

Development of Eco-Friendly Charcoal Stove

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Abstract

Energy is one of the most crucial needs of mankind and substantial efforts and technologies have been channeled towards providing affordable and sustainable energy for the entire human race. Cooking happens to be a domestic as well as commercial process which requires lots of energy for boiling, steaming, frying and cooking meals. This study aimed to design, develop and assess the performance of an 80% saved charcoal stove, which uses charcoal as its major fuel. The design was modeled using Autodesk Inventor. The concept of the design was to create a cooking stove that uses charcoal as its source of fuel. To do this, a required combustion chamber was created. Since fuel economy is a leading subject regarding the efficiency and overall performance of energy-based machines, an air vent was also incorporated to enrich the burning mixtures and enhance combustion. The thermal efficiency of the design was evaluated by the use of the water boiling test (WBT) where the useful heat was compared to the heat generated from the fuel used. Thermal efficiency of 26.4% was obtained. Hence, the developed 80% saved charcoal stove therefore has economic advantage over the regular charcoal stoves.

Keywords: Energy Efficiency, Charcoal Stove, Fuel Savings, Insulated Combustion Chamber, Reduced Emissions, Cost Savings.

Introduction

Charcoal is a solid biomass fuel obtained through the carbonization (also called pyrolysis) of wood. It has an average energy content of 30 MJ/kg. In comparison, firewood has an average energy content of 18 MJ/kg average (Sepp, 2014).

The traditional use of charcoal stoves in many developing countries contributes significantly to deforestation and air pollution (Staton and Harding, 1998), while also posing health risks due to indoor air pollution. The 80% saved charcoal stove is an innovation aimed at mitigating these issues by drastically reducing the amount of charcoal needed for cooking (Seboka, 2009). This paper examines the technology behind these stoves, their environmental impact, and their potential to improve livelihoods.

The 80% efficient saved charcoal stove is a groundbreaking innovation in the realm of energy-efficient cooking technologies (Tran *et al.*, 2021), particularly in regions where charcoal remains a primary fuel source for daily cooking needs. This stove represents a vital advancement in addressing several pressing global challenges (Arakawa *et al.*, 2001), including energy inefficiency, environmental degradation, health risks associated with indoor air pollution, and economic burdens on low-income households.

Charcoal stoves are widely used across many parts of the developing world (Mwampamba *et al.*, 2013), particularly in sub-Saharan Africa, Southeast Asia, and parts of Latin America. In these regions, charcoal is often the preferred cooking fuel due to its availability, affordability, and higher energy content compared to other biomass fuels like wood. However, traditional charcoal stoves are notorious for their inefficiency, typically converting only 10-30% of the charcoal's energy into useful heat for cooking (Njenga *et al.*, 2017). The remaining energy is lost to the environment, resulting in higher fuel consumption, increased costs for households, and greater environmental impacts due to the demand for more charcoal. The environmental implications of inefficient charcoal use are profound (Zulu and Richardson, 2013). The high demand for charcoal is a significant driver of deforestation in many parts of the world, as trees are cut down to produce charcoal (Santos *et al.*, 2017). This deforestation contributes to a host of environmental problems, including loss of biodiversity, disruption of ecosystems, and increased carbon emissions, which exacerbate climate change. Moreover, the inefficient burning of charcoal in traditional stoves produces large amounts of smoke and other harmful emissions, including carbon monoxide and fine particulate matter, which are major contributors to indoor air pollution (Miah *et al.*, 2009).

Indoor air pollution is a critical public health issue, particularly in developing countries where it is a leading cause of respiratory illnesses, cardiovascular diseases, and premature deaths (Spengler and Sexton, 1983). Women and children, who spend more time near cooking areas, are disproportionately affected by these health risks (Holm *et al.*, 2018). The World Health Organization (WHO) estimates that exposure to smoke from traditional cookstoves is responsible for millions of deaths each year, making the need for more efficient and cleaner cooking technologies an urgent priority (Desai *et al.*, 2004).

The development of this 80% efficient saved charcoal stove is a direct response to these challenges (Mehetre *et al.*, 2017). By significantly improving the thermal efficiency of charcoal stoves, this innovative design drastically reduces the amount of charcoal needed for cooking, thus lowering both the economic and environmental costs associated with charcoal use (Wang *et al.*, 2016). The stove's advanced combustion technology ensures that a much higher percentage of the charcoal's energy is converted into usable heat, minimizing energy waste and reducing the overall consumption of charcoal (Bhattu *et al.*, 2019).

