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Construction And Evaluation Of A Biomas Powered Stove

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Abstract:** An electrically powered biomass stove was constructed using bricks coated with mud. The performance evaluation of the powered stove was done using fire wood and rice husk briquette. The briquettes were produced using rice husk and binder (Detarium microcarpum) in the ratio of 85:15. There was a significant difference ($p \leq 0.05$) in the performance of the stove when powered and not powered. It took between 10 to 41 minutes for the fire wood to bring 20 litres of water to boiling point at natural air flow and volumetric air flow rate of $0.18 m^3/s$, $0.20 m^3/s$ and $0.25 m^3/s$). Similarly, it took between 9 to 62 minutes while burning rice husk briquettes at the same conditions to bring equal quantity of water to its boiling point. A reasonable amount of time was conserved when the stove was powered. The task that would be done in about 16.4 hours was reduced to about 4.4 hours. There was significant difference between the volumetric air flow rate and fuel type ($p \leq 0.05$) in percentage heat utilized. The results indicated that the percentage heat utilized increased with increase in volumetric air flow rates for both biomasses. The percentage heat utilized by the stove ranged from 35.45% to 72.20%. The average (overall) percentage heat utilized by the stove when briquette was used was 61.46% while wood was 60.01%. There was significant difference ($p \leq 0.05$) in thermal efficiency of the stove between the volumetric air flow rates and the fuel type. The thermal efficiencies obtained for fire wood ranged from 24.28 to 68.22% while the thermal efficiencies obtained for briquette ranged from 29.52 to 69.25%. The overall thermal efficiency of the powered biomass stove increased as the volumetric air flow rate increases. It was observed that wood performed better than briquette at natural air flow. But as the air is supplied by means of the blower, the rate of combustion increased thus making briquette to perform better since it has higher calorific value.

***Keywords:** Airflow rate, Briquettes, Heat, Performance, Stove.*

I. INTRODUCTION

A Stove is an enclosed space in which fuel is burned to provide heating, either to heat the space in which the stove is situated, or to heat the stove itself and the items placed on it (Harris, 2012). The development of stove is intertwined with human history. The old English word stofa meant any individual enclosed space, such as a room, and stove is occasionally used in that sense, as in 'stoved in'. Until well in 19th century stove was used to mean a single heated room (Bilger, 2009). Challenge often sparks innovation. From a cooking perspective, the ingredients of the modern kitchen came together only about 200 years ago with the first appearance of a true range that is, a flat-topped heat source combined with an oven. Credit goes to Benjamin Thompson, better known as Count Rumford, who designed the earliest such cooking devices to scientifically control heat as early as the 1790s (Bryden, 2011). Metal stoves came into use in the 18th century. An early and famous example of metal stove is Franklin stove, said to have been invented by Benjamin

Franklin in 1742. As the Age of invention waxed in the 1880s and ’90s, stove manufacturers began a search for heat sources beyond wood and coal, and an unlikely combination of forces led them to gas ((Harris, 2012). In the 19th century, gas was made from bituminous coal and was primarily an illuminant used to power street and indoor lights. Though gas cooking had found a place in England by the 1860s, and range manufacturers were beginning to ship their product overseas, in America gas was considered too expensive a fuel to be burned for cooking (Beychok, 2005).

Improved cooking stoves have been developed over the years, many of these fail to achieve significant burning efficiency (Stokes et al., 2012); most of these indigenous stoves only provide a marginal reduction in harmful emissions (Bruce et al., 2012). However, Alakali et al. (2010) reported that powered stove is capable of utilizing wood, charcoal and corncobs for domestic cooking with significant improvement compared to manually driven stove and stove that use natural air flow. Powered stove reduces the rate of consumption of biomass with decrease in the volumetric air flow rates, while the time taken to successfully cook the food items increased with decreased in the volumetric air flow rates (Alakali et al., 2009). Researches have shown that cook stoves with powered fans have been able to achieve significant emission reductions, with improved efficiency (Alakali et al., 2009; Stokes et al., 2012). Bello et al. (2015) reported that improved charcoal stove showed more than 20% increased efficiency, power input of 2.26 kW (0.691Kw/hr) and overall thermal efficiency of 36.74% for the improved stove, the stove is thermally efficient more than the traditional stove. They further reported that boiling a liter of water with each stove would take 0.5 hr/kg and 0.36 hr/kg respectively while total specific time spent in boiling yam, with 1ltr of water was 0.95kg/hr to 1.48kg/hr for traditional and improved stoves. In cooking rice, the traditional stove spent 1.17hr/kg while improved stove spent 0.89hr/kg. This is an indication that the improved stove has the potential of reducing significantly the time spent in cooking which would conserve both human energy and resources needed for cooking.

