

## Performance Evaluation of Biomass Stove

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### ABSTRACT

The performance evaluated of biomass stove was investigated. The machine consists mainly: combustion chamber, the air inlet compartment, the chimney, ash collection tray, briquettes storage chamber, stove stand and the supporting frame. Performance evaluation revealed biomass stove has thermal fuel efficiency for the four common energy sources ranged between  $58.74 \pm 5.65$  firewood (*Anthonothamacrophylla*) and  $72.93 \pm 4.34$  (red mangrove). Duncan Multiple Range Tests (DMRT) and Analysis of variance (ANOVA) indicated significant difference for the thermal fuel efficiency for the four energy sources tested ( $P < 0.05$ ). The specific fuel consumption for the fuel sources were  $210.59 \pm 5.71$  g (briquette),  $231.02 \pm 8.97$  g (charcoal),  $272.21 \pm 9.04$  g (firewood) and  $297.42 \pm 8.05$  g (red mangrove). The utilization of biomass stove to investigate the water boiling time for four common energy sources were  $15.58 \pm 0.29$  min (briquette),  $13.16 \pm 0.50$  min (charcoal),  $10.17 \pm 0.23$  min (firewood) and  $8.67 \pm 0.08$  min (mangrove). Biomass stove produced competed favourably with other traditional and improved stove.

**Keywords:** Biomass stove, fuel, water boiling time, burning rate, thermal efficiency, chimney

### INTRODUCTION

The majority of the rural dwellers use traditional biomass stove and this faced with some challenges and limitations. Some of these challenges includes: environmental and gender friendly, low combustion efficiency, energy losses as a result of poor insulations, inadequate draft and air-to-fuel ratio and this eventually leads to incomplete or inefficient combustion of fuel and thus, high level of smoke and harmful emissions [1]. Some of the traditional stove lack considerations of the size, geometry and control of airflow. More than half of the world's population relied on biomass fuels in form of wood, crop residue, animal dung and aquatic weeds as their primary domestic energy source [2]. Many a time, the combustion of these fuels is done indoors over open fires with little or no means of ventilation. Regular exposure to harmful emissions of biomass fuel can induce the risk of acute respiratory infections, chronic bronchitis and obstructive pulmonary disease on the users and as well as people around the environment [1]. Poor indoor air quality associated with biomass fuel combustion is responsible for 2.7% of the global burden of disease [2]. Women and children are more vulnerable to the health risks associated with biomass fuel combustion and poor indoor air

quality [2]. About 1.6 million women and children died annually and this can be attributed to indoor air pollution. More than 56% of the total annual deaths are children under the age of five [3].

Energy is a necessary requirement for everyday life. The production of briquettes and pellets have been considered as a better way of alleviating the shortfall in fuel wood and most importantly reduced deforestation in the rural areas where tree have been cut down for domestic cooking and fish smoking and drying.. Energy is the mainstay of Nigeria economic growth and development. Densification for briquetting improves the handling and combustion characteristics of biomass and thereby reduces transportation cost as well as production of a uniform, clean, stable fuel, or an input for further refining processes of biomass [4, 5]. The production of briquettes, pellets and their packaging will engenders spring up of small and medium scale enterprise opportunities for production of screw and hydraulic presses for densification of agricultural and aquatic wastes. Larger percentage of Nigerians living in the rural areas rely solely depend on fuelwood for cooking despite the discomfort posed on the user as a result of smoke [6, 7].

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Renewable energy such as firewood, twigs and charcoal contributed approximately 51% of the total annual energy consumption in Nigeria[8]. Akinbami [9] reported various types of energy sources which involves; natural gas (5.2%), hydroelectricity (3.1%), and petroleum products (41.3%).The upsurge observed in the demand for firewood consumption contributed the present fuelwood scarcity in the developing countries such as Nigeria. It is highly imperative to shift from commonly known energy sources that not environmental friendly to the sustainable energy sources such as briquettes and pellets[10].The survey conducted on biomass cooking stoves, bucket stove accounted for 71%, three-stone (open fire stove) stove accounted for 18% and 11% other types of stoves that use fuel such as rice husk, sawdust and biogas of rural families [11]. The greater percentage of rural dwellers in Nigeria use metal trivets; the trivet consists of a horizontal metal ring to which three legs are attached [12]. The biomass cooking stoves are far less efficient compared to modern stoves such as oil, gas, and electric. The thermal fuel efficiency of kerosene or Liquefied Petroleum Gas (LPG) fuelled stoves can be as high as 45-48%, while that of a wood stove averages only 15-20%. The efficiency of stove performance varied from 20.86 to 33.95% [13]. The efficiency of Meechairice huskstove was 23% and sawdust stove was 17%. An appropriate biomass stove should be simple, reproducible, adaptable to any fuel stove, and reflect local cooking practices [14].