The stove achieves this enhanced efficiency through several key design features (Mekonnen, 2022). A central component is the insulated combustion chamber, which retains heat and directs it more effectively towards the cooking vessel. This design minimizes heat loss and maximizes the transfer of energy, meaning that less charcoal is required to achieve the same cooking performance as a traditional stove (Pacheco *et al.*, 2012). Additionally, the stove incorporates a carefully designed airflow system, with

adjustable air vents that allow users to control the oxygen supply to the charcoal, ensuring more complete and efficient combustion (Gumino *et al.*, 2020).

Aim and Objectives of this Research

Aim:

This is to develop an 80% saved charcoal stove using locally sourced materials that is capable of reducing quantity of charcoal to be used, minimizes heat loss and maximizes the transfer of energy, producing reduction in cooking time, elimination of smoke hazards during cooking, and support health benefit through establishment of guided exit of smoke to serve as the fire intensity (burning rate).

Objectives:

The specific objectives of this research are to:

- a) design and fabricate locally developed 80% saved charcoal stove; and
- b) evaluate the energy performance of the developed 80% saved charcoal stove.

Justification of the Study

Traditional cooking methods often involve open fires or inefficient stoves that produce high levels of indoor air pollution. This pollution primarily consists of particulate matter, carbon monoxide (CO), and volatile organic compounds (VOCs). Prolonged exposure to these pollutants can lead to various health problems, hence, the development of an efficient 80% saved charcoal stove is justified as it can substantially reduce these emissions, thus contributing to promoting better health among users and minimizing the risks.

Literature Review

Historical Reviews of Charcoal Cook Stoves

Early on in human existence, cooking was mostly done over an open fire with its fuel arranged in a pyramid shape. This method of cooking was designed primarily for roasting meat and keeping the body warm. But when there was a lack of proper control over the heat, smoke, and fire hazards that occurred, it became a major concern (Drave *et al.*, 2015). The development of pots of various shapes and sizes was a critical step in the evolution of cook stoves. This prompted a change in the open-fire system, with a three-stone arrangement introduced to balance the pots over the open-fires. The stones were usually arranged at approximately one hundred and twenty degrees (120°) to each other on a leveled ground.



Fig 1: The Traditional 3-stone stove

This modified system of cooking not only aided in balancing the pots over the fires but in addition, it prevented spreading and/or quenching of fires by strong winds as well as increasing the cooking efficiency (Drave *et al.*, 2015). However, the three-stone arrangement had significant drawbacks, similar to the open fire system. As a result, the three-stone was replaced with a U- shaped mud in a similar 120° orientations, with the front opened for fuel feeding and air entry for easy combustion. The mud's upper shape was a hump, which served as a stable pot rest as well as improved combustion of volatile matter and an exit for exhaust gas. All of these changes and innovations were created based on the users' own experiences with the cook stoves. These systems' innovations were successful in terms of increasing the efficiency of cook stoves, but health and other hazards persisted. From these times to the present, it has been observed in the developing world that 75% of the population still uses the three-stone or a shielded fire for cooking, just as their pre-historic ancestors did many centuries ago (Drave *et al.*, 2015). Looking back to the 1950s in India, the first phase of developing Improved charcoal cook stove began with attempting to improve cook stoves that used biomass as fuel. Improved multi-pot stoves were the first to address the issue of smoky working environments during cooking sessions. It was indicated by (Drave *et al.*, 2015) that Theodorolic tested the biomass burning improved cook stove and this was a controlled laboratory test. He was the first to conduct a test on a charcoal cook stove even though the thermal efficiency of the cook stove wasn't tested. Further testing and studies were conducted by measuring the cook stove efficiency of a similar design to the mud stone which was introduced by (Raju, 1954).

