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Design and Performance Evaluation of Energy Efficient Biomass Gasifier Cook Stove Using Multi Fuels

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Authors' contributions

This work was carried out in collaboration among all authors. Authors IFO designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors EOI and IOY managed the analyses of the study. Author EOI managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Since the beginning of civilization, cooking has been done by using biomass as fuel. They are used in stoves which cause wastage of fuel and also health problems. Thus, there is the need to analyze the thermal performance of a developed cook stove that operates on multifuel conditions. The stove was designed to work on sawdust, wood, groundnut and charcoal as the primary fuel. Prior to fabrication, design parameters were obtained using the appropriate governing equations. Inputs were further made to simplify the construction of the stove and to minimize heat loss to the surroundings. A thermal efficiency of 32.18%, 80.10%, 38.73% and 50.33% was achieved when the stove was fuelled with charcoal, sawdust, wood and groundnut husk respectively. The highest flame temperature was recorded as 205ºC when wood was used as fuel. The highest stove body temperature recorded was 56ºC. Wood took the shortest time (20 mins) to boil water compared to sawdust, charcoal and groundnut husk which took 29, 23 and 27 minutes respectively for 2 kg of

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water. The developed cook stove was found to be energy efficient for domestic cooking especially in the rural communities of Nigeria. Although it has the potential to save fuel, further research could be carried out in the aspect of removing CO emission.

Keywords: Cook stove; biomass; fibre; gasification; updraft.

1. INTRODUCTION

Biomass is a source of renewable energy from agriculturally based economy [1]. Biomass fuels include items as diverse as residential yard waste, manure, agricultural residues, and dedicated energy crops. In industrialized nations, bio-energy facilities typically use biomass fuels in large industrial cogeneration applications [2]. The problems that surround burning biomass for cooking purposes affect a very large number of people, and this number is not likely to be reduced significantly soon [3]. In recent years, designers of household cook stoves have focused on improving efficiency and reducing emissions to mitigate the health impacts associated with the use of solid biomass fuel [4]. However, ongoing public health research is expected to reveal that greater emission reductions are needed to substantially reduce health risks [5].

Several works have been carried out on cook stoves and biomass fuel performance. Odesola and Kazeem (2012) produced a biomass cook stove, to meet cooking energy requirement using biomass gasification principle. The stove fuelled by charcoal works with a forced draft mode and was insulated by fire clay (Sawdust 50%, Kaolin 40%, and Ball clay 10%) to minimize heat losses to the surroundings. Khadija and Munir [6] developed a biomass natural draft gasifier stove at ABEI workshop, Narc, Islamabad using mild steel sheet gauge, glass wool and mica for insulation. The results obtained showed that the gasifier wood stove has a maximum thermal efficiency of 30%. Similarly, useful heat energy output per kg of wood used was 1239.60 kJ/ kg. Motghare et al. [7] compared the performance evaluation and heat transfer analysis of a biomass gasifier cook stove to that of traditional stove. Cotton waste was used as fuel. It was reported that the stove emits pollutants because of improper design of the combustion zone and low thermal efficiency.

The focus of this work is to develop an energy efficient biomass gasifier cook stove that works with multi fuels. Objectives include:

- To implement simulative parameters for the design and fabrication of the cook stove.
- To analyze thermal performance of the constructed cook stove with multifuel (admittance) conditions.
- To characterize cook stove emission under specified operational conditions.

2. MATERIALS AND METHODS

2.1 Biomass Stove Design

The biomass stove was designed using the natural draft gasification principle. The parameters considered germane to the desired design of the gasifier stove include: fuel, air flow rate, insulation, material selection, safety, design for manufacture, economics and stove usage conditions.

2.2 Combustion Chamber Diameter, Height and Cross-sectional Area

The height and diameter of the combustion chamber were designed based on simulation using heat transfer equations. The height of the combustion chamber also determines the total time the cook stove can be in operation before refueling. At a range of Reynolds number >2300, fluid flow is laminar and turns to turbulent at values above. Transition occurred at a diameter of 220 mm which, implies that the stove tends to burn with yellow flame. It was deduced from Fig. 1 also that it increases as the aspect ratio increases. Transition occurred at a height of 460 mm with a diameter of 220 mm. This serves as a criterion for the design of the intended cook stove.