Komolafe and Awogbemi, (2010) reported that with the power input of 2.26 kW (0.691Kw/hr) and overall thermal efficiency of 36.74% for the improved stove, the stove is thermally efficient more than the traditional stove. They further remarked that there exists a comparative advantage between an improved charcoal stove available in the market and the aspirated stove when considering comfort, ease of operation and environmental friendliness. Several researchers such Alakali et al. (2010); Komolafe and Awogbemi, (2010) etc., reported that the specific fuel consumption value of the improved stove was less than that of the traditional metal stove. The superiority of the improved stove to traditional metal stove was demonstrated by (Komolafe, 2000). Agidi et al. (2013) reported efficiencies of 21% and 8% for both the improved and traditional metal stoves respectively as against 34% and 11% obtained when the vent was fully opened reported by (Komolafe and Awogbemi, 2010).

Despites the technological advancement and innovation in the history of stove, biomass cook stove remained the main tool used by both middle and low income earners for the combustion of fuels for domestic application. A biomass burning stove is a system in which solid biofuels such as wood, corn cobs, sawdust, etc. can be burnt to provide energy for cooking, heating and other domestic applications (FAO, 2011). Various types of biomass burning stoves have been developed over the years and these include: Three-stone cooking tripod, charcoal stove, Sawdust stove, Mud stove and Improved/powered wood burning stove. Rice husk and other agricultural wastes are abundantly available as a biomass fuel. The waste biomass generated in rice processing could be utilized as a substitute to wood fuel (Sengar et al., 2012). The opportunity to utilize more efficiently agricultural residues, with a reduction in pollution levels, has in recent years aroused the interest of developing countries, as well as some industrialized countries, in making suitable devices (stoves) through which this can be achieved (Grover and Mishra, 1996). Notwithstanding, in developing countries like Nigeria, decentralized solutions offering cheap access to rural energy, employment and income generating opportunities to the rural population are scarce (Shekhar, 2010). The development of a model biomass burning stove in which agricultural waste and crop residues such as rice husk, corn cobs, cassava sticks and stems could be burnt efficiently to provide energy for domestic and agro-allied industrial applications is one sure way of achieving this aim (Ameh, 2000). Presently, there is inadequate information on powered stove that can be used for combustion of biomass for effective and efficient heat utilization. Similarly, there is inadequate information on the use of unconventional sources of fuel such as agricultural wastes for cooking and heating operations using powered stove. Dearth of information compelled this research.

II. MATERIALS AND METHODS

Rice husk (fuel biomass) were obtained from rice processing centres at Wurukum, *Detarium microcarpum* was purchased from modern market in Makurdi Local Government Area, Benue State, Nigeria. The mould, Compaction Machine, water, weighing balance, separation sieve and measuring cylinder were obtained from the Department of Mechanical Engineering, University of Agriculture, Makurdi. The materials and apparatus included in the performance tests are listed below: Pot, water, Fuels (wood and rice husk briquettes), food items (one variety of rice), weigh balance, mercury- in- glass thermometer, stop watch, measuring cylinder and matches. The material used during this research comprised a weighing scale, a measuring tape, Digital thermometer, stop watch, stainless steel, corrugated iron, Digital camera, hard wood (firewood).

A. DESIGN FEATURES OF THE POWERED STOVE

The model wood and agricultural waste burning stove has the following principal features.

- ✓ A closed hearth where combustion of biomass fuel takes place. This protects the fire from vagaries of wind.
- ✓ A single pot hole design that can carry a single pot at a time.
- ✓ A variable aperture for air intake which controls the combustion rate of fuel materials.

- ✓ A manually driven winder that helps in supplying air for effective combustion of biomass fuel.

B. EXPERIMENTAL PROCEDURE

The biomass stove was operated without blower that is at natural air flow and the weather conditions for the days the experiment was conducted was (speed of wind was 1.5m/s and 1m/s). And subsequently, the biomass stove was powered and operated at volumetric air flow rate of 0.18m^3/s, 0.20m^3/s and 0.25m^3/s, using firewood and briquette. The experiment was carried out at North Bank Makurdi located on Lat 07^{o}41^{1}N, Long 08^{o}37^{1}E and Alt 106.4m.

C. PREPARATION OF RICE HUSK

The rice husk residues were air dried for ten days to reduce the moisture content of the materials and thereafter chopped into small pieces using a hammer mill (BrookCrompton, Series 2000 Type 8 Lab Mill, England) to pass through 1.70mm screen size and stored in polyethylene bag. The procedure as highlighted in ASAE 424.1 (2003) was followed in determining the chosen particle size. The reduction of size of the particles increased the total surface area, pore size of the material and the number of contact points for inter-particle bonding in the compaction process (Lloyd and Davenport, 1980).

D. PREPARATION OF DETARIUM MICROCARPUM

The seeds of *Detarium microcarpum* were dried and milled using attrition mill, sieved using a 1.77mm aperture sieve, and the flour obtained packaged in polyethylene bags.

E. PREPARATION AND FORMULATION OF BRIQUETTE SAMPLES

All the briquettes produced were formed using *Detarium microcarpum* flour as binding agent. The formulation was done using 85% rice husk and 15% *Detarium microcarpum* flour. The binder was mixed with the rice husk to obtain a uniform mixture. They were then compacted in a fabricated rectangular mould of 10.00cm length by 5.10cm width dimensions at a pressure of 10MPa for 2 minutes in a compacting machine. The compacted briquettes were ejected gently from the mould and dried at room temperature for 7 days after which they were used for the evaluation of the powered stove.