The second phase of Improved charcoal cooker development was based on detailed thermodynamic principles and involved extensive research studies, specifically heat transfer and aerodynamic studies, which resulted in a sounder technique. As time passed, more systematic and design procedures were gradually established. This concept of laboratory testing spread to various charcoal cook stove models in many developing and developed countries. During the 1970s and 1980s, there was a lot of advocacies for the use of improved cook stoves, and international donors were very strong in influencing, promoting, and assisting processes to prioritize the improved charcoal cooker in Africa, Asia, and Latin America. After some years past, these international bodies, unfortunately,

became short lived. This was as a result of the inability of the programs to meet the expectations and requirements of the consumer, specific objectives, and some systematic institutional arrangements. In the transition to the third (3rd) Phase, which was mostly in the 1980s, the influences that led to charcoal cook stove designs and testing shifted towards the decisions and needs of the users. These needs were as a result of problems encountered during the second (2nd) phase of charcoal cook stove designs and usage. Users feedback on the criteria for them choosing a particular cook stove was not only centered on fuel saving ability but also cooking in smoke-free kitchens, convenience and safety of the cook stove which are all very important factors to consider.

Conventional charcoal stoves typically suffer from low thermal efficiency, with much of the energy from burning charcoal lost to the environment rather than being utilized for cooking (Kumar *et al.*, 2013). To address this, the design of the efficient stove focuses on maximizing heat transfer to the cooking vessel while minimizing heat loss (Prasanna and (Uma Nand, 2011). One of the core features of this stove is the incorporation of an insulated combustion chamber (Champie *et al.*, 2011). The insulation, often made from materials such as fibre or ceramic or clay, helps retain heat within the stove, ensuring that more of the energy produced by burning charcoal is directed towards the cooking process (Korjamins *et al.*, 2013). The combustion chamber is also designed to optimize airflow, allowing for better control of the oxygen supply (Baukal, 2010). This improves combustion efficiency, resulting in a higher temperature and more complete burning of the charcoal, which reduces the overall amount of fuel needed (Permchart and Kouprianov, 2004). Different programs had mixed but generally unsatisfactory results. The authors recommend that cookstove designers consider smoke and heat removal and fuel availability before other factors in cookstove design. Several studies show that improved cookstoves save not only wood or charcoal, but also cooking time and cooking drudgery (Guzmán JC *et al.*, 2020; Adeyanju *et al.*, 2019). Some studies suggest "rocket" technologies for cookstove design (Adkins *et al.*, 2010).

The improved cookstove is a cooking appliance with higher energy efficiency than the traditional cookstove. There are different types of improved cookstoves in different countries and regions. It is known by different names taken from local languages (such as sakkanal and diambar in Senegal, sewa in Mali, Kenyan jiko in Kenya, Nansu in Benin, ouaga métallique in Burkina, etc (IFDD, 2011). Different materials are used in the design of improved cookstoves including: clay, cow dung, sheet metal, ceramic materials etc (IFDD, 2011). The implications of this efficiency are far-reaching. Environmentally, the reduced charcoal consumption translates into less pressure on forests, helping to curb deforestation and its associated impacts (Gorte and Sheikh, 2010). Economically, households benefit from significant cost savings, as they need to purchase less charcoal (Zulu and Richardson, 2013). These savings can be especially important in low-income communities, where fuel costs represent a substantial portion of household expenses.

The real problem in developing countries is that some cookstoves come onto the market and are marketed as improved cookstoves without prior testing and studies having been carried out on these cookstoves. The other problem often encountered is that cookstoves improved for energy performance are not durable and do not offer sufficient safety to users and are therefore not economically viable. Energy performance should not be separated from safety and durability. It is therefore this gap that this study fills by studying the performance (safety, energy efficiency and durability) of the different cookstove technologies available on the Beninese market.

The study of the energy performance and safety of cooking stoves has been addressed in previous research work. These studies, although they did not address the combined analysis of the two parameters of energy performance and cookstove safety, have attempted to study them separately. In fact, the energy performance of cooking stoves has long been a concern for the various researchers in the field because of the close link between them and the consumption of solid fuel, the preservation of the environment and the household economy. In Benin, for example, the performance of cookstoves has been evaluated by the water boiling technique (Adeyanju *et al.*, 2024). This study revealed that losses are higher for metal and clay stoves. Another study reveals that in Benin, fossil fuel stoves have the best economic performance, but the very low cost of wood fuels gives them an advantage (Anjorin, 2014). A comparative study of two types of traditional improved cookstoves (clay cookstoves and Malagasy cookstoves) indicates that the clay improved cookstove performs better than the Malagasy cookstove (egbefia *et al.*, 2018).

