.1 = 0.7424 kW$

Thermal Efficiency $\eta = \frac{Total\ Power\ Supplied}{Stove\ power} \times 100\% = \frac{0.4561}{0.7424} \times 100\% = 61.44\%$

Calculation of thermal efficiency simmer test
From Table 4;

Burning Rate (BR) $= \frac{M_f}{t} = \frac{145.4}{30} = 4.847 g/min$

$Stove\ Fuel\ Consumption\ (SFC) = \frac{M_f}{V} = \frac{145.4}{1} = 145.4 g/litre$

$Water\ loss\ (WL) = \frac{M_e}{t} = \frac{311.12}{30} = 10.37 g/$
$min = \frac{10.37}{60} = 0.1728 g/sec$

$Total\ power\ supplied\ by\ the\ fuel\ to\ water\ (P) =$
$(M_w C_w \Delta\theta)_{Water} + (M_k C_k \Delta\theta)_{kettle} +$
$Water\ loss \times L = \frac{937.3 \times 4.2 \times 0}{30 \times 60 \times 1000} + \frac{390.5 \times 0.5 \times 0}{30 \times 60 \times 1000} +$
$0.1728 \times 2.261 = 0.3907 kW$

$Stove\ power\ = \frac{4.847}{60} \times 15.1 = 1.21984 kW$

Thermal Efficiency $\eta = \frac{Total\ Power\ Supplied}{Stove\ power} \times 100\% = \frac{0.3907}{1.2198} \times 100\% = 32.03\%$

Determination of thermal efficiency on the fabricated ethanol clean cook stove using cassava ethanol gel

Calculation of thermal efficiency for cold test

From Table 2;

Burning Rate (BR) $= \frac{M_f}{t} = \frac{41.75}{13.23} = 3.156 \, g/min$

$Stove \, Fuel \, Consumption \, (SFC) = \frac{M_f}{V} = \frac{41.75}{1} = 41.75 \, g/litre$

$Water \, loss \, (WL) = \frac{M_e}{t_{avg}} = \frac{24.64}{13.23} = \frac{1.8624 g}{min} = \frac{1.8624}{60} = 0.03104 \, g/sec$

$Total \, power \, supplied \, by \, the \, fuel \, to \, water \, (P) = (M_w C_w \Delta\theta)_{Water} + (M_k C_k \Delta\theta)_{kettle} + Water \, loss \, \times L = \frac{937.3 \times 4.2 \times 63.8}{13.23 \times 60 \times 1000} + \frac{390.5 \times 0.5 \times 63.8}{13.23 \times 60 \times 1000} + 0.0313 \times 2.261 = 0.40529 \, kW$

$Stove \, power \, = \frac{3.156}{60} \times 15.1 = 0.79426 \, kW$

Thermal Efficiency $\eta = \frac{Total \, Power \, Supplied}{Stove \, power} \times 100\% = \frac{0.40529}{0.7942} \times 100\% = 51.03\%$

Calculation of thermal efficiency for hot test

From Table 3;

Burning Rate (BR) $= \frac{M_f}{t} = \frac{34.60}{12.31} = 2.81 \, g/min$

$Stove \, Fuel \, Consumption \, (SFC) = \frac{M_f}{V} = \frac{34.6}{1} = 34.6 \, g/litre$

$Water \, loss \, (WL) = \frac{M_e}{t_{avg}} = \frac{30.5}{12.31} = 0.04130 \, g/sec$

$Total \, power \, supplied \, by \, the \, fuel \, to \, water \, (P) = (M_w C_w \Delta\theta)_{Water} + (M_k C_k \Delta\theta)_{kettle} + Water \, loss \, \times L = \frac{937.3 \times 4.2 \times 59.2}{12.31 \times 60 \times 1000} + \frac{390.5 \times 0.5 \times 59.2}{12.31 \times 60 \times 1000} + 0.04130 \times 2.261 = 0.42452 \, kW$

$Stove \, power \, = \frac{2.81}{60} \times 15.1 = 0.7071 \, kW$

Thermal Efficiency $\eta = \frac{Total \, Power \, Supplied}{Stove \, power} \times 100\% = \frac{0.42452}{0.7071} \times 100\% = 60.04\%$

Calculation of thermal efficiency simmer test

From Table 4;

Burning Rate (BR) $= \frac{M_f}{t} = \frac{143.27}{30} = 4.776 \, g/min$

$Stove \, Fuel \, Consumption \, (SFC) = \frac{M_f}{V} = \frac{143.27}{1} = 143.27 \, g/litre$

$Water \, loss \, (WL) = \frac{M_e}{t} = \frac{308.18}{30} = 0.1712 \, g/sec$

$Total \, power \, supplied \, by \, the \, fuel \, to \, water \, (P) = (M_w C_w \Delta\theta)_{Water} + (M_k C_k \Delta\theta)_{kettle} + Water \, loss \, \times L = \frac{937.3 \times 4.2 \times 0}{30 \times 60 \times 1000} + \frac{390.5 \times 0.5 \times 0}{30 \times 60 \times 1000} + 0.1712 \times 2.261 = 0.3871 \, kW$

$Stove \, power \, = \frac{4.776}{60} \times 15.1 = 1.2020 \, kW$

Thermal Efficiency $\eta = \frac{Total \, Power \, Supplied}{Stove \, power} \times 100\% = \frac{0.3871}{1.2020} \times 100\% = 32.20\%$

Conclusion

The fabricated ethanol clean cook stove and and its performance evaluation was successful. The test results reveals that every time one (1) litre of water is boiled while the stove is still hot, 12.5 g/L of fuel are saved, with highest simmering thermal efficiency of 38%. Also, the fabricated ethanol clean stove takes longer to boil one liter of pure water than other stoves.

An optimal thermal efficiency of 61.44% was achieved after testing the fabricated stove using the water boiling test, and found to be appropriate for domestic use.

The fabricated ethanol stove has lower thermal efficiency, a higher production cost when compared to kerosene and LPG stove, but it has a lower fuel economy and would deliver significant long-term returns. It also produces less carbon soot, emits less greenhouse gases, and supports renewable energy consumption. Though the use of ethanol as a fuel is slightly more expensive, with growing crude oil prices and the hunt for alternatives to modern cooking fuels, it can still be considered a feasible option in the near future.

The research has developed an environmentally friendly clean cook stove that runs on bioethanol fuel as an alternative to fossil derived fuel.

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