



Design, Construction, and Performance Evaluation of an Efficient Ethanol Stove for Domestic Cooking Application

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Abstract

The demand for sustainable and cleaner household energy alternatives has increased due to growing global concerns about indoor air pollution, deforestation, and dependence on fossil-based cooking fuels. Ethanol, a renewable and clean-burning biofuel, has gained considerable attention for domestic cooking applications, particularly in developing regions where traditional biomass fuels remain dominant. This study presents the design, construction, and performance evaluation of an improved ethanol stove intended to provide a safe, efficient, and environmentally friendly cooking solution. A comprehensive design analysis was conducted, including material selection, structural stability, flame control mechanisms, thermal considerations, and stress analysis of the cooktop. The fabrication process involved cutting, drilling, welding, surface finishing, and assembly using locally available materials. Performance evaluation was carried out through boiling and cooking tests to determine heat output, fuel consumption, and operational efficiency. The results demonstrated that the developed ethanol stove achieved efficient combustion with low carbon monoxide emissions, reduced cooking time, and stable flame control. The stove exhibited good structural integrity, effective flame regulation through a choke mechanism, ease of ignition and extinguishing, and safe handling during operation. Boiling tests showed that 1 L of water reached boiling point within approximately 460 seconds, while cooking tests indicated that 500 g of rice could be prepared within 24 minutes using 0.2 L of ethanol fuel. The findings confirm that ethanol stoves can significantly reduce indoor air pollution, fuel costs, and environmental degradation associated with traditional cooking methods. The study recommends further optimization of airflow design, incorporation of ceramic wick materials, and exploration of lightweight structural components to improve performance and durability. This study contributes to ongoing efforts toward sustainable energy utilization and clean cooking technologies, supporting global goals related to public health, climate mitigation, and environmental sustainability.

Keywords: Ethanol Stove; Clean Cooking; Renewable Energy; Biomass Alternatives; Combustion Efficiency; Domestic Stove Design.

1.0 Introduction

The quest for cleaner substitutes to traditional cooking fuels has grown momentum due to increasing concerns about environmental degradation, public health, and access to sustainable energy [1, 2]. Traditional fuels such as firewood, charcoal, and kerosene remain widely used in many developing countries and contribute significantly to indoor air pollution, deforestation, and greenhouse gas emissions [3,4]. According to Warwick et al. [3], and Smith et al. [5] pollutants produced from open-fire cooking are a major cause of respiratory and eye disorders, particularly among women and children who spend extended periods near cooking areas.

Studies by Balat and Balat [6], and Dimitris et al. [7] stated that ethanol has been recognized by mankind for thousands of years, primarily through fermentation processes utilized for producing alcoholic beverages. Early civilizations, including Egyptians and Greeks, understood fermentation but did not initially explore the potential of ethanol as a fuel. Ethanol, a renewable energy resulting from the fermentation of biomass, has given the impression as a promising substitute for domestic cooking [8, 9]. The issue of clean combustion, low emissions, and renewable production pathways make it ideal for maintainable household energy systems [10]. Its use as an energy source started to emerge in the 19th century, where ethanol served as a lighting and heating fuel before being substituted by kerosene during the Industrial Revolution [11, 12]. Efforts to use ethanol for cooking commenced in Europe and the United States in the late 19th and early 20th centuries when scientists experimented with clean alternatives to coal and wood [11, 12]. Nevertheless, widespread adoption did not occur until the late 20th century, when global importance on clean energy and sustainable development improved. The concept of ethanol as a cooking fuel grown prominence in the late 20th century, driven by global initiatives promoting clean energy and enhanced public health. One prominent effort is Project Gaia, co-founded by Harry Stokes in 2000, which aimed to increase access to clean-burning ethanol stoves across Africa. This creativity promoted ethanol as a clean household fuel, specifically in Africa, where biomass fuels were contributing to severe health and environmental problems. The environmental groups and World Bank in 2014 reinforced similar initiatives to make known to clean-burning ethanol stoves in developing regions [10].

Recently, ethanol cooking systems have increased significant traction in countries such as Brazil, Ethiopia, Kenya, and India [2, 13]. These involvements emphasize the potentials of ethanol to lessen indoor air pollution, provide energy security, and support climate mitigation efforts. Several advantages over traditional cooking options have been provided by ethanol stoves including portable, environmentally friendly, and well-organized, offering a smokeless flame with negligible particulate matter emission [14, 15]. The ethanol stoves comprise of a burner, fuel reservoir, air ventilation system, ignition mechanism, and flame control unit. The flame control mechanism, designed as choke, allows users to regulate combustion intensity and safely extinguish the flame after cooking. Its portability and simple operation make it appropriate for off-grid households, emergency conditions, and everyday domestic cooking. Ethanol stoves differ from liquefied petroleum gas (LPG) stoves because do not require pressurized gas cylinders or complex piping systems [16, 17]. While ethanol stoves may not provide the same precision as gas cooktops, but provide adequate heat for most household meals [14, 15]. Safety, fuel efficiency, and ventilation remain important considerations in the use of ethanol stoves. Gas stoves support a wide range of cookware and remain popular in urban households [16]. Nevertheless, they require proper ventilation, reliable gas supply, and safety mechanisms to prevent leaks. The utilization of ethanol supports the circular economy by changing biomass waste into valuable energy, contributing to environmental sustainability [8, 9].

A lot of ethanol stove designs have been globally constructed and evaluated. Jetter et al. [14], and Sprecher [18] that their complication, fuel capacity, and efficiency vary meaningfully liable on design purpose, extending from ultralight backpacking stoves to semi-industrial household models. Also, Jani et al. [19] opined on how traditional stoves cause substantial heat loss and release large amounts of pollutants. Factors affecting stove adoption amid households have been analysed and prompt the redesigned of multi-purpose stove that decreased smoke emissions, fuel consumption, and cooking time [20]. This revealed the reputation of stove versatility, compatibility with cooking practices, and cultural acceptance. As it has been reviewed by Kaputo et al. [21] on improved cookstoves programs and recognized key barriers including user resistance, lack of technical compatibility, and socio-cultural constraints, *moreso*, ICS impacts in rural Nigeria has been studied by Onyeneke et al. [22]. Facts been that improved stoves saved fuel and time, they did not significantly lessen pollution-related diseases because of stove design limitations and user behaviour highlighting the requirement for efficiency-focused redesign.