Different Types of Charcoal Cook Stoves

Wood and Stoves

This research is a practical contribution to the global effort to reduce the burden borne by the rural poor in order to meet the energy requirements for daily cooking, processing, and preserving farm produce. Man has been using fire for a very long time. Fire's early discoverers used it for hunting, clearing land for agriculture, and cooking, among other things. Metal, clay, and ceramic have all been used to build charcoal stoves (Usman, 2017).

Inverted Frustum Metal Stove

This stove is made of metal and has the shape of an inverted frustum of a square pyramid, as illustrated in figure 1. The stand is a square or rectangular base with an air hole cut in it. Poor draft, air hole blocking, and poor efficiencies due to excessive heat loss are all common flaws in this design. Appropriate air hole sizing and careful insulation will improve the stove's performance (Baldwin, 1987).

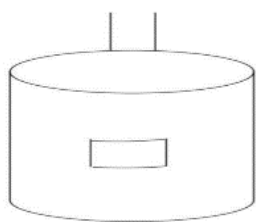


Fig 2: Inverted frustum charcoal stove

Channel Type Stove

The combustion chambers of channel type stoves are smaller cylindrical (figure 2). This implies that the combustion chamber has a uniform cross-sectional area along its length. Depending on the design and purpose, clay or metallic can be used. The clay type is typically fired after molding to increase hardness, whereas the metallic type is typically painted to prevent rust. The clay type is prone to breaking either at the point of application or during transportation. The stove body has a tendency to store a lot of heat and that affects the amount of heat that is made available to the pot. A very outstanding advantage of the clay type is that the stove wall serves as heat shield to the user. The metal type obviously is lighter and conducts heat faster than the clay type. The higher heat conduction rate exposes the user to danger of being burnt, unless properly lagged. The metallic type is more portable and durable, hence the choice for this work (Usman, 2017).

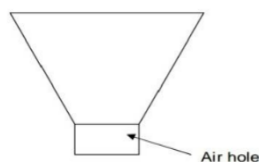


Fig 3: Channel type charcoal stove

Improved Charcoal Cook Stoves

The apparent ineffectiveness of several government measures and other sectors in alleviating the suffering of the rural poor has prompted some Non-Governmental Organizations (NGOs) involved in basic needs programs and rural development at the household level to develop and disseminate relevant energy alternatives centered on stoves. Their efforts are bearing fruit in Africa, India, and other developing countries.

Sazawa Charcoal Stove

It is made of metallic part called cladding, two clay liners and binding materials mainly is the mixture of cement, water and vermiculite or rice husk ashes as a substitute to vermiculite. Binding materials are used to bind together the two clay liners and the cladding. Sazawa also has a bent round bar that serves as a pot rest, legs, handles, a metallic belt, an ashes

collector, and a door for primary air inlet. Sazawa intends to save a significant amount of charcoal used in household cooking.



Fig. 4: Sazawa Charcoal Stove

Method and Materials

Design Analysis of the 80% saved charcoal

The components identified and analyzed are listed as follows:

- a) Cylinder/Outer Casing: This is the outer casing (covering) of the circular shape saved charcoal stove,
- b) Ash tray: Used for the collection of ashes.
- c) Stove Handle: For lifting the stove
- d) Stove Stand: This serves as a support for the stove to stand upright.
- e) Stainless steel pot (combustion chamber): Used for the generation of heat.
- f) Stove top: This supports the cooking utensil above the flames for effective combustion.
- g) Bottom plate: This serves as the covering, beneath the charcoal stove,

Design Theory and Calculations

The Concept of this design is to develop an 80% saved charcoal stove which uses charcoal as its source of fuel. To do this, a chamber where the charcoal will be contained (combustion chamber) is required. Naturally, air will be added to the combustion process to enrich the burning mixtures and enhance combustion. In line with these objectives, Figure below shows Isometric views of the 3D model.