The performance of charcoal bucket stoves was found to have significant effect on stove size, air inlet area, gap height, grate holes area, aluminum pot size, quantity of water used in the test, and quantity, quality and mass of charcoal. It was also found that stove performance improves with increased in stove diameter, the air inlet area is decreased, or the gap height is reduced. The thermal fuel efficiency of a bucket stove fuelled by different types of biomass such as charcoals, different firewood species, sawdust, rice husk, and lignite briquettes varied with the fuel type used and ranged from 18.5 to 33.1% [15].

## MATERIALS AND METHODS

The design of biomass cooking stove was based on the following considerations: the availability of materials locally to reduce the cost of production; easiness of loading and off loading of briquettes; easy evacuation of ash from the system; chimney was installed for proper

discharge of smoke; there is provision for storage and drying of briquettes in the system; different types of biomass briquettes or pellets can be used; it is desired that there should be minimum or no loss of heat during the combustion. The Physical and combustion properties of the fuel briquettes were considered in the determination of the design parameters of the biomass cooking stove. These properties include briquettes size and shape, and angle of repose of the briquettes. Also considered were moisture content, density, and static and dynamic coefficient of friction of the briquettes.

## A Brief Description of the Biomass Stove

The machine consists mainly of the combustion chamber, the air inlet compartment, the chimney, ash collection tray, briquettes storage chamber, stove stand. The frame which holds all the components together at their relative positions was constructed using 3 mm x 8 mm x 38 mm angle iron. The major components of the prototype are shown in the assembly drawing (Fig.1). The stove is rectangular shape and made of gauge 18 metal sheet. The sides are insulated using sawdust to prevent loss of heat. There are four pot stands situated at equal distance around the circumference of the fuel bed.

The Combustion chamber is fabricated from mild steel plate of 16mm and with capacity of 518.6cm<sup>3</sup>. The machine was insulated using sawdust surrounded by a steel plate enclosure designed to accommodate charcoal or fire wood or any biomass material as fuel. A screen 200mm diameter is provided at its base to allow for free air intake by updraft and the passage of ashes produced during combustion. Air inlet compartment was made for adequate ventilation within the stove and proper combustion of fuel charge (briquettes, charcoal and firewood). The dimension was 120x60 mm air inlet round the combustion chamber. Chimney was constructed to vent hot flue gases in the combustion chamber to the atmosphere. Ash collection tray is made of mild steel sheet metal. It is folded below the combustion chamber and inner base of the air inlet chamber. Ashes are expected to drop during fuel combustion for immediate disposal.

Fuel briquettes storage chamber is made of mild steel enclosure provided directly below the ash collector chamber for storing unused briquettes. The strategic location of this chamber facilitates drying of briquettes in storage. A loading door was also provided for gaining into this chamber.

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The stove stands are four 5.1 cm height metallic structures located at equal distances at each edge of the bottom part of the stove. These were provided to prevent rusting and heat losses

through leakage occasioned by direct contact between the stove bottom and the ground surface. The major components of the prototype are shown in the assembly drawing (Fig.2).