F. DETERMINATION OF THE VOLUMETRIC AIR FLOW RATE

Before the commencement of parboiling test, the volumetric flow rate of air produced by the fan in the blower unit was determined using tachometer at three (3) different speeds. The tachometer was switched on and its light was pointed directly at the center of the rotating shaft. The result of the tachometer reading (Fan speed in m/min) was displayed digitally. The volume flow of air, V, was determined from the relation (Osborn, 1976).

Volumetric air flow rate = fan speed× area of the connecting pipe.

$V = nA$ (Eqn 1)

Where, V = volumetric air flow rate. (m^3/s), n = speed of the fan (m/s), A = Area of the fan impeller (m).

G. WATER BOILING TEST (WBT)

The details of the procedures followed in carrying out the WBT were as outlined by Alakali *et al.* (2010). A specific amount of fuel and pot and its cover were weighed and filled with water to about 75% of its volumetric capacity. Mercury in glass thermometer was fixed through the cover of the pot. One Kg of briquettes was measured and arranged on the powered stove and sprinkled with about 1 ml of kerosene to aid ignition of the fire. Power was switched on and the temperature of water in the pot was monitored after every two minutes interval until the water boiled to 98^{o}C. Fire was reduced and maintained at a level just sufficient to keep the water simmering for 30 minutes. The fire was then put out using water. The weight of the unused fuel, if any, was recorded. The weight of the pot and the remaining content was recorded.

Heat given by fuel = weight of fuel consumed x calorific value of fuel.

Heat obtained from recovered charcoal = weight of charcoal x calorific value of charcoal. Net heat supplied to stove = Heat given by fuel used – Heat obtained from recovered charcoal. Heat utilized in raising water temperature = weight of water heated x temperature difference x specific heat of water. Heat utilized in evaporation of water = weight of water evaporated x latent heat of vaporization of water. Heat used in raising pot temperature = weight of pot x temperature difference x specific heat of material of the pot.

Total heat utilized = Heat utilized in raising water temperature + Heat utilized in evaporation of water + Heat used in raising pot temperature.

H. PERCENTAGE HEAT UTILIZED

This is otherwise known as thermal efficiency or energy: The numerator gives the net heat supplied to the water while the denominator gives the net heat liberated by the fuel. This was determined by the method described by Alakali *et al.* (2010).

Percentage Heat Utilized (PHU) = Total heat utilized divided by net heat supplied x 100%

$$PHU=\frac{M_wC_p(T_b-T_o)+M_{fw}L}{M_fE_f}x100\% \qquad \text{(Eqn 2)}$$

Where: M_p= mass of empty pot with lid (kg).

C_p= specific heat capacity of pot material (KJ/kg.K).

t_c = Initial temperature of pot with water (0C).

t_p = Final temperature of pot (0C).

t_w = Final temperature of water (0C).

M_w = Initial mass of water (Kg).

C_w = Specific heat capacity of water (42,000 KJ/Kg.K).

M_v = Mass of water evaporated (Kg).

L = Latent heat of vaporization of water (2,200 KJ/Kg.K).

M_f = Mass of fuel burnt (Kg).

E_f = Calorific value of fuel kJ/Kg (wood=15,500, corncobs=17,163.

M_{fw} = Mass of fuel wood recovered (Kg)

B_c = Calorific value of briquette (29,000 KJ/Kg)

I. POWER OUTPUT

This determines the available amount of energy released from the fuel in a given time. It was determined by the method described by Ayo (2009). Mathematically, it is defined by the relationship:

$$\text{Power output} = \frac{M_f \text{ x } E_f}{t} \qquad \text{(Eqn 3)}$$

where,

E_f= calorific value

J. BURNING RATE

This determines the rate at which a certain mass of fuel is combusted in air. It was determined by the method described by Ayo (2009).

$$\text{Burning rate} = M_f/t \qquad \text{(Eqn 4)}$$

Where,

M_f= mass of fuel burnt (kg)

t = time (min)

K. SPECIFIC FUEL CONSUMPTION (S.F.C)

This is defined as the amount of solid fuel equivalent used in achieving a defined task divided by the weight of the task. This is an expression of the quantity of fuel consumed per unit mass of cooked food. This was determined by the method described by Alakali *et al.* (2010).

$$\text{S.F.C}= \frac{\text{mass of fuel consumed (kg)}}{\text{time taken to cook food (min)}}$$

$$S.F.C = \frac{Mf(1-X)-1.5MC}{Mk-Mp}$$

(Eqn 5)

Where;

M_f=mass of burnt fuel (kg)

M_p=mass of pot with lid

M_k= mass of pot with lid and cooked food (kg)

X= moisture content of the fuel used (%)

M_c= mass of charcoal left recovered (kg)

L. SPECIFIC TIME (S.T)

This refers to the specific time spent per unit mass of food cooked with the fuel and this was determined by the method described by Alakali *et al.* (2010).