Design Parameters and Calculation for the Components

Combustion Chamber:

The combustion chamber holds the charcoal and provides an enclosed space for the combustion of the charcoal. It has an opening to the top from which the heat meets with the cooking utensil. To determine the design parameters for the combustion chamber; A cylinder is used to create the combustion chamber. Figure below shows the combustion chamber;

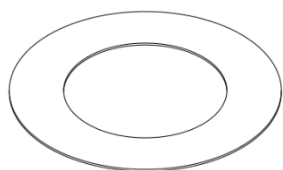


Fig. 5: Model of the Combustion Chamber

Dimensions of the combustion chamber:

Overall diameter = mm

Overall height = mm

Cylinder capacity = $\frac{\pi}{4} d^2 h = \text{mm}^3$

Surface area = $2\pi r(h + r) = \text{mm}^2$

3.1.3.2 Stove Top:

The stove top supports the cooking utensil above the flames for effective combustion. It also allows for the fumes from the combustion process to flow freely away from the combustion chamber. A metal sheet marked out with circular hole formed at the center of the plate via a baby grinder machine and welded with the combustion chamber. The figure below is the stove top design;

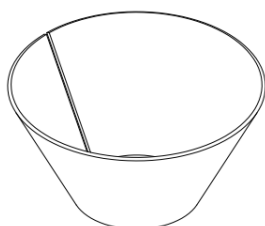


Fig. 6: Model of the Stove Top

The Ash Tray:

The ash tray collects ashes from the burnt charcoal. It is placed directly below the combustion chamber so the ash can drop into it by gravity. It has enough padding to slide in between in and out of the combustion chamber. The figure below is the ash tray design;

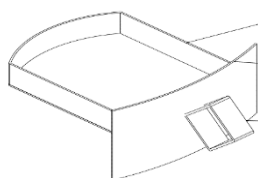


Fig. 7: Model of the Ash Tray

Stainless Steel Plate:

This retains heat and allows for distribution of air within the combustion chamber. It is a frustum shape with holes at the bottom which allows ashes to seep through it into the ash tray. The figure below is the stainless plate design;

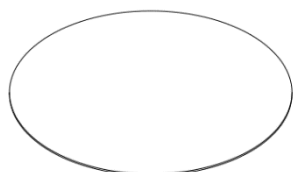


Fig. 8: Model of the Stainless-Steel Plate

Stove Handle:

This is used to lift the charcoal stove. The figure below is the stove handle design:

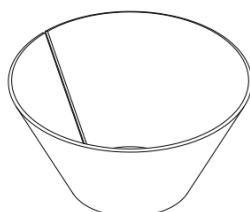


Fig. 9: Model of the Stove Handle

Bottom Plate:

This is a circular plate of Ø248mm and 2mm thickness mild steel plate welded beneath the charcoal stove. The figure below is the bottom plate design:

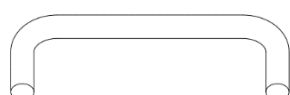


Fig. 10: Model of the Combustion Chamber

Materials

The materials used in the construction of these stoves were selected based on the following criteria of durability in high temperature, material availability, cost of production, maintenance and easy to manufacture. The major materials selected in the construction of the stoves include fibre, stainless steel plate, a 2 mm and 1 mm mild steel sheet. Equipment used for the production of the stove parts include: tape rule, scribe, guillotine shear, center punch, cutting disc, hand rolling machine, hand grinding machine, A/C welding machine, electrode gauge 12 and bending machine. The materials used are locally sourced, making them affordable and accessible.

Table 1: Materials selected for the production of the stove

S/NO	Component	Selected material	Reason for selection
1	Stove casing	Mild still	Ability to withstand high temperature
2	Ash tray	Mild steel	Ability to withstand high temperature
3	Combustion chamber	Stainless steel	Ability to withstand and retains heat
4	Insulation	Fibre	Provides insulation and retains heat
5	Stove handle	wood	Ability to resist heat transfer
6	Stove stand	Mild steel	Strength to withstand the load

Description of the Charcoal Stove

The 80% saved charcoal is fed with the required charcoal into the combustion chamber and ignited at the start of the cooking process. The heat from the charcoal is transferred through radiation to the cooking vessel, the cooking vessel sits close to the surface of the fuel (charcoal). Below is the picture of the fabricated 80% saved charcoal stove:



Fig. 11: The side view picture of the fabricated circular shape 80% saved charcoal stove



Fig. 12: The front view of the fabricated circular shape 80% saved charcoal stove