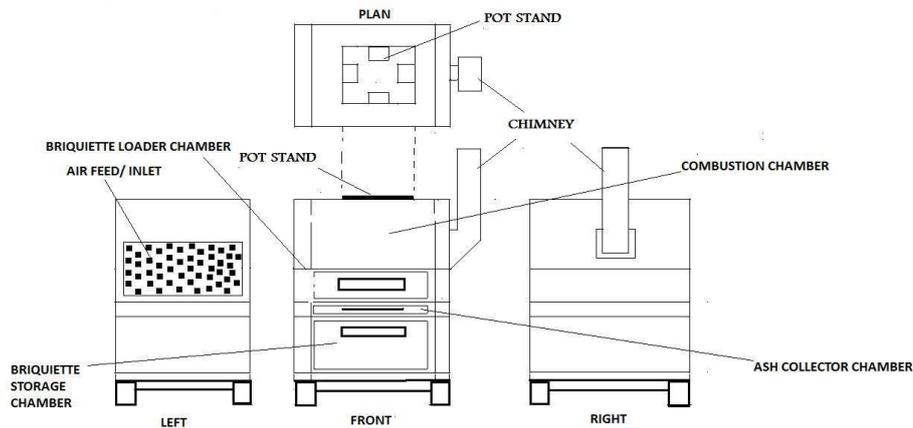


Figure 1. The biomass-cooking stove



Figure 2. Pictorial View of the Biomass Cooking Stove.

## PERFORMANCE EVALUATION

The water boiling time of the briquette, red mangrove wood, firewood and bituminous charcoal were investigated using biomass stove. The volume of a pot was measured and filled to 2/3 of its volume by water. Pot was kept on a biomass stove and covered with propped lid to minimize the losses. The thermometer was fixed in the central part of the pot. 2kg of briquettes was measured and made into four parts for testing. The ambient temperature and initial temperature of water in the pot were measured. The setting time of fire was recorded after lighting the fire. The final temperature of water after boiling was measured. Kept the fire continued by burning briquettes to heat water to vaporize until the given briquettes were used up. Quickly pot lid was removed and evaporation was continued for 20 minutes. Pot from the biomass

stove was separated; cooled for 2 hours and volume of water of were measured [16, 17] thermal efficiency was calculated. The thermal fuel efficiency of the bituminous charcoal, red mangrove wood, firewood and briquette were determined using equation [18]

$$TFE = \frac{M_w C_p (T_b - T_o) + M_c L}{M_f E_f} \quad (1)$$

TFE = Thermal fuel efficiency of the energy;

P = Power Output;

$M_w$  = Mass of water in the pot (kg);

$C_p$  = Specific heat of water (kJ/kgK);

$T_o$  = Initial temperature of water (K);

$T_b$  = Boiling temperature of the water (K);

$M_c$  = Mass of water evaporated (kg);

$L$  = Latent heat of evaporation (kg);

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$M_f$  = mass of fuel burnt (kg);

$E_f$  = Calorific value of the fuel (kJ/kg);

$M_w$  = Mass of water (kg);

$t$  = Time taken to burn fuel (secs).

$$SFC = \frac{\text{Mass of consumed fuel}}{\text{Total mass of smoked fish}} \quad (2)$$

## RESULTS AND DISCUSSIONS

The thermal fuel efficiency of the four traditional and common energy sources ranged between 58.74±5.65 firewood (*Anthonothamacrophylla*) and 72.93±4.34 (red mangrove). The analysis of variance revealed significant difference for the thermal fuel efficiency for the four energy sources tested ( $P < 0.05$ ). The thermal fuel efficiency of briquettes produced from cashew shell was 15.5% as reported by [19]. The obtained values from this study are higher than the corresponding values. The thermal fuel efficiency observed for firewood was lower compared to other energy sources. This could be due to losses caused by stronger flame. The corresponding thermal fuel efficiency for sawdust and rice husk ranged between 19.97 and 21.64% and 26.20 and 27.27% respectively [20]. Performance test results show that the biomass stove has a highest thermal efficiency of 72.93±4.34%. The thermal fuel efficiency of biomass stove produced showed improve performance over traditional mud stove of 17.9% [21]. The performance evaluation based on fuel consumption rate of kilakala stove reported to have about 30% fuel saving capacity compared to other traditional stove [22, 23, 24]. According to performance test conducted on the wood stove by Ayo, [25] revealed that the wood stove had a maximum thermal efficiency of 64.4% and minimum specific fuel consumption of 0.447. The utilization of biomass stove to determine the water boiling time for three traditional energy sources and fuel briquettes were 15.58±0.29 min