2.3 Cook stove Performance Background Theories

The parameters below will be used for the performance analysis of the stove, Ijagbemi [8]

2.3.1 Percentage heat utilized (Thermal efficiency %)

$$\text{Heat supplied to the water} = Mw * Cp\,(Tb - Te) + Me * L \qquad (1)$$

Net heat liberated from the fuel = mf * Ef (2)

Percentage Heat Utilized (P.H.U) =

$$\frac{\text{Heat supplied to the water}}{\text{Net heat liberated from the fuel}} \text{ x } 100\% \quad (3)$$

$$\text{Thus; P.H.U} = \frac{\text{Mw Cp (Tb}-\text{To)} + \text{MeL}}{\text{mf Ef}} \text{x } 100\% \quad (4)$$

where;

Mw = mass of water in the pot (kg)
Cp = specific heat of water (kJ/kg ºC)
Tb = boiling temperature of water (ºC)
To = initial temperature of water (ºC)
Me = mass of water evaporated (kg)
mf = mass of fuel burnt (kg)
Ef = calorific value of the fuel
L = latent heat of vaporization of water at 100ºC (kJ/Kg)

2.3.2 Burning rate (b.r)

This is the rate at which a certain mass of fuel is combusted in air. It is calculated as;

$$\text{Burning rate} = \frac{\text{mf}}{\text{t}} \quad (5)$$

where; t = time taken to burn fuel (secs)

2.3.3 Specific fuel consumption (s.f.c)

$$\text{S.F.C} = \frac{mf}{mc} \quad (6)$$

where; mc = mass of cooked food in the pot (kg).

2.3.4 Time spent in cooking per kilogram of Cooked Food (t)

$$\text{T} = \frac{\text{Total time spent in cooking}}{\text{Total weight of cooked food}} \text{(hr/kg)} \quad (7)$$

2.4 Superficial Air Velocity

The speed of air flow in the fuel bed is referred to as superficial air velocity. The air flow rate and diameter of the combustion chamber determines the velocity.

$$\text{velocity} = \frac{4 * A.F.R}{D^2} \quad (8)$$

where:

A.F.R = Air flow rate
D = Diameter

The optimized properties and dimensions of the stove are presented in Table1.

2.5 Design Preparation

The design of the stove was based on the principle of top lit updraft gasifier. After finalizing the conceptual design of the stove, a 3D AutoCAD drawing was prepared to ensure consistency throughout the different assemblies. A 2D drawing was also prepared to serve as a guide in the fabrication of the different parts of the stove. The complete cook stove is shown in Fig. 3.

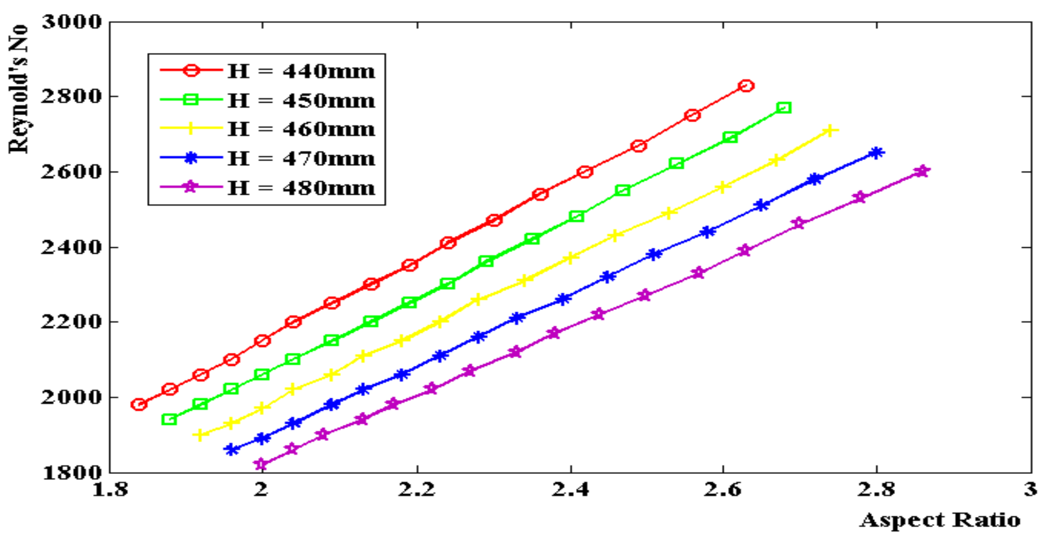

Fig. 1. Graph of Reynolds number against Aspect ratio at varying height

Table 1. Table of properties and dimensions

S/No	Content	Value
1	Mode of operation	Natural updraft gasifier
2	Insulation	Fibre
3	Biomass type (Multi-fuel)	Wood, Groundnut husk, Charcoal, Sawdust
4	Fuel feeding	Manual
5	Height of reactor	460 mm
6	Diameter of reactor	160 mm
7	Diameter of stove	220 mm
8	Insulation gap	30 mm

3. RESULTS AND DISCUSSION

3.1 Stove Performance

The water boiling test was used to evaluate the thermal performance of the cook stove. The thermal performance of the stove was evaluated using equation (4.0) as 32.18%, 80.10%, 38.73% and 50.33% for charcoal, sawdust, wood and groundnut husk respectively. Table 2 presents the percentage heat utilized (thermal efficiency) of the stove when tested with the fuels.