Mode of Fabrication

The first step involved in the fabrication was the marking out of 1.5mm mild steel plate for the casing, i.e., combustion chamber according to specifications through measuring tools like measuring tape, scribe, and engineering chalk, this was cut-out with the aid of a guillotine shear machine. Then, the cut-out metal sheet was rolled to form a cylindrical shape via manual rolling machine and joined the two ends together by means of an arc welding machine with a fibre insulator attached. The ash tray was also marked out. Baby angle grinder was used to cut-out places marked and make use of bending device to form

the ash tray. The handle for the ash tray was welded to the tray, allowing for seamless opening and closing of the ash tray. A stainless-steel plate was perforated with holes at the bottom to allow passage of air and equally allows ash drops on the ash tray. The stove handle was formed via 20mm mild steel rod after being cut to a required size by an angle grinder. The stove stand was also formed using a flat bar and carefully cut to sizes and welded to the beneath of the stove. Moreover, the saved stove parts were debugged using grinding machine and assembled to have a very good finishing. Lastly, the body of the charcoal stove was sprayed with paint to make it aesthetically pleasing.

Performance Evaluation

Test and Analysis Procedure:

Water boiling test (WBT) was carried out in order to generate the data required for assessing the performance of each of the fabricated 80% saved charcoal stove for the purpose of comparison. To carry out the tests, the following steps were taken:

- 1) 2 Kg – 2.5 Kg of charcoal was weighed separately and the moisture content determined.
- 2) The pot was cleaned and dried. The pot was filled with water to 2/3 (two-third) of its capacity. The pot with water was then weighed and the weight was recorded.
- 3) The ash tray, pot support and charcoal container were positioned so that the required quantity of charcoal is loaded into the stove.
- 4) The charcoal was sprinkled with some quantity of kerosene and lit.
- 5) The pot was then put on the stove after the combustion had fully commenced and the temperatures at the bottom of the water was recorded with the aid of dry bulb thermometer.
- 6) After the water had boiled for 25 minutes, the combustion process was halted and the fire quenched by the use of water.
- 7) Time taken for the process was measured using a stop watch.

The weight of the remaining charcoal and water in the pot were taken by means of a balance and recorded. The data obtained from the test are shown in table 4.1 below:

Table 2: Water boiling test data

S/N	PARAMETERS	VALUE
1	Initial mass of water (Kg)	5kg
3	Boiling temperature of water (°C)	100°C
4	Initial temperature of water(°C)	27°C
5	Mass of pot with water before water boiling (kg)	7.5kg
6	Mass of pot with water after boiling (kg)	6.5kg
7	Mass of charcoal loaded into the burner (kg)	2.5kg
8	Mass of charcoal after combustion (kg)	2kg

In the water boiling test (WBT), the heat generated by the fuel (charcoal) is compared to the useful heat absorbed by the water in the pot/container. Thus, the thermal efficiency, η_c is defined as the ratio of used heat energy to the input heat energy;

$$\eta_c = \frac{\text{Net heat Used to evaporate the water}}{\text{Total heat supplied by the water}}$$

The sensible and latent heat absorbed by boiled water amounts to the useful heat energy, whereas input heat energy is that which was released from the burning charcoal. With these definitions, the efficiency of the charcoal stove, η_c can be expressed mathematically as:

$$\eta_c = \frac{M_w C_{pw}(T_b - T_i) + M_{we} L_v}{M_{\text{Charcoal Used}} C_{Vc}} \quad (1)$$

where;

M_w = Initial mass of water in Kg

C_{pw} = Specific heat capacity of water = $4.2 \times 10^3 \text{ J/Kg}$ T_b = Boiling temperature of water in degrees Centigrade

T_i = Initial temperature of water in degrees Centigrade

M_{we} = Mass of water lost due to evaporation

(Mass of container with water before water boiling minus Mass of container with water after boiling) in Kg

L_v = Latent heat of vaporisation of water = $2.258 \times 10^6 \text{ J/Kg}$

$M_{\text{Charcoal used}}$ = Mass of charcoal used = (Mass of charcoal with the burner before combustion - Mass charcoal with the burner after combustion) in Kg,

C_{Vc} = Calorific value of charcoal = $2.8 \times 10^7 \text{ J/Kg}$.