Due to the growing attention in ethanol as a domestic fuel, a lot of existing ethanol stove models are optimized for camping or outdoor utilization rather than for standard household cooking [16, 18]. Such designs often lack adequate load-bearing capacity, ergonomic features, and safe flame-control mechanisms required for domestic use.

Therefore, this study aims to design, fabricate, and evaluate an improved ethanol stove suitable for domestic cooking applications using locally available materials. The study focuses on structural design, fabrication methods, and performance evaluation to determine the suitability of the developed stove for household cooking.

2.0 Methodology

The procedure for the design of ethanol stove takes in a systematic process that guarantees efficiency, safety, structural reliability, and ease of fabrication. This procedure combines feasibility assessment, engineering calculations, material selection, and functional design considerations. Specific component was designed to meet exact operational and safety standards required for a domestic cooking stove.

2.1 Design Requirement

The design of the ethanol stove was based on functional performance, safety considerations, user ergonomics, and ease of fabrication. Table 1 summarizes the major design parameters and their corresponding descriptions.

Table 1: Basic Design Requirements

Parameter	Description
Material Selection	Aluminum and mild steel were selected due to their strength, heat resistance, affordability, and availability.
Structural Shape	A rectangular configuration was selected to provide stability and ease of handling.
Fuel Reservoir	Designed to safely store ethanol and regulate fuel delivery to the burner.
Ignition System	Designed to allow simple ignition using common sources such as matches or lighters.
Cooktop Structure	Designed to support cooking utensils and distribute load uniformly.
Flame Control	A choke mechanism regulates airflow and controls flame intensity.

2.2. Selected Design

The selected ethanol stove design is a compact rectangular, system consisting of four main components:

- i. Canister (Fuel Reservoir)
- ii. Choke (Flame Adjuster)
- iii. Stove Housing
- iv. Cooktop

The shape was chosen due to:

- i. It supports firm placement of cooking utensils.
- ii. It enables precise airflow for efficient combustion.
- iii. It enhances user safety by means of shielded flame exposure.
- iv. It allows easy fabrication using standard workshop tools.
- v. It supports a 2 L fuel capacity fit for household cooking needs

2.3 Canister Design

The canister serves as the primary fuel storage chamber for the reason that the issue are structural integrity and corrosion resistance are critical for the reason that ethanol is a volatile and flammable liquid.

2.3.1 Canister Material Selection

Internal line of the canister was by the use of aluminium because of its:

- i. high resistance to corrosion in the environments
- ii. low reactivity under normal conditions
- iii. lightweight nature, improving stove portability
- iv. good machinability for drilling and finishing

The canister exterior was reinforced with mild steel for a stronger frame when inserted into the stove housing.

2.3.2 Calculating the Volume of the Canister

The dimensions of canister used for the volume calculation are presented in Table 2.

Table 2: Canister Design Specifications

Parameter	Value
Canister height	2.5 cm
Canister diameter	32 cm
Canister material	Aluminium + mild steel
Canister top opening diameter	1 cm

The volume, V of cylindrical Canister is calculated using Equation 1.

$$V = \pi r^2 h \quad (1)$$

Where:

$$r = \frac{d}{2} = \frac{32}{2} = 16 \text{ cm}$$

$$h = 2.5 \text{ cm}$$

$$V = \pi(16)^2(2.5)$$

$$V = \pi \times 256 \times 2.5$$

$$V = 2010.62 \text{ cm}^3$$

Conversion from cm^3 to litres

$$1000 \text{ cm}^3 = 1L$$

$$V = \frac{2010.62}{1000} \approx 2 L$$

The canister has the capacity of holding approximately **2 liters** of ethanol, appropriate for multiple cooking sessions.

2.3.3 Chemical Compatibility of Canister Materials

The reaction between ethanol with aluminium under normal environments is slowly because of the presence of naturally occurring aluminium oxide protective layer. Nevertheless, at high temperatures or in the presence of catalysts, the following reaction may occur:



However, the rate of reaction remains insignificant at typical stove operating temperatures, warranting long-term safety and durability.

2.4 Stove Housing Casing

Stove housing incorporates all major components and provides structural stability. It's designed in a form of rectangular box of 3 mm mild steel sheet. It offers the following functions:

1. structural support for all internal components
2. improves airflow to sustenance combustion
3. protects users from extreme heat exposure
4. supports the cooktop and allocates load uniformly
5. enhances aesthetics and modern stove appearance
6. warrants' safety by isolating the fuel canister from direct contact

2.5 Stability and Centre of Gravity Computation

Stability is an important factor to prevent tipping when cookware is positioned on the stove. The stove housing must support as presented in Table 4 values:

Table 4: Parameters for Center of Gravity

Parameter	Value
Load weight (W_1)	2 kg
Stove housing height (d_1)	15 cm
Filled canister weight (W_2)	1.578 kg
Canister distance from bottom (d_2)	5 cm

The Center of Gravity (CG) was determined using Equation 3:

$$CG = \frac{\sum W_i d_i}{\sum W_i} \quad (3)$$

$$CG = \frac{(2 \times 15) + (1.578 \times 5)}{2 + 1.578}$$

$$CG = \frac{30 + 7.89}{3.578} = 10 \text{ cm}$$

A center of gravity of **10 cm** (lower than the stove height of 15 cm) guarantees excellent stability, dropping tipping risks.

2.6 Choke (Flame Adjuster) Design

The choke is also called the flame adjuster or air-regulation disc which controls the amount of air entering the combustion chamber. This permits the user to:

- i. Open choke (Increase the flame)
- ii. Partially closed choke (Reduce the flame)
- iii. Fully closed choke (Completely extinguish the flame)

The choke is designed in the form of a circular sliding plate made of 2 mm mild steel, with perforated holes aligned with corresponding holes on the top of the stove.

2.6.1 Functional Requirement of the Choke

1. Regulate Airflow: Regulates the amount of oxygen entering the combustion area to control flame height.
2. Ensure User Safety: Permits flame extinguishing without blowing out or manually covering the fire.
3. Heat Resistance: Must resist direct exposure to high temperatures ($> 300^\circ\text{C}$).
4. Smooth Operation: Designed with a sliding mechanism for easy movement.

2.6.2 Design Dimensions

- Choke diameter = 10 cm
- Number of air openings = 6
- Diameter of each opening = 1 cm
- Thickness = 2 mm mild steel

The airflow rate is determined by total open area.