$$S.T. = \frac{\text{Total time spent in cooking (min)}}{\text{Total mass of cooked food (kg)}} \qquad \text{(Eqn 6)}$$

M. THERMAL EFFICIENCY

It was determined by the method described by Ayo (2009).

$$\text{Thermal Fuel efficiency} = \frac{MfCp(tp-tc)+MwCw(tw-tc)+MvL}{M_f B_f} X\ 100\% \qquad \text{(Eqn 7)}$$

where:

M_w = initial mass of water, kg,

C_p = specific heat of water, kJ/kg °C

t_w = final temperature of water, °C,

t_c = initial temperature of pot with water, °C

M_v = mass of water evaporated, kg,

L = Latent heat of water = 4.200kJ/kg

B_f = calorific value of fuel used, kJ/kg

t_p= final temperature of pot, ^{o}C

The numerator gives the net heat supplied to the water while the denominator gives the net heat liberated by the fuel.

The temperature-time variation of the water was also recorded.

N. ELECTRIC POWER CONSUMPTION OF THE STOVE

The power consumption requirement of the stove was estimated using the method described by Akaaimo and Raji (2006). Bills were estimated on kilowatt hours usage, which are 1,000 watt hours. If the instantaneous power (P*i*) is known and the load is constant, then P*t* was calculated by multiplying P*i* by the time (in hours). Power usage for constant loads was determined using the expression:

$$P= Pi \text{ x } t \qquad \text{(Eqn 8)}$$

Where,

P= power usage by the device (Wh or KWh.),

P*i* = instantaneous power (W)

t = time (min)

III. RESULTS AND DISCUSSION

A. WATER TEMPERATURE VARIATION

Figures 1-2 show plots of experimental data for changes in temperature during water boiling test using the powered stove. The temperature-time graphs are characterized by relatively slow temperature rise in the first few minutes of the experiment, followed by a sharp rise to 99.8^{o}C which was maintained for the remaining time of the experiment. The temperature-time graphs have similar characteristic features for both wood and briquette. It was observed that burning fuel wood at natural air flow and volumetric air flow rates of 0.18m^3/s, 0.20m^3/s and 0.25m^3/s, it took 41 for the natural air flow and 14, 11 and 10 minutes for the three air flow rates respectively to bring 20 litres of water to boiling point. Similarly, while burning rice husk briquettes at natural air flow and volumetric air flow rate of 0.18m^3/s, 0.20 m^3/s and 0.25 m^3/s, it took 62 for natural air flow, 13, 11, and 9 minutes to bring 20 litres of water to its boiling point.

The slow rise in temperature at the initial stage was due to: low rate of heat supply resulting from the time spent in establishing the fire and heating the system itself (Alakali *et al.*, 2010); and thus a good proportion of the heat supplied at the initial stage was absorbed as sensible heat. On the other hand, the rapid rise in water temperature could have been because the fire became fully established and the system had attained steady state and thus making the rate of energy absorption as sensible heat by the water was noticed to be at the zenith. And consequently, water temperature rose steadily to reach the peak and stabilized. This trend is in agreement with the findings of Alakali *et al*. (2010) who observed that when heat transfer attains steady state, the temperature stabilized would correspond to the maximum rate of the heat absorbed.

Figures 1-2 also show that while burning fuel wood at natural air flow and volumetric air flow rate of 0.18m^3/s, 0.20 m^3/s and 0.25 m^3/s, it took between 10 to 41 minutes to bring 20 litres of water to boiling point. Similarly, while burning rice husk briquettes at natural air flow and volumetric air flow rate of 0.18m^3/s, 0.20 m^3/s and 0.25 m^3/s, it took 9 to 62 minutes to bring the same quantity of water to its boiling point. It took nearly equal time to bring equal volume of water to boiling point using both fuel wood and briquette under forced convection at the same volumetric air flow rate with briquette showing better performance. The result indicates that when the stove was powered, shorter time was taken to bring the same quantity of water to its boiling point. The higher the volumetric air flow rate, the better the combustion and the greater the amount of heat supplied. The volumetric air flow rate has direct proportionality with the quantity of heat supplied. The air supplied assisted in directing the flames from the fire source to the bottom of the pot, thereby increasing the severity of the heat supplied which rapidly brought the water to its boiling point (Alakali *et al*., 2010). On the other hand, time spent to bring the same volume of water to boiling point under natural air flow was longer 62 minutes for briquettes and 41 minutes in the case of fuel wood. The longer time taken to bring water to its boiling point in the case of natural air flow might be due to inability of the briquettes to undergo proper combustion. Furthermore, it might be due to unfavorable conditions that did not enhance effective combustion of the biomass (fuel wood and briquettes) and thus the stove performed minimally with low heat output. This finding is in agreement with Micuta (1985) and Alakali *et al*. (2010) who independently reported that to ensure efficient/proper combustion in an enclosed fire box, it was necessary to provide adequate but not excessive supply of air to sustain adequate heat supply.