Fig. 3 shows the picture of the designed Cook stove. Kerosene oil was spread initially on top of the fuel bed. Combustible gas (producer gas) and blue flame was established within few minutes of ignition. The use of kerosene was limited to experimental purpose only. For actual operation, loose biomass catches fire easily such as leaves can be used to ignite the stove. The ignition time for the fuels is given in Table 3.

One of the instruments used is shown in Fig. 4. Ash was collected from the base after operation. It was noted that the most ash was produced when the stove was operated on wood followed by groundnut husk, charcoal and sawdust respectively. From Fig. 5. the carbon monoxide concentration dropped over a period of time as the fuel in the combustion chamber reduces. Wood produced the most CO emission while the other fuels have the same range of emission. Thus, it is proposed that the stove should be used outdoor when fuelled with wood.

Fig. 6 present the highest ambient temperature recorded for the fuels as 28.9ºC, 28.4ºC, 28ºC and 28.4ºC for charcoal, sawdust, wood and groundnut husk respectively. This shows that the operating environment was still conducive for the operator since the human acceptable temperature range is 29-30ºC.

3.2 Safety during Operation

The maximum outside temperature of the stove was recorded as 56ºC which can cause bodily harm to users. It is recommended to use the handle when moving or handling the hot stove. Carbon monoxide was produced during the operation which is toxic. The stove should be used in an open area when fueled with wood. After completion of the operation, unburned fuel should be extinguished to prevent fire hazard. Also, it should be disposed in a safe place or wait until it cools to a safe temperature.

Fig. 2. Inner wall (left) and Outer wall (right) of combustion chamber

Table 2. Percentage heat utilization of the stove

Parameter	Charcoal	Sawdust	Wood	Groundnut husk
Mass of water (kg)	2.02	2.03	2.02	2.04
Specific heat capacity of water (kJ/kgºC)	4.20	4.20	4.20	4.20
Initial temperature of water (ºC)	26	27	25	26
Calorific value of fuel (kJ/kg)	34080	16320	20034	18491
Boiling temperature of water (ºC)	100	100	100	100
Mass of evaporated water (kg)	0.135	0.11	0.14	0.12
Latent heat of vaporization at 100ºC (kJ/kg)	2660	2660	2660	2660
Weight of burnt fuel (kg)	0.09	0.07	0.13	0.10

Fig. 3. The designed cook stove in operation

Fig. 4. Eagle 2X combustion analyzer

Table 3. Thermal performance of the stove for the fuels

Fuel	Ignition time (min)	Thermal efficiency (%)	Power rating (kW)
Charcoal	3 – 4	32.18	1.69
Sawdust	6 – 7	80.10	1.48
Wood	2 – 3	38.73	1.65
Groundnut husk	5 – 6	50.33	1.54