Area of a single hole calculation:

$$A_1 = \pi r^2 \quad (4)$$

For hole diameter of 1 cm:

$$r = \frac{1}{2} = 0.5 \text{ cm}$$

$$A_1 = \pi(0.5)^2 = 0.785 \text{ cm}^2$$

Total airway area calculation:

$$A_T = 6 \times 0.785 = 4.71 \text{ cm}^2$$

Airflow control levels are as follows:

- i. **Fully open** = 4.71 cm²
- ii. **Half open** ~2.35 cm²
- iii. **Fully closed** = 0 cm²

2.7 Cooktop Design

The cooktop was designed to:

- i. hold cooking pots ranging from 1–10 kg
- ii. dispense heat homogenously
- iii. prevent twisting under load
- iv. allow proper heat discharge around the pot

2.7.1 Cooktop Structure

- i. Shape: Rectangular
- ii. Material: 3 mm mild steel sheet
- iii. Supports: Cylindrical legs (4 in number)
- iv. Opening: Circular cut-out directly above the flame
- v. Heat vents: Side perforations of 2 × 4 cm each in dimension (4 in number)

This provision of optimal oxygen supply for clean ethanol combustion and efficient flame control was done by this area.

2.7.2 Cooktop Dimensions

The cooktop dimensions were presented in Table 5.

Table 5. Cooktop Dimension

Component	Dimension
Cooktop length	35 cm
Cooktop width	30 cm
Support leg height	4 cm
Thickness	3 mm

2.7.3 Load Estimation on Cooktop

To guarantee safety, a maximum load of **10 kg** was selected ($\approx 98.1 \text{ N}$).

Assuming uniform load distribution using Equation 5:

$$q = \frac{W}{A} \quad (5)$$

Where:

$$W = 98.1 \text{ N}$$

$$A = 0.35 \times 0.30 = 0.105 \text{ m}^2$$

2.7.4 Stress Analysis of the Cooktop

Using simple bending stress estimation for a plate supported on four corners as presented in Equation 6:

$$\sigma = \frac{My}{I} \quad (6)$$

Where:

$$M = \frac{WL}{4}$$

$$y = \frac{t}{2}$$

$$\sigma = \frac{bt^3}{12}$$

Where:

$$W = 98.1 \text{ N}$$

$$L = 0.35 \text{ m}$$

$$B = 0.30 \text{ m}$$

$$T = 0.003 \text{ m}$$

Computing for the Moment (M)

$$M = \frac{98.1 \times 0.35}{4} = 8.588 \text{ Nmm}$$

Computing Distance (y)

$$y = \frac{0.003}{2} = 0.0015 \text{ m}$$

Computing for the Moment of Inertia (I)

$$I = \frac{0.30 \times 0.003^2}{12}$$

$$I = \frac{0.30 \times 27 \times 10^{-2}}{12}$$

$$I = 6.75 \times 10^{-9} \text{ m}^2$$

Computing for the Bending Stress (σ)

$$\sigma = \frac{8.588 \times 0.0015}{6.75 \times 10^{-9}}$$

$$\sigma = 1.91 \times 10^6 = 1.91 \text{ MPa}$$

Base on the designed calculation, the yield strength of mild steel is **250 MPa**, and computed stress is **1.91 MPa**. Therefore, **the design is safe**, with a large margin of safety.

2.8 Cost Analysis

A detailed cost analysis was carried out to determine the total expenditure required for materials and labour. Prices are in line with local workshop rates. The material cost and labour cost were presented in Tables 6 and 7.

Table 6: Material Cost

Material	Quantity	Unit Cost (₦)	Total (₦)
Mild steel sheet (3 mm)	1 sheet	15,000	15,000
Aluminum sheet	1 sheet	12,000	12,000
Mild steel rod (support legs)	4 rods	500	2,000
Welding rods	10 sticks	300	3,000
Bolts & nuts	1 pack	1,500	1,500
Paint (heat-resistant)	1 can	3,000	3,000
Sandpaper & finishing materials	1 set	800	800
Total Material Cost			37,300

Table 7: Labour Cost

Activity	Cost (₦)
Cutting & shaping	5,000
Welding & assembly	7,000
Polishing & finishing	3,000
Testing & adjustments	2,000
Total Labour Cost	₦17,000

Total Fabrication Cost

The total fabrication cost of the ethanol stove is as follows:

$$\text{Total Cost} = \text{Material Cost} + \text{Labour Cost}$$

$$\text{Total Cost} = 37300 + 17,000 = \text{₦}54,300$$

This total cost is significantly lower than imported ethanol stoves, making the design economically viable and scalable for mass production.

2.9 Fabrication of Ethanol Stove

The ethanol stove was fabricated in a standard metal workshop using conventional fabrication tools to ensure reproducibility and affordability. The fabrication process involved four major stages: construction of the stove housing, fabrication of the fuel canister, fabrication of the choke mechanism, and construction of the cooktop.

The stove housing was constructed from a 3-mm thick mild steel sheet (Figure 1, Plate 1). The sheet was first measured and marked according to the design dimensions of $35 \times 30 \times 15$ cm. The marked sections were cut using a mechanical cutting machine and then bent at right angles using a hydraulic sheet-bending machine to form a rectangular casing. The edges were subsequently welded using arc welding to produce a rigid structural frame. Ventilation openings measuring 2×4 cm were drilled on the side panels to facilitate airflow during combustion. After welding, the surfaces were polished and coated with heat-resistant paint to improve durability and aesthetics.

The fuel canister was fabricated from an aluminium sheet shaped into a cylindrical form using a rolling machine (Figure 2, Plate 2). The edges were joined using TIG welding to ensure a leak-proof structure. A circular base plate was welded to the bottom of the cylinder, and a 1 cm diameter opening was created at the top to allow ethanol fuel to enter the reservoir. The canister was then filled with water to test for leakage before installation.

The choke mechanism was fabricated from a circular mild steel plate with a diameter of 10 cm (Figure 3, Plate 3). Six holes of 1 cm diameter were drilled symmetrically around the plate to regulate airflow into the combustion chamber. A handle was welded onto the choke plate to allow easy manual adjustment of the airflow during operation.

The cooktop was fabricated from a 3-mm thick mild steel plate measuring 35×30 cm (Figure 4, Plate 4). A circular opening was cut at the center to allow flame passage from the burner. Four support legs made from mild steel rods were welded beneath the cooktop to elevate the cooking vessel above the flame and provide structural stability.