Time spent in cooking (T_s);

It is equally necessary to compute the time spent in cooking a kilogram of cooked food when comparing stoves performance which is expressed as;

$$T_s = T / W_f \quad (2)$$

Where;

T = Total time spent in cooking,

W_f = Total weight of cooked food.

Bill of Engineering Measurement and Evaluation

Designs and fabrication of machines in engineering goes beyond putting materials together to construct something useful. Instead, several things are put into consideration before a well-conceived design is brought to life. Some of these considerations involve cost and cutting expenses as much as possible. The bill of engineering measurement and evaluation deals with the expenses directly associated with the design and fabrication of 80% saved charcoal stove. These expenses include: labour cost, procurement cost, cost of transportation, and after proper estimate and evaluations, the total cost is tabulated below.

Table 3: List of Engineering Bill and Measurement

S/N	Description of Items	Quantities	Unit Price (N)	Total (N)
1	1mm mild steel Plate	1/6 Plate	30,000.00	5,000.00
2	Stainless Pot	1 No	2,300.00	2,300.00
3	3mm Stainless Plate	1/72 Plate	94,000.32	1,305.56
4	1.5mm mild Steel	1/32 Plate	41,000.00	1,281.25
5	10mm Mild Steel rod	600mm	300.00	300.00
6	Wooden Handle	2 pcs	100.00	200.00
7	Stainless Electrode of Gauge 12	5 pcs	150.00	750.00
8	Mild Steel Electrode of Gauge 12	10 pcs	50.00	500.00
9	Smooth Emery Cloth	1 pc	200.00	200.00
10	Paint	¼ tin	8,000.00	2,000.00
11	Fibre glass	10kg	200.00	2,000.00
12	Cutting disc	1 pc	1,000.00	1,000.00
13	Grinding disc	1 pc	1,200.00	1,200.00
14	Thinner	¼ tin	8,000.00	2,000.00
	Total			20,036.81

Results and Discussion

Water boiling and cooking test (WBT) results

The water-boiling and cooking time responses using 5 liters of water, (from 27 °C to 100 °C), is shown in (Table 5.1). Boiling 5 liters of water with this developed 80% saved stove takes 25mins/kg using equation (2). In cooking rice, the developed 80% charcoal stove spent 35mins/kg using equation (2).

Table 4: Water-boiling and cooking tests time responses using 5 liters of water

S/N	PERORMANCE VARIABLES	DEVELOPED 80% SAVED CHARCOAL
1	Total operating time to boil 5 liters of water	25mins/kg
2	Total time spent in cooking 1kg of rice	35mins/kg

2.5kg of charcoal in the developed 80% saved charcoal stove is sufficient to provide energy to cook a household meal and excess energy can be used to heat water for other domestic purposes based on the fact that it consumes less fuel (charcoal) and retains higher percentage of heat produced in the process. The used heat energy of 1.8×10^7 joule, the input heat energy of 7×10^7 joule using equation (1) and thermal efficiency of 26.4% using equation (1). Based on these findings, the developed 80% saved charcoal stove is thermally efficient more than the regular stoves and at the same time would favorably compete with the imported ones. Below is the results of the operating performance of charcoal in the 80% saved charcoal stove in terms of fuel consumption rate, charcoal produced, thermal

efficiency, and others is as shown in Table 5. The production of the locally made 80% saved charcoal stove has been successfully achieved. The materials for the production were made known and equally their mode of selection.

Table 5: The operating performance of the developed 80% saved charcoal stove

S/N	PERFORMANCE VARIABLES	DEVELOPED 80% SAVED CHARCOAL
1	Weight of charcoal consumed	0.5kg
2	Thermal efficiency (%)	26.4%
3	Used heat energy	1.8×10^7 joules
4	Input heat energy	7×10^7 joules
5	Total operating time to consume fuel	2hrs 30mins

Conclusion

The production and performance evaluations of the 80% saved charcoal stoves were achieved. The materials used for the production of the machine were locally sourced. These fabricated 80% saved charcoal stove represents a critical innovation in the quest for sustainable and efficient energy use in cooking. By significantly reducing charcoal consumption, this stove not only help protect the environment but also offer substantial economic and health benefits to users. The total cost of producing the fabricated/developed 80% saved charcoal stove is #20,036.81.

Recommendations

This research presents the following recommendation:

- To enhance further durability and performance, galvanized and stainless-steel material should be used for the production.

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