(briquette), 13.16±0.50 min (charcoal), 10.17±0.23 min (firewood) and 8.67±0.08 min (mangrove) (Table 1). The variation in these values of the boiling time of the energy sources revealed significant important. Among the energy sources mangrove had the lowest water boiling time while charcoal had the longest duration of water boiling time. The result showed that there is strong relationship between calorific value and water boiling time. The variations in values were similar with the corresponding values between 8-26 minutes for bio-coal briquettes produced by blending the materials at different concentration of 10 -50% with coal as reported by Onuegbu et al. [17]. The water boiling time ranged from 7 min to 25 min was reported for briquettes of spear grass and charcoal [17].

The burning rate values of the traditional energy sources and fuel briquettes varied between 0.89±0.13 g/min (charcoal) and 2.13±0.11 g/min (firewood) (Table 1). The different in the burning rate values of fuel types was significantly important ( $P < 0.001$ ). Charcoal revealed the lowest burning rate as compared to other energy sources. Onuegbu et al. [17] reported factors that could be responsible for burning rate of biomass such as chemical composition, volatile matter content and geometry (bulk and packing orientation) of the biomass. The specific fuel consumption of the three traditional fuel sources and briquettes were 210.59±5.71 g (briquette), 231.02±8.97 g (charcoal), 272.21±9.04g (firewood) and 297.42±8.05g (red mangrove) as shown in Table 1. The different in the specific fuel consumption of the studied energy sources was significantly different ( $P < 0.001$ ). Though, biomass of higher ash content tends to consume more fuel for cooking than biomass of lower ash content. According to Onuegbu et al. [17] reported that percentage ash content is one of the factors that affect specific fuel consumption of fuel briquettes negatively.

**Table 1.** Comparative studies of combustion characteristics of water lettuce briquette, mangrove wood, firewood and charcoal

Combustion parameters	Briquettes Mean±SEM	Charcoal Mean±SEM	Firewood <i>Anthonothamacrophylla</i> Mean±SEM	Red mangrove wood Mean±SEM
Thermal fuel efficiency (%)	65.31±2.23b	72.93±4.34a	58.74±5.65d	60.68±3.04c
Specific fuel consumption (g/l)	210.59±5.71d	231.02±8.97c	272.21±9.04b	297.42±8.05a
Burning rate (g/min)	0.89±0.13d	0.96±0.12c	1.94±0.11b	2.13±0.11a
Boiling time (min.)	15.58±0.29a	13.16±0.50b	10.17±0.23c	8.67±0.08d

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Means with same letter along the column are not significantly different ( $P>0.05$ ) using DMRT, SEM-standard error of mean.

### CONCLUSION

The biomass stove was produced using locally available materials and this makes the machine more affordable. The machine does not require any highly technical expertise for its operations. Performance evaluation indicated that biomass stove has thermal fuel efficiency for the traditional energy sources and fuel briquettes ranged between  $58.74\pm 5.65$  firewood (*Anthonothamacrophylla*) and  $72.93\pm 4.34$  (red mangrove). The energy source with lowest specific fuel consumption corresponds to briquettes. The highest and lowest water boiling time corresponded to briquette and mangrove. Biomass stove produced competed favourably with other traditional and improved stove.