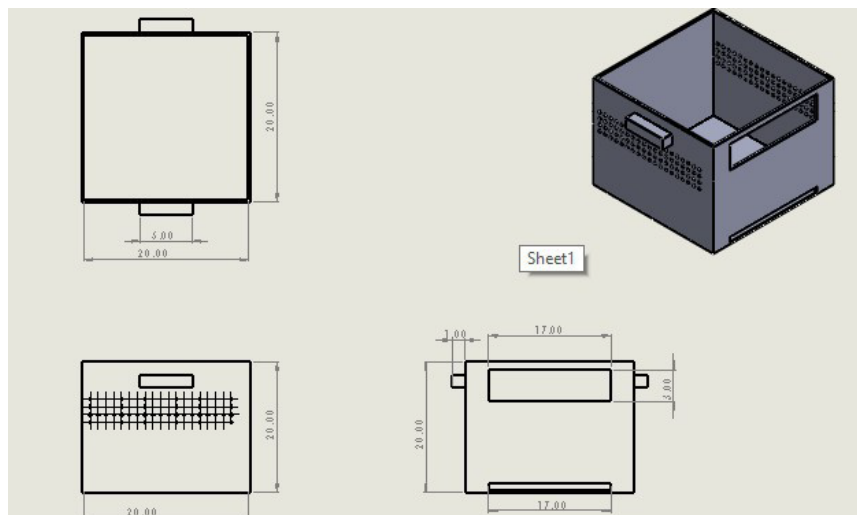


Figure 1. First angle projection of stove housing

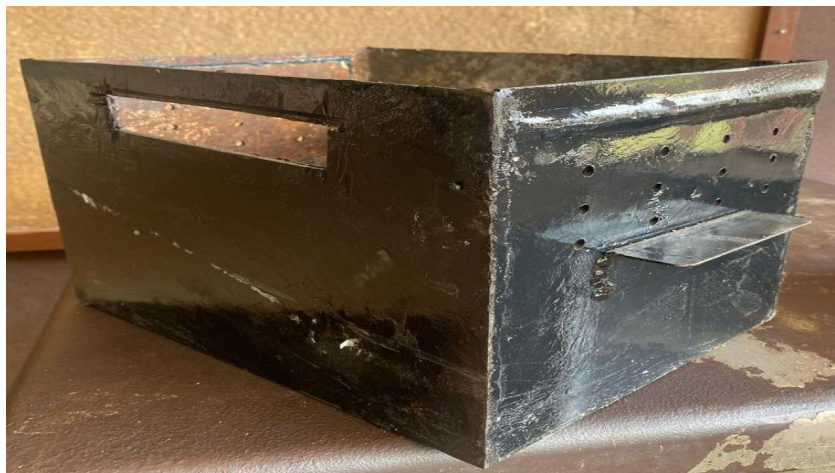


Plate 1. Fabricated stove housing

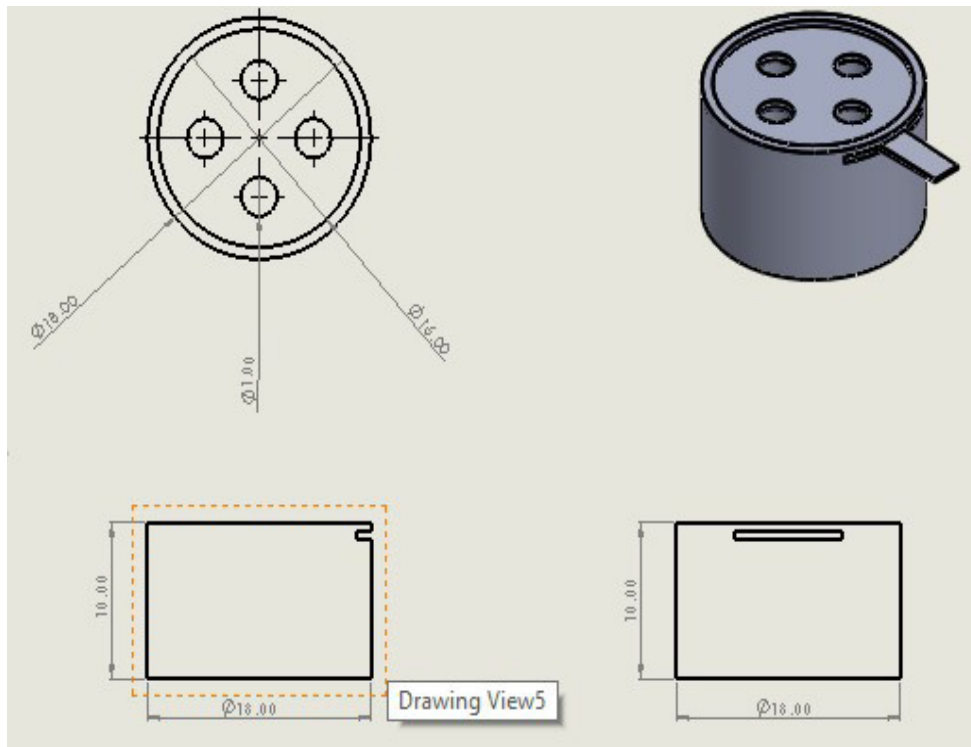


Figure 2. First angle projection of the canister



Plate 2. Fabricated canister

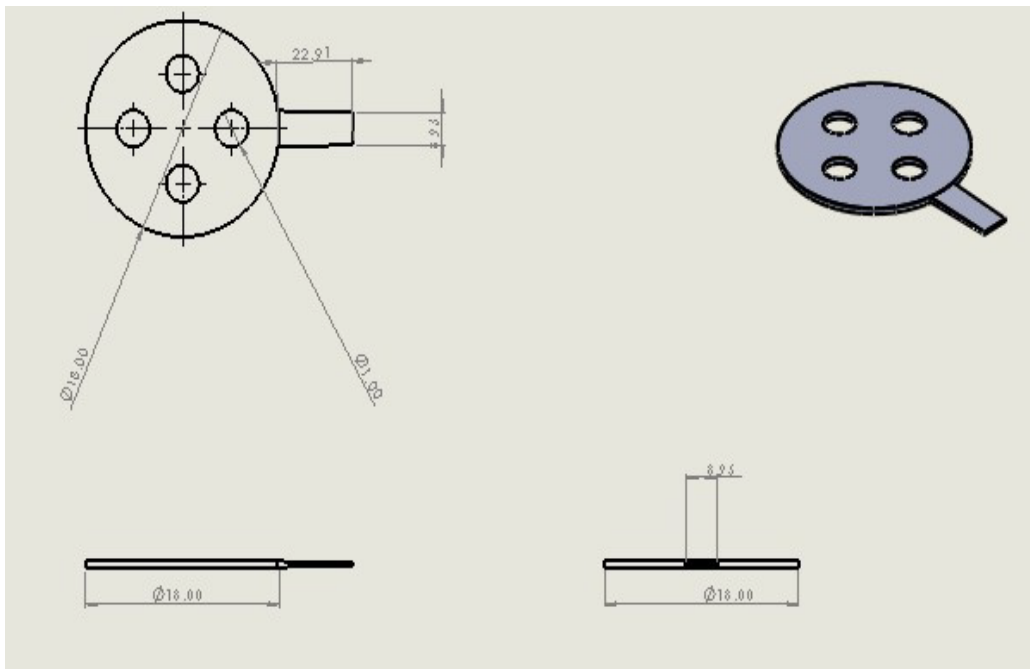


Figure 3. First angle projection of choke



Plate 3. Fabricated choke

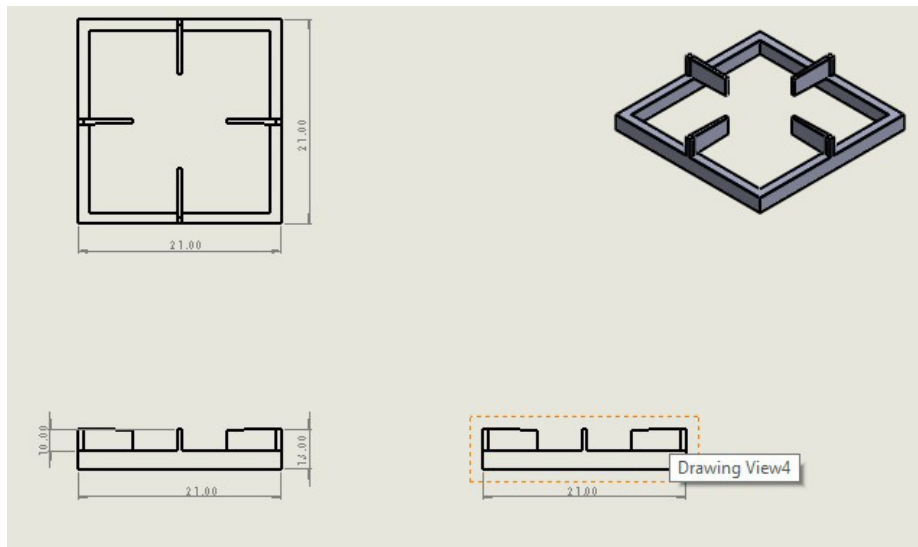


Figure 4. First angle projection of cooktop



Plate 4. Fabricated cooktop

2.10 Assembly of the Stove Components

The assembly drawing of the ethanol stove components is presented in Figure 5 and assemblage of fabricated ethanol stove in Plate 5, which illustrate the arrangement and relationship between the fabricated parts. After the fabrication of all individual components such as the stove housing, fuel canister, choke plate, and cooktop, the final assembly of the stove was carried out systematically to ensure proper functionality, structural stability, and user safety.

The first stage of the assembly process involved the installation of the fuel canister. The canister, which serves as the container for the ethanol fuel, was carefully inserted into the lower section of the stove housing. Adequate clearance was maintained between the canister and the surrounding housing walls to prevent excessive heat transfer from the combustion zone to the fuel container. This spacing is important because it minimizes the risk of overheating and ensures safe fuel storage during stove operation.