The result shows that the rise in water temperature was sharper when forced convection was used compared to natural air flow and these trends were similar for both fuel wood and briquettes. The time taken to bring 20 litres of water on the powered stove was comparatively shorter than those reported by Alakali *et al*. (2010) who reported that it took about 10-14 minutes to bring some 4.5 litres of water to its boiling point at volumetric air flow rate of 0.13-0.16m^3/s during performance evaluation of powered stove using fire wood, saw dust and wood shavings. Similarly, Awulu (2006) reported that it took about 39 minutes to bring 4 litres of water to its boiling point; Belonio *et al*. (2011) reported 42 minutes to bring 1.75 litres of water to its boiling point. Therefore, it can be deduced that powering the stove was better for both biomasses. The study also revealed further that using briquette was better than fire wood for heating.

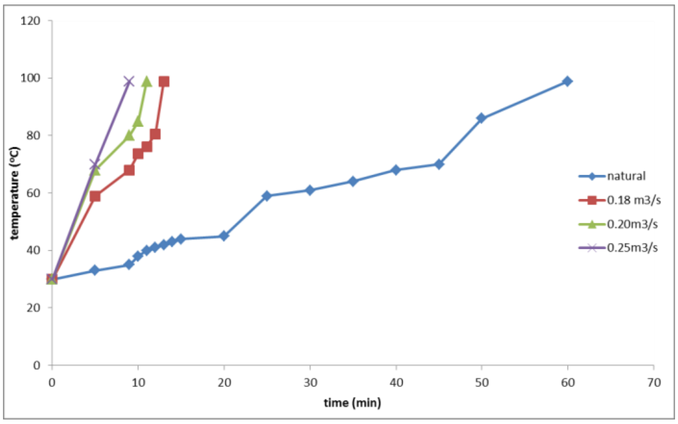

Figure 1: Temperature- time graph for briquettes at varying volumetric air flow rate

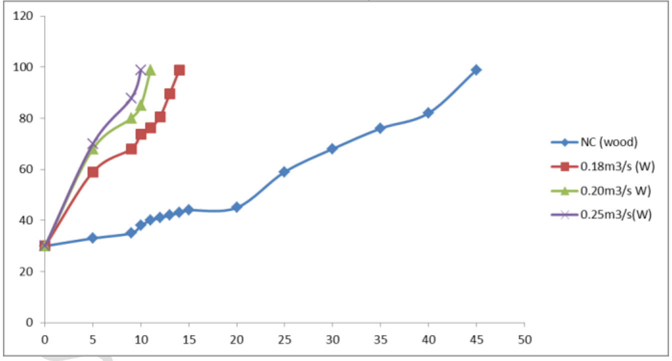

Figure 2: Temperature time graph for wood at varying volumetric air flow rate

B. ENERGY REQUIREMENT FOR THE STOVE AND THE MONETARY IMPLICATION

Table 1 shows the energy requirement for the stove and the monetary implication for both fuel wood and briquette. This was estimated using the equations (13) and (14). About N80.40 and N75.60 is needed to pay electricity bill for one month if the stove is powered at volumetric air flow rate of 0.18m^3/s for wood and briquette respectively. About N64.20 is needed to pay bill for one month if the stove is powered at volumetric air flow rate of 0.20m^3/s for wood and briquette respectively. While about N56.40 and N52.20 is needed to pay bill for one month if the stove is powered at volumetric air flow rate of 0.25m^3/s for wood and briquette.

Fuel type	Flow Rate (m^3/s)	Time boiling water (min)	Electricity used (kWh)	Amt(~~N~~) rate =16.75	Amt/day (8hr)	Amt/month (30day)
Wood	N.A	41	-	-	-	-
	0.18	14	0.020	0.34	2.68	80.40
	0.20	11	0.016	0.27	2.14	64.20
	0.25	10	0.014	0.24	1.88	56.40
Briquette	N.A	62	-	-	-	-
	0.18	13	0.018	0.32	2.52	75.60
	0.20	11	0.016	0.27	2.14	64.20
	0.25	9	0.013	0.22	1.74	52.20

Table 1: Energy Requirement for the stove and the monetary implication

A reasonable amount of time was conserved when the stove was powered. The task that took about 16.4 hours using natural air flow was reduced to about 4.4 hours. The electric power usage and the quantity in (kWh) indicated that it is economical to power the stove than using natural air flow. The billing was based on the present rate used by public electric supply in Nigeria. The amount of money that would be spent has inverse proportionality with the volumetric air flow rate. More money would have been spent when lower air flow rates were used for both fuels. Increasing the air flow rate is advantageous since the percentage heat utilized increased with increase in air flow rate as shown in the discussion under percentage heat utilized.

Assuming a worker is to be paid five hundred naira hourly; about six thousand naira (N 6,000.00) would be saved for every 16.4 hours spent in comparison to 4.4 hours spent when the stove was powered. The present electric billing in Nigeria is about N16.75 kWh (JEDC, 2015). Going by the same estimation, about N 0.34 was required for electricity bill if the stove were to be powered using public grid according to the present billing rate for electricity consumption in Nigeria. From the results of this work, powering the stove at higher air flow rates was better than natural air flow rates. Similarly, the study further revealed that it was better to use briquettes for heating than using fire wood. It can be deduced that briquette is a good alternative for fire wood.