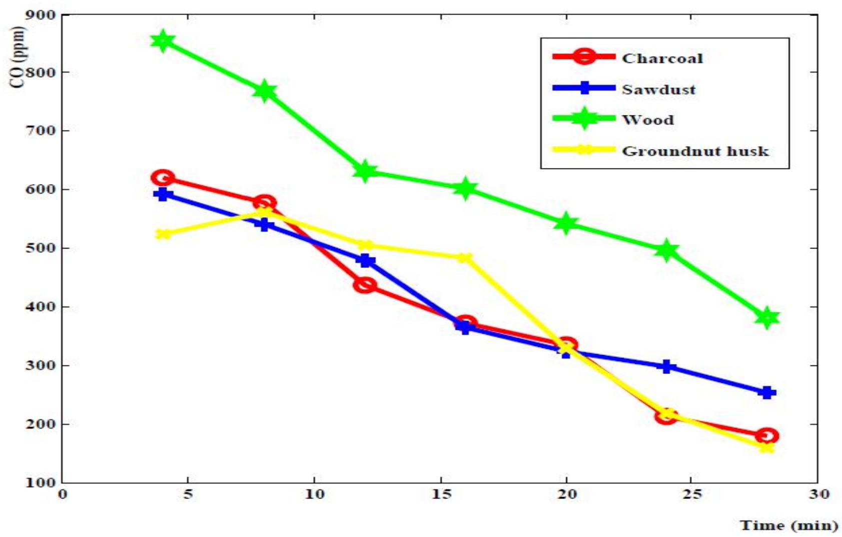

Fig. 5. Graph of CO emission over time interval

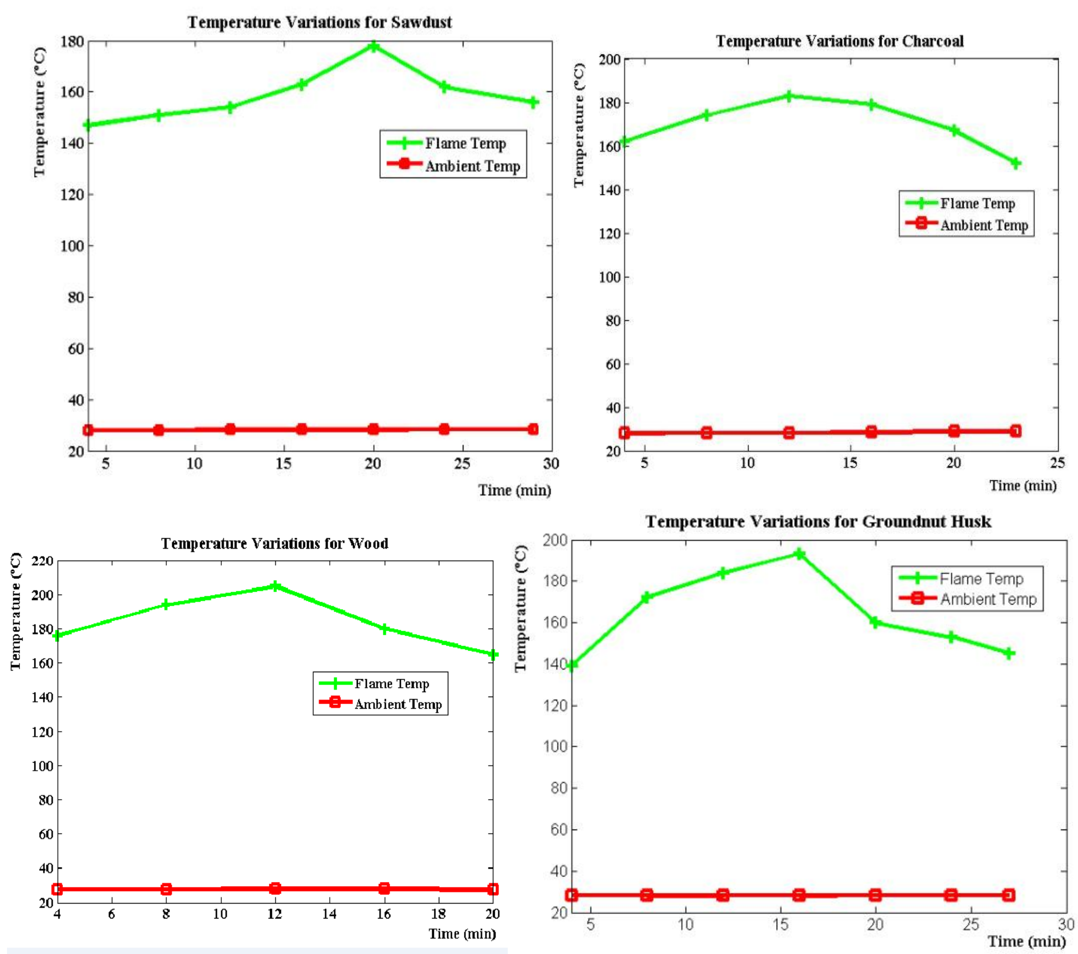

Fig. 6. Temperature variations for the fuels

4. CONCLUSION AND RECOMMENDATIONS

An energy efficient biomass gasifier cook stove was designed, fabricated and tested with charcoal, sawdust, wood and groundnut husk respectively. It has a potential to burn fuels efficiently and it emits less pollutants to the atmosphere. Its convenience of use, efficiency and safety will make it readily acceptable for both household and business-related usage especially in the rural communities.

The cook stove performed as designed judging by the results enumerated above. However, there is a need to improve on its efficiency and also reduce the CO emission. Thus, to achieve this, it is suggested that;

- Stoves with different insulation materials should be fabricated to determine their effect on efficiency. Also, their layer thicknesses should be varied to check the effect on efficiency.
- The fabricated stove should be tested with other biomass fuels such as briquettes, cashew nuts and maize husk.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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