Following the placement of the fuel canister, the choke mechanism was installed. The choke plate, which is responsible for regulating the airflow and controlling the intensity of the flame, was mounted directly above the canister opening. It was secured using screws and integrated with a sliding mechanism that allows the user to adjust the amount of air entering the combustion chamber. This adjustment capability helps regulate the combustion rate of ethanol fuel and enables the user to increase or reduce the heat output depending on the cooking requirement.

The next stage involved the installation of the cooktop. The cooktop functions as the upper support structure where cooking utensils such as pots and pans are placed during operation. It was positioned on the upper part of the stove housing and firmly welded to ensure structural rigidity and durability. Proper alignment was ensured during welding to guarantee that the cooktop remains stable and capable of supporting cooking loads without deformation or displacement.

After all components were assembled, a final inspection and quality check was conducted to verify the integrity and safety of the stove. This inspection involved examining the entire assembly for the presence of sharp edges that could pose a risk to users, checking for any loose or weak weld joints that might compromise structural strength, and confirming that the choke mechanism moved smoothly along its sliding path without obstruction. In addition, the overall stability and ease of handling of the stove were evaluated to ensure that the device could be safely used during cooking operations.

Upon completion of these inspections and adjustments, the assembled ethanol stove satisfied the required safety, functional, and ergonomic standards, confirming that the design and assembly process were successfully executed.