C. COMBINED AND MAIN EFFECT OF VOLUMETRIC AIR FLOW RATE AND FUEL TYPE ON THE PERFORMANCE PARAMETERS OF THE POWERED BIOMASS STOVE

The average effect of both volumetric air flow and fuel wood type on the performance parameters of the powered biomass stove is presented in Table 2. In general, there was significant ($p<0.05$) increase in the performance characteristics among the volumetric air flow rates. The percentage heat utilized (PHU) by the stove was 35.45%, 65.90%, 69.38% and 72.20% for natural air flow, $0.18m^3/s$, $0.20m^3/s$ and $0.25m^3/s$ respectively. On the other hand the percentage heat utilized using the briquette (61.46%) was significant different ($p<0.05$) from that using wood (60.01%). Similar trends were observed for the other performance parameters of the powered biomass stove.

VFR	PHU	BUR	DFE	SFC	SPT	PWO	THE
N.A.	35.45	0.023	0.36	0.016	8.80	1.47	26.93
0.18	65.90	0.085	0.68	0.028	6.10	14.84	30.82
0.20	69.38	0.094	0.71	0.050	5.20	15.25	55.15
0.25	72.20	0.11	0.73	0.056	2.30	16.34	68.73
LSD	**1.25**	**0.0085**	**0.018**	**0.0012**	**0.12**	**0.013**	**0.28**

VFR= volumetric air flow rate (m^3/s); N.A= natural air flow; PHU= Percentage heat utilized (%); BUR= Burning rate (kg/min); DFE= degree of fuel efficiency; SFC= specific fuel consumption (kg biomass/kg paddy); PWO= Power output (kJ/sec); SPT= specific time (min/kg paddy); THE= thermal efficiency (%); LSD= least significant difference.

Table 2: Combined (Average) Effect of Volumetric Air Flow Rate and Fuel Type on the Performance Parameters of the Powered Biomass Stoves

In Table 3, there was significant differences ($p<0.05$) in the performance parameters of the powered biomass stove were observed between fuel types at different air flow rates. At natural air flow, the PHU for wood was 40.30%, higher than that of briquettes (30.60%). On the other hand at $0.25m^3/s$ air flow rate, PHU for wood was lower (68.90%), while that of briquettes was higher (75.50%). Similar observations were recorded for the other performance parameters of the powered biomass stove.

a. PERCENTAGE HEAT UTILIZED

Table 2 shows the main effects of volumetric air flow rate and fuel type on the performance characteristics of the powered biomass stove. There was significant difference ($p \leq 0.05$) in the percentage heat utilized between the volumetric air flow rate and fuel type. The results indicated that the percentage heat utilized increased with increase in volumetric air flow rate and this was independent of the type of the biomass used. The highest PHU for wood was (68.90%) lower than that of briquettes (75.50%). As the volume air increased due to increase in the speed of the blower, the rate of combustion increased and the heat utilized increased. Even though both briquette and fire wood performed satisfactorily, in terms of heat utilization, the values obtained using briquettes were significantly ($p<0.05$) higher than those obtained with the fire wood. This is attributable to the higher calorific value of briquette 18.367kJ/g as against fuel wood 16.988kJ/g as reported by Gravalos *et al*. (2010).

These findings support the result obtained by Ayo (2009) who reported 72.84% as percentage heat utilized during performance evaluation of a biomass stove. These percentages were higher comparatively than those obtained by Alakali *et al*. (2010) who reported 42.02%, 38.93%, and 30.53% at volumetric air flow rate of $0.16m^3/s$ $0.14m^3/s$ and $0.13m^3/s$ when fuel wood was used to evaluate the performance of powered stove. The difference could be due to differences in air flow rates used by the researcher. The result obtained was also higher than those obtained by Odesola and Kazeem (2014) who reported percentage heat utilization of stove 40.65%; Panwar and Rathore (2008), 25%; Dixit *et al*. (2006) reported 37% and Yohannes (2011) reported 31%. The higher percentage heat utilized observed in this work might be attributed to higher air flow rate used in this work. Fuel wood performed better than briquette at natural air flow and this can be attributed to ineffective combustion of the briquette in comparison to wood (Ayo, 2009). Thus, it can be deduced that using higher air flow rates were better to obtain high percentage heat utilized. Furthermore, the study revealed that briquettes performed better than fire wood in terms of percentage heat utilized; therefore briquettes can be used as substitute for fire wood in heating.