### REFERENCES

- [1] Schreiner NH 2013. Performance characteristics and design recommendations for biomass-burning stoves using earthen construction materials. Unpublished M.Sc.Thesis, 1- 49. Michigan Technological University.
- [2] World Health Organization 2002: Reducing risks, Promoting Health Life. Geneva, Switzerland, The World Health Report.
- [3] Warwick, H., Doig A. 2004. Smoke - the killer in the kitchen. London, UK, ITDG Publishing
- [4] Adegbulugbe AO. 1994. Energy-environmental issues in Nigeria. International Journal of Global Energy Issues,6(12), 7-18.
- [5] Bamgboye A., Bolufawi, S. 2008. Physical Characteristics of Briquettes from Guinea corn (sorghum bi-color) Residue. Agricultural Engineering International: the CIGR Ejournal. Manuscript 1364.
- [6] Jekayinfa SO., Omisakin OS. 2005. The energy production of some agricultural wastes as local fuel materials in Nigeria. Agricultural Engineering International the CIGR E-Journal of Scientific Research and Development Vol. VII, Manuscript EE 05 003: 10-19.
- [7] Sambo AS. 2009. Strategic Developments In Renewable Energy In Nigeria. International Association for Energy Economics 1-23. Retrieved from <https://iaee.org/de/publications/newsletterdl.aspx?id=75>
- [8] Emerhi EA. (2011). Physical and combustion properties of briquettes produced from sawdust of three hardwood species and different organic binders. Advances in Applied Science Research, 2 (6), 236-246.
- [9] Akinbami JFK. 2001. Renewable energy resources and technologies in Nigeria: present situation, future prospects and policy framework. Mitigation and Adaptation Strategies for Global Change,6, 155-181.
- [10] Olorunnisola AO. 2007. Production of fuel Briquettes from Waste Paper and Coconut Husk Admixtures. Agricultural Engineering International: the CIGR Ejournal. Manuscript EE 06 066. Vol. 1X.
- [11] Ponnoum S., Wongopalert, A., Arnold, J., Jr. 1982, Stove Experiments and cooking Observations, Meat Systems Inc., Thai Group, February, 1982.
- [12] Osi OA. 2008. Survey of fish processing machinery in Bayelsa State Nigeria (Unpublished B.Sc. Thesis). Niger Delta University, Nigeria.
- [13] Joseph S., Shanahan Y., Trussell J, Bialy J. 1980 Compendium of Tested stove design ITDG Stoves Programme for the UN Food and Agricultural Organization.
- [14] Chomcharn A. 1981. Energy from Wood (5): Test for Efficiency of Fuel and Bucket Stove, Forestry Meeting Annual Report, Forest Products Research Division, pp. -29 -254, 1981.
- [15] Rathore NS., Panwar NL 2008. Renewable Energy Theory and Practice, Himanshu Publication, New delhi, 273.
- [16] Onuegbu TU, Ekpunobi UE, Ogbu IM, Ekeoma MO, Obumsele FO. (2011). Comparative studies of ignition time and water boiling test of coal and biomass briquettes blend. IJRRAS ; 7(2):153-159.
- [17] Kuti, OA. 2009. Performance of Composite Sawdust Briquette Fuel in a Biomass Stove under Simulated Condition. AU J.T. 12(4): 284-288.
- [18] Sengar SH., Mohod AG., Khandetod YP., Patil SS., Chendake AD. 2012. Performance of Briquetting Machine for Briquette Fuel, International Journal of Energy Engineering, 2(1): 28-34.
- [19] Prasad KK and Verhaart P 1983. Wood Heat for Cooking, Indian Academy of Sciences, Bangalore, Macmillan India Press.
- [20] George R. 1997. Commercialization of technology for domestic cooking applications in biomass energy systems. Venkata Ramana, P.; and Srinivas, S.N. (Eds.). Tata Energy Research Institute (TERI), New Delhi, India.
- [21] Crewe E. 1990. Morogoro fuel wood stove project, Women Training Center, Christian Council of Tanzania, Review and Recommendations, Intermediate Technology Development Group (ITDG), Rugby, UK.
- [22] Otititi, T. 1991. Improved stoves in Tanzania, Stove

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- Notes 6, FWD and ACTS Press, Nairobi, Kenya.
- [22] Pal RC., Joshi V. 1989. Improved cook stoves for household energy management - a case study. *Productivity* 30(1): 53-59.
- [23] Singh T., Kumar S. 2014. Improved biomass solid fuel based cooking devices and adoptability issues. *International Journal of Scientific Research Engineering and Technology* 2(11) 711-716
- [24] Singh VK, TejaPLR., Kumar K., Sundaresan R. (2013). Improved Biomass Solid Fuel Based Cooking Devices and Adoptability Issues. *International Journal of Scientific Research Engineering and Technology*, 2 (11) 711-716.

**Citation:** *Davies R.M. and Zibokere D.S," Performance Evaluation of Biomass Stove", International Journal of Research Studies in Science, Engineering and Technology, vol. 6, no. 1, pp. 17-22, 2019.*

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