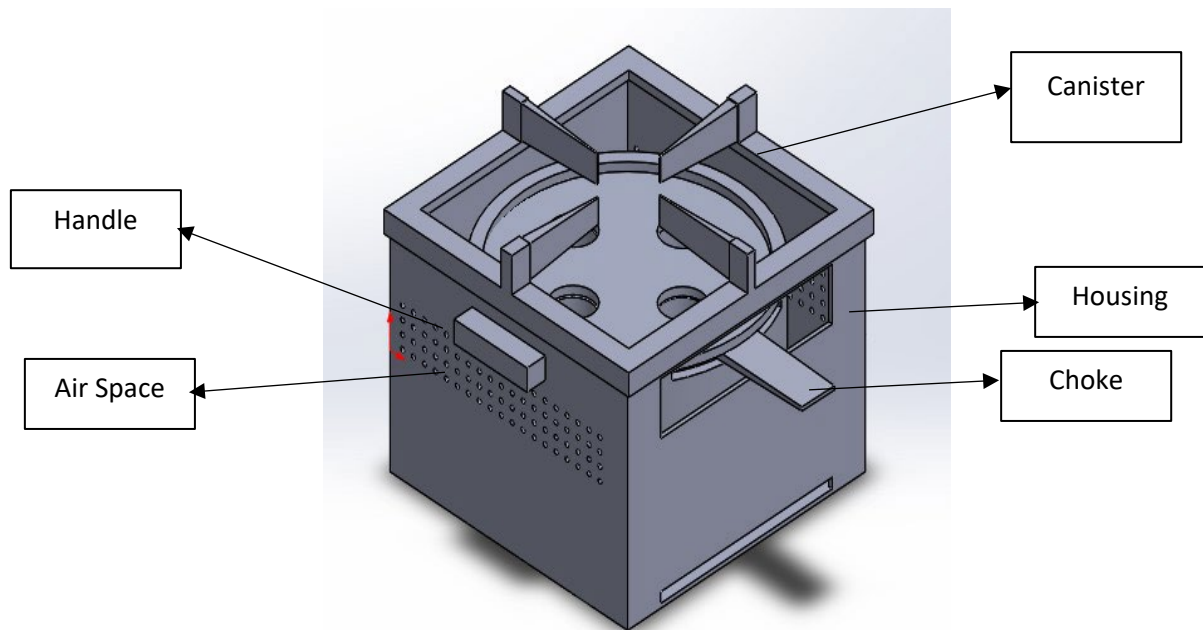


Figure 5a. Assembling drawing of the ethanol stove components

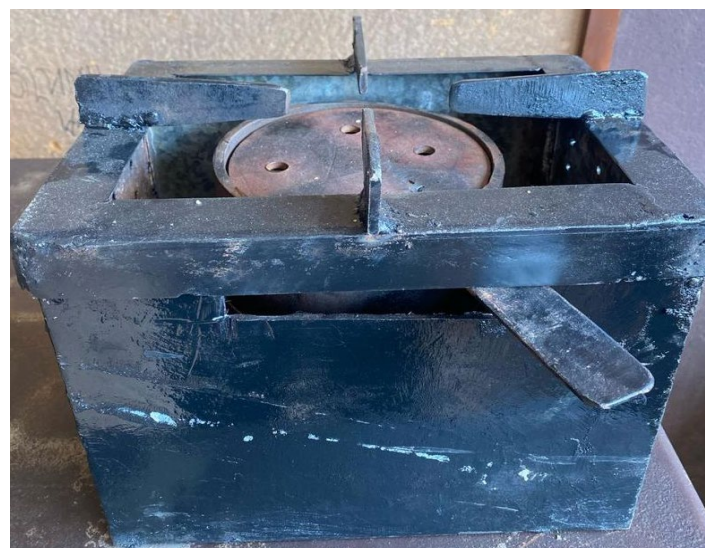


Plate 5. Fabricated ethanol stove components

2.11 Testing of the Ethanol Stove

The performance of the developed ethanol stove was evaluated to determine boiling time, fuel consumption rate, heat output, thermal efficiency, cooking performance, and operational safety and stability. All tests were carried out in a well-ventilated laboratory environment.

2.11.1 Boiling Time Test

The boiling time test was conducted by measuring the time required to heat different volumes of water to boiling temperature. A measured quantity of water (0.5 L, 1.0 L, and 1.5 L) was poured into a standard cooking pot placed on the stove cooktop. The choke was adjusted to its maximum opening to allow full airflow. The ethanol fuel was ignited using a matchstick, and the time required for the water to reach boiling point was recorded using a stopwatch. The ambient temperature during the experiment was approximately 29°C. Heat energy was determined using Equation 7:

$$Q = mc\Delta T \quad (7)$$

where:

Mass of water (m) = 0.5, 1, 1.5 kg

Specific heat capacity (c) = 4200 J/kg°C

Change in Temperature (ΔT) = 100 – 29 = 71°C

2.11.2 Fuel Consumption Test

The fuel consumption test was carried out to determine the quantity of ethanol fuel utilized by the stove during operation. This test was conducted simultaneously with the water boiling test so that the rate at which fuel is consumed during a typical cooking process could be accurately determined. Evaluating fuel consumption is important because it provides information on the efficiency of the stove and helps in assessing its economic and practical suitability for household cooking applications. To begin the experiment, the fuel canister of the ethanol stove was filled with a known and carefully measured volume of ethanol fuel. This ensured that the starting fuel quantity was accurately established before ignition. After filling the canister, the initial volume of ethanol contained in the fuel reservoir was recorded. The stove was then ignited and allowed to operate during the boiling test under normal operating conditions. During the boiling process, ethanol was gradually consumed as combustion occurred to generate heat for cooking. At the completion of the boiling test, the stove flame was extinguished and the remaining volume of ethanol in the canister was measured. The amount of fuel used during the test was determined by calculating the difference between the initial volume of ethanol placed in the canister and the remaining volume after the boiling process.

Fuel consumption rate was calculated using Equation 8:

$$F = \frac{V_c}{t} \quad (8)$$

Where:

Volume consumed (V_c), L

Time (t), s

2.11.3 Cooking Performance Evaluation

The cooking performance of the developed ethanol stove was evaluated through a practical cooking test using rice as the test meal. Rice was selected because it represents a common staple food in many households and provides a realistic method of assessing the stove's ability to generate sufficient heat for everyday cooking activities. In the cooking experiment, 500 g of rice was first carefully washed to remove impurities. The washed rice was then placed in a cooking pot containing 1.2 liters of clean water, which represents a typical water-to-rice ratio used in household cooking. The pot was positioned securely on the cooktop of the ethanol stove. The stove was then ignited and the choke mechanism was opened fully to allow maximum airflow into the combustion chamber. This ensured that the ethanol fuel burned efficiently and produced the highest possible flame intensity during the cooking process. Once the flame was stabilized, the pot containing the rice and water mixture was placed on the stove and the cooking process began. During the cooking operation, the time required to completely cook the rice was carefully recorded using a stopwatch. In addition, the amount of ethanol fuel consumed during the cooking process was measured by comparing the initial and final volumes of fuel in the canister. The results obtained from the cooking performance test indicated that the rice was completely cooked within 24 minutes, while the stove consumed approximately 0.2 liters of ethanol fuel during the process. Based on these results, the developed ethanol stove demonstrated the ability to produce sufficient and consistent heat output for typical domestic cooking tasks. The relatively short cooking time and moderate fuel consumption indicate that the stove design is efficient and suitable for household cooking applications. The performance evaluation therefore confirms that the fabricated ethanol stove can serve as a practical and effective alternative cooking device for domestic use.