b. BURNING RATE

As shown in Table 2, there was significant difference ($p<0.05$) in the burning rate between wood and briquette. Similarly, there was significant difference ($p<0.05$) in burning rate between wood and briquette for the combined effect of volumetric air flow rate and fuel type as shown in Table 4. The results indicate that the quantity of biomass burnt increased with an increase in volumetric air flow rate and the burning rates were higher in briquettes for every given air flow rate. These findings are in agreement with the reports of Kuti (2009) and Onuegbu *et al*. (2011) who independently observed that briquettes are more porous than wood and the rate of combustion is controlled among other factors by bulk, packing and orientation of the material. They further remarked that briquette has more volatile matter than wood and because of its porosity it allows easy infiltration of oxygen and out flow of combustion products. Therefore, increasing the volumetric air flow would give rise to observed higher burning rate in briquette than wood. The study revealed that using higher flow rates were better than natural air flow. Similarly, the study revealed that briquettes performed better than fire wood and therefore a good substitute for fire wood in heating processes.

c. DEGREE OF FUEL EFFICIENCY

As shown in Table 2, there was significant difference ($p<0.05$) in degree of fuel efficiency in terms of the flow rates and no significant difference in terms of fuel type. The combined effect of volumetric air flow rate and fuel type as shown in Table 3 revealed that there is significant difference ($p<0.05$) between wood and briquette. The degree of fuel efficiency was independent of fuel type but depended on air flow rate, increasing with increase in air flow rate.

The performance of the stove in terms of fuel efficiency was satisfactory because the values of fuel efficiency observed in this work (0.36 to 0.73) are within the range reported by Ayo (2009). The author reported 0.64 as degree of fuel efficiency during performance evaluation of wood stove. Therefore, comparatively the degree of fuel efficiency in this work was better than those reported by the author. Similarly, Alakali *et al*. (2010) reported lower values of 0.47 and 0.42 for fuel wood during performance evaluation of biomass powered stove. The degree of efficiency obtained was higher comparatively with those cited above, therefore, it can be deduced that the biomass powered stove performed more efficiently. The lowest degree of efficiency obtained was (0.36) with briquettes when natural convection was used and the highest degree of fuel efficiency obtained was 0.73 using briquettes at volumetric air flow rate of $0.25m^3/s$. Therefore, it can be deduced that powering the stove at higher volume of air flow was better than using natural air flow.

The higher degree of fuel efficiency observed in this work might not be unconnected with the fact that briquettes have higher calorific values of briquette (18.367kJ/g) as against fuel wood (16.988kJ/g) as reported by Gravalos *et al*. (2010). The findings also revealed that briquette was better than fire wood in terms of degree of fuel efficiency; therefore it is a good substitute for fire wood.

d. SPECIFIC FUEL CONSUMPTION (SFC)

As shown in Table 2, there was significant difference ($p\leq0.05$) in specific fuel consumption between air flow rate and the fuel type. The combined effect of volumetric air flow rate and fuel type as shown in Table 3 revealed that there was significant difference ($p\leq0.05$) between wood and briquette. The powered stove was used to parboil paddy rice and the specific fuel consumption of the stove was expressed in kilogrammes of fuel consumed per kilogramme of rice parboiled. The kilogramme of briquettes consumed per kilogramme of paddy parboiled was higher than the kilogramme of wood consumed. The higher quantity (kilogramme) of briquettes burnt than wood during rice parboiling might be attributed to faster burning rate of briquettes fuel. Thus, higher quantity of briquettes was required to parboil the same quantity of paddy compared to fuel wood. The result supports the findings of Onuegbu *et al*. (2011); Bantelay and Gabbiye (2014); Ovueni (2014) remarked that increasing the burning rate of biomass is expected to increase the amount of fuel consumed or burnt. From the results of this work, it can be deduced that powering the stove at higher volume of air flow was better than using natural air flow. The findings also showed that briquette was better than fire wood in terms of specific fuel consumption; therefore it is a good substitute for fire wood.

e. POWER OUTPUT

As shown in Table 2, there was significant difference ($p\leq0.05$) in power output for both volumetric air flow rate and the fuel type. Similarly, there was significant difference ($p\leq0.05$) between wood and briquette for the combined effect of volumetric air flow rate and the fuel in Table 4. The difference in the power output might be attributed to higher rate of combustion when the air flow rates were increased. The power output for natural air flow for both fuels were minimal compared to those obtained with forced convection. The results indicated that power output has direct relationship with the volumetric air flow rate increasing with an increase in the volumetric air flow rate. The power output recorded was higher than those reported by Ayo (2009) recorded power delivery of 2.52kW during performance evaluation of a stove. The higher power output might be due to the materials used in construction as well as the fuel source as suggested by Kimambo (2007). The study revealed that powering the stove at higher volume of air flow was better in terms of power output than using natural air flow. The findings also revealed that briquette was better than fire wood in terms of power output; therefore it is a good substitute for fire wood.

f. SPECIFIC TIME (ST)