2.12 Safety and Stability Test

The stability test involved loading the stove with maximum pot weight, and lateral push test of 10 kg, and 50 N, respectively. The stove keeps on stable and did not topple. Heat shielding successfully resisted unnecessary outer casing temperature ($> 50^{\circ}\text{C}$).

3.0. Results and Discussion

Results of the boiling time and fuel consumption tests for the developed ethanol stove made from locally available materials are presented in Table 8.

Table 8. Summary of test results

S/N	Volume of Water, L	Energy Required, J	Fuel Consumption, L/s	Time, s
1	0.60	178920	0.0058	441.6
2	0.80	238560	0.0059	450.8
3	1.00	298200	0.006	460
4	1.20	357840	0.0061	469.2
5	1.40	387660	0.0062	478.4

3.1 Boiling Time Performance

The results showed that fabricated stove recorded 478.4 seconds for 1 to 1.40 liter of water (Table 8 and Figure 6), which is within the performance range of similar ethanol stoves (6 – 10 minutes). This finding proves that the stove offers sufficient heat output for domestic cooking. The findings prove that ethanol is a feasible household cooking fuel when efficiently combusted over a properly engineered stove system. This agrees with the finding of Goldemberg et al. [10], and Bailis et al. [17].

Faster boiling was achieved through efficient airflow through the choke mechanism adequate fuel vaporization, and direct heat transfer from the stable flame under the cooktop. When compared with the Zeph Starlyte and White Box stove models studied by Sprecher [18], the performance of the developed ethanol stove falls within competitive limits for boiling efficiency.

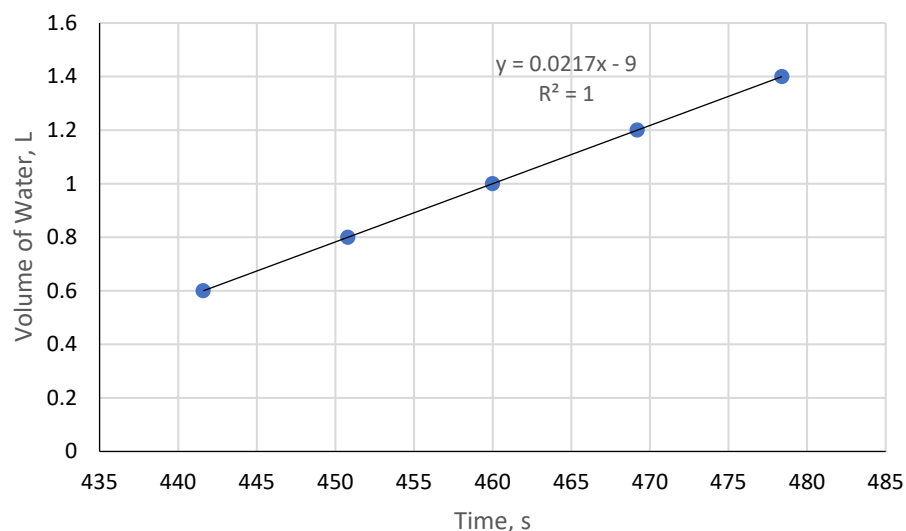


Figure 6: Variation of Volume of Water against Time

3.2 Fuel Consumption Analysis

Result of the fuel consumption rate of the developed ethanol stove ranged from 0.0058 to 0.0062 L/s, translating to approximately (Table 8 and Figure 7). This reveals moderate fuel efficiency consistent with calorific value of ethanol and the stove's airflow design. Factors that improved efficiency of the stove include short fuel-air diffusion distance, aluminium canister promoting favourable vaporization conditions, controlled air admixture through the choke. The combustion proficiency consistent with combustion theory was enhanced by choke-

controlled airflow. This aligns with the studies by Turns [23] Çengel and Boles [24]. The consumption rate is a little higher than ultralight backpacking stoves, but this is anticipated because of larger flame size desirable for domestic cooking.

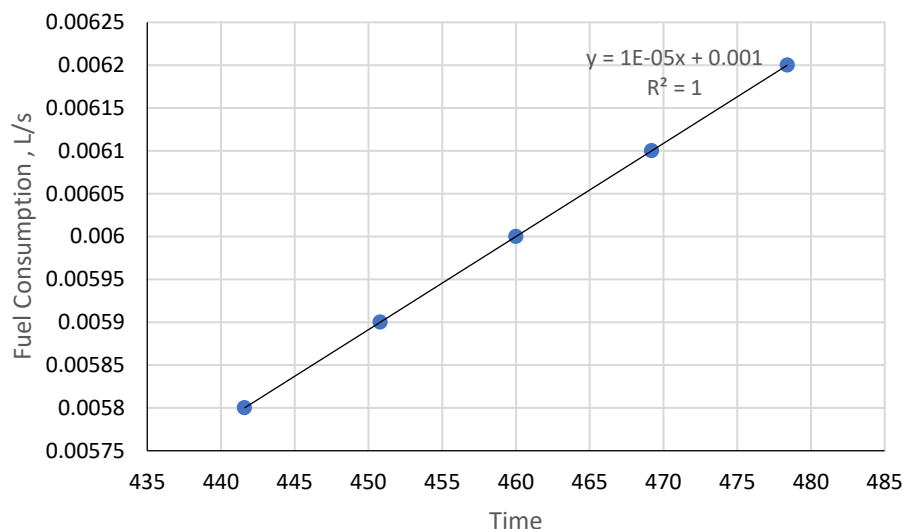


Figure 7: Fuel Consumption vs Time

3.3 Cooking Performance Evaluation

The developed ethanol stove successfully cooked 500 g of rice in 24 minutes using 0.2 L of ethanol. This demonstrates that it is appropriate for home cooking that calls for moderate to high heat levels. The result supports the findings of Gill-Wiehl et al. [20], who reported that user acceptance of improved cookstoves is strongly dependent on cooking speed and fuel reliability. The distribution of heat was uniform, and the flame remained steady throughout cooking. The experimental boiling time and fuel consumption fall within acceptable clean cookstove performance benchmarks as reported in previous studies by Jetter et al. [14], and Mukhopadhyay et al. [15].

3.2. Stability and Safety Performance

The ethanol stove's structural reliability based on stability test confirmed that a 10 kg load without deformation was supported by it, and also resisted toppling under a 50 N lateral push, validating the centre of gravity computations. Additionally, the outer casing temperature remained below 50°C, lessening burn hazards. Based on safety results reflect design improvements over earlier simplified ethanol stoves, which lacked proper housing and often posed risks of spills and burns [21]. Finally, the environmental benefits also align with global clean cooking transition goals of WHO [1], and IEA [2].

4.0 Conclusion

This study successfully designed, fabricated, and evaluated an ethanol stove suitable for domestic cooking applications. The developed stove demonstrated good structural stability, with a center of gravity that prevents tipping even when supporting loads up to 10 kg. Performance tests indicated that the stove achieved a boiling time of approximately 460 seconds for 1 L of water and successfully cooked 500 g of rice within 24 minutes using 0.2 L of ethanol fuel. The experimental results confirm that ethanol can serve as an efficient and clean cooking fuel when used in an appropriately designed stove. The use of locally available materials reduced fabrication costs to approximately ₦54,300, making the stove economically viable for local production and widespread adoption. Overall, the developed ethanol stove provides a safe, efficient, and environmentally friendly alternative to traditional biomass cooking methods. Future improvements may include the use of stainless-steel components for improved durability, integration of a fuel level indicator, and improved insulation of the fuel chamber to enhance vaporization efficiency.

References

- [1] World Health Organization (WHO). Household air pollution and health. WHO Press (2021).
- [2] International Energy Agency (IEA), "World energy outlook 2022", Clean cooking access, IEA Publications (2022).

- [3] Warwick, H., Doig, A., Martin, C., & Sones, K., “Smoke, health and household energy use developing countries”, World Health Organization (2004).
- [4] Bonjour, S., Adair-Rohani, H., Wolf, J., Bruce, N. G., Mehta, S., Prüss-Ustün, A., & Smith, K. R., “Solid fuel use for household cooking: Country and regional estimates for 1980–2010”, *Environmental Health Perspectives*, 121(7), 784–790. <https://doi.org/10.1289/ehp.1205987>, (2013).
- [5] Smith, K. R., Bruce, N., Balakrishnan, K., Adair-Rohani, H., Balmes, J., Chafe, Z., & Pope, D., “Millions dead: How do we know and what does it mean? Methods used in the comparative risk assessment of household air pollution”, *Annual Review of Public Health*, 35, 185–206. <https://doi.org/10.1146/annurev-publhealth-032013-182356>, (2014).
- [6] Balat, M., & Balat, H., “Recent trends in global production and utilization of bio-ethanol fuel”, *Applied Energy*, 86(11), 2273–2282. <https://doi.org/10.1016/j.apenergy.2009.03.015>, (2009).
- [7] Dimitris, L., Kalfas, G., & Santos, M., “Ethanol production and utilization in modern energy systems”, *Renewable Energy Review*, 20(4), 99–118, (2016).
- [8] Demirbas, A., “Progress and recent trends in biofuels”, *Progress in Energy and Combustion Science*, 33(1), 1–18. <https://doi.org/10.1016/j.pecs.2006.06.001>, (2007).
- [9] Suiran, L., & Jing, Y., “Renewable ethanol and its applications”, *Journal of Alternative Fuels*, 3(2), 90–105, (2009).
- [10] Goldemberg, J., Coelho, S. T., & Guardabassi, P., “The sustainability of ethanol production from sugarcane”, *Energy Policy*, 36(6), 2086–2097. <https://doi.org/10.1016/j.enpol.2008.02.028>, (2008).
- [11] Patrick, A., “Evolution of household fuel use”, *Journal of Historical Energy Studies*, 27(1), 50–63, (2019).
- [12] Alison, J., “History of clean fuel technologies”, Green Flame Publishing.
- [13] Clean Cooking Alliance, “Clean cooking market assessment report”, Clean Cooking Alliance, (2020).
- [14] Jetter, J., Zhao, Y., Smith, K. R., Khan, B., Yelverton, T., DeCarlo, P., & Hays, M. D., “Pollutant emissions and energy efficiency of improved cookstoves”, *Environmental Science & Technology*, 46(19), 10827–10834. <https://doi.org/10.1021/es301693f>, (2012).
- [15] Mukhopadhyay, R., Sambandam, S., Pillarisetti, A., Jack, D., & Bates, M. N., “Cooking practices, air quality, and the acceptability of advanced cookstoves in India”, *Indoor Air*, 22(6), 458–469. <https://doi.org/10.1111/j.1600-0668.2012.00779.x>, (2012).
- [16] Clendinning, J., “Domestic cookstoves: Performance and safety review”, *Energy for Development Journal*, 12(3), 44–56, (2008).
- [17] Bailis, R., Drigo, R., Ghilardi, A., & Masera, O., “The carbon footprint of traditional woodfuels”, *Nature Climate Change*, 5(3), 266–272. <https://doi.org/10.1038/nclimate2491>, (2015).
- [18] Sprecher, J., “Comparison of modern alcohol stoves for outdoor and household use”, *Stove Review Magazine*, 19(3), 22–30, (2022).
- [19] Jani, D. B., Reddy, T. V., & Patel, R., “Improved design of multi-purpose cookstoves”, *International Journal of Thermal Engineering*, 8(1), 11–20, (2020).
- [20] Gill-Wiehl, A., Price, P., & Kammen, D. M., “User preferences and design needs for improved cookstoves in low-income communities”, *Journal of Sustainable Energy*, 15(2), 77–91, (2021).
- [21] Kaputo, K., Mwale, F., & Nyirenda, G., “Challenges in adoption of improved cookstoves in Sub-Saharan Africa”, *Clean Energy Policy Journal*, 9(1), 1–14, (2023).
- [22] Onyeneke, R. U., Emenyonu, C. A., & Nwajiuba, C. A., “Environmental and health impacts of cookstoves in rural Nigeria”, *Nigerian Journal of Environmental Science*, 14(2), 115–128, (2022).
- [23] Turns, S. R., “An introduction to combustion: Concepts and applications” (3rd ed.). McGraw-Hill, (2012).
- [24] Çengel, Y. A., & Boles, M. A., “Thermodynamics: An engineering approach”, (8th ed.). McGraw-Hill Education, (2015).
- [25] ASTM International, “Standard test methods for cookstove performance (ASTM E3053–17)”, ASTM International, (2018).