As shown in Table 2, there was significant difference ($p\leq0.05$) in the specific time for both volumetric air flow rate and the fuel type. Similarly, there was significant difference ($p\leq0.05$) between wood and briquette for the combined effect of volumetric air flow rate and the fuel as shown in Table 4. The results indicate that the time spent reduced with an increase in the volumetric air flow rate. The longest time spent was 9.00min/Kg of paddy parboiled and this was obtained under natural air flow when briquettes were used. The shortest time spent was 4.00min/Kg when briquettes were used for volumetric air flow rate of $0.25m^3/s$. It can be deduced from these findings that powered stove has helped to reduce the time spent in the parboiling process. The findings is in agreement with Alakali *et al*. (2010) who reported that cooking time for rice, beans and yam increased with decreased volumetric air flow rates. The results of this work revealed that powering the stove at higher volume of air flow was better than using natural air flow. The findings also revealed that briquette was better than fire wood in terms of time spent; therefore it is a better substitute for fire wood.

g. THERMAL EFFICIENCY (%)

As shown in Table 3, there was significant difference ($p<0.05$) in the thermal efficiency for both volumetric air flow rate and the fuel type. The overall thermal efficiency of the powered biomass stove increased as the volumetric air flow rate increases. The findings are in agreement with the results of Smith *et al*. (2000); Rahman and Razia (2013) and Agidi *et al*. (2013) who reported that thermal efficiency of a biomass stove increases with an increase in the volume of air supplied. This means higher amount of effective energy utilization which in turn means less energy input. Therefore, it can be deduced that briquette which has higher thermal efficiency can be suitably used as substitute for fuel wood thus curtailing indiscriminate falling of trees.

Fuel Type	VFR	PHU	BUR	DFE	PWO	SFC	SPT	THE
Wood	N.A	40.30	0.027	0.42	1.93	0.018	8.60	29.58
Briquette	N.A	30.60	0.018	0.30	1.00	0.014	9.00	24.28
Wood	0.18	64.30	0.06	0.48	14.74	0.025	6.40	29.70
Briquette	0.18	67.50	0.11	0.46	14.94	0.031	5.80	31.93
Wood	0.20	66.53	0.067	0.50	15.01	0.025	5.60	54.10
Briquette	0.20	72.23	0.12	0.71	15.50	0.075	4.80	56.20
Wood	0.25	68.90	0.073	0.68	16.00	0.026	2.60	68.22
Briquette	0.25	75.50	0.15	0.73	16.67	0.085	2.00	69.25
LSD		**0.012**	**0.012**	**0.025**	**0.019**	**0.0017**	**0.17**	**0.39**

VFR= volumetric air flow rate (m^3/s); N.A= natural air flow; PHU= Percentage heat utilized (%);BUR= Burning rate (kg/min); DFE= degree of fuel efficiency; SFC= specific fuel consumption (kg biomass/kg paddy); PWO= Power output (kJ/sec); SPT= specific time (min/kg paddy); THE= thermal efficiency (%); LSD= least significant difference.

Table 3: Main Effect of Volumetric Air Flow Rate and Fuel Type on the Performance Parameters of the Powered Biomass Stoves

The powered biomass stove has a maximum thermal efficiency of 69.25% when briquette was used at volumetric air flow rate of $0.25m^3/s$. This compares with 24.28% under natural air flow. The result obtained indicated a better performance when compared to the average thermal efficiency value of 64.40% reported by Ayo (2009) during performance evaluation of an improved wood stove. Similarly the result is better than the reports by Crewe (1990) and Otiti (1991) who observed average thermal efficiency values across fuels that vary from 10% to 23% during the performance evaluation of improved vented mudstove (IVM). Furthermore, the thermal efficiency of the powered biomass stove is higher when compared to the thermal efficiencies of petroleum based fuel stoves such as the LPG stove, the kerosene wick stove, and the kerosene pressure stove whose thermal efficiencies range from 47% to 53.6% as reported by TERI (1987).

The enhanced thermal efficiency of the powered biomass stove used in this work can be attributed to a number of factors such as; the insulation provided round the combustion chamber that minimized the rate of heat loss by conduction and radiation across the wall of the combustion chamber and ensures that a good proportion of heat is conserved within the chamber and directed towards the top of the chamber for heating. The design of the pot seat and the position of the hearth ensure that the base of the pot sinks to a depth inside the pothole such that there is no vertical clearance between the pot base and the top of the stove, ensuring longer interaction between the flame and the pot base, and maximum heat transfer to the pot. Since forced convection is used during the experiment, there is also the factor of availability of sufficient air that ensures the complete combustion of the fuel. This is in agreement with the findings of Itodo *et al*. (2007) and Ayo (2009) who observed similar phenomenon during performance evaluation of an improved wood stove. The results of this work revealed that powering the stove at higher volume of air flow was better than using natural air flow. The findings also revealed that briquette was better than fire wood in terms of thermal efficiency; therefore it is a better substitute for fire wood.

IV. CONCLUSION

The power consumption of the stove showed that it is economical to use. Also the stove can be powered using solar energy since its energy requirement was minimal. The powered biomass stove constructed was able to effectively and efficiently combust biomass and improved on heat generation over natural convection. It took shorter time to boil water when the stove was powered compared to natural air flow. The percentage heat utilized from fuel wood and briquettes increased with an increase in air flow rates with briquettes performing better at higher air flow rates. The thermal efficiencies obtained for fuel wood and briquettes also followed similar trends and these increased with an increase in air flow rates.

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