IJISET - International Journal of Innovative Science, Engineering & Technology, Vol. 2 Issue 12, December 2015.
www.ijiset.com
ISSN 2348 – 7968

Fabrication and Performance Evaluation of an Improved Briquette Stove

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Abstract

The study was to design and fabricate an improved stove that uses biomass briquettes as fuel and to determine the performance of the stove using briquettes produced from a combination of rice husk and corncob in the proportion 75% rice husk and 25% corn cob. The stove design principles specified in literatures were taken into consideration while designing the stove and the stove was fabricated using the specified parameters in the design. The moisture content of the briquette used was 13.3%, the heat of combustion was 15641.4 kJ $kg^{-1}$and the burning rate of the fuel was calculated to be 0.45Kg/hr. The efficiency of the stove was determined using Water Boiling Tests (WBT). The efficiency was 51.2%, the time required to boil 1.2 kg of water was 23mins from cold start, the specific fuel consumption of the stove was gotten to be 3.39kg/kg and the time spent in cooking was 18.6kg/hr. The results are near standards and modification can be done to improve stove efficiency

Keywords: *Briquette, fuel, stove, rice husk, corn hob, biomass*

1. Introduction

Tree felling has increased over the years despite government intensive efforts and operations to prevent the dangers of unselective felling of trees and its consequences on deforestation and associated consequences on land degradation; due to its mass need for firewood because it is the major source of energy for cooking mainly in rural areas with over 85% of houses said to be relying solely on firewood for cooking and other domestic heating. So many research have been carried out within Nigeria and beyond in other to minimise the adverse effect of tree felling. Stoves of different sizes, shapes, configurations, burning efficiencies with minimum fuel consumption and high heat conservation potential have been designed, fabricated and improved upon over the years. These stoves used mostly firewood and charcoal which are direct products of trees as fuel. Charcoal is a fuel derived from thermal decomposition of wood in the process of carbonization, the wood loses its volatile content and the lighter yet energy-dense char remains. Due to the ease of transport and use, charcoal has become a predominant cooking fuel in many homes in the urban areas (Biomass briquettes, 2015).

Briquette fuels are fuels made from compacted organic matter or biomass (Biomass briquettes, 2015). Briquettes was introduced and its use as domestic fuel is gradually taking over the conventional use of firewood and charcoal as it is more economical, made from waste products of processed biomaterials and it is environmental friendly as most briquettes produced emits less poisonous gases e.g. carbon monoxide compared to firewood. Briquettes can be made from any of five categories of biomass: industrial waste or co-products, food waste, agricultural residues, energy crops and virgin lumber (Biomass briquettes, 2015).

Biomass briquettes, made up of ground nut shells, solid waste, agricultural waste and other organic materials, are commonly used for electricity generation, heat and cooking fuel. The composition of the briquettes varies due to the availability of raw materials. The raw materials are gathered and compressed into briquette in order to burn longer and make transportation easier (www.Biomass.net). A briquette stove is a stove that burns compacted wood or plant waste to generate heat for residential and sometimes industrial spaces. By steadily feeding fuel into a burning pot area from a storage container, the fuel creates a constant flame that requires little or no physical adjustments. The special advantage of the charcoal briquette stove is that inside the house the smoke emission is minimal, because the cook does not have to tend the fire all the time.

2.0 MATERIALS AND METHODS

2.1 Materials

The Briquette Stove was fabricated using locally available and standardized materials/metals. Metal selected and used for this project work includes; mild steel sheet, and steel tube.

2.1.1 Specifications and Quantities:

1. 2.0mm mild-steel sheet 1.5m x 2.4m half sheet
2. 5cm diameter metal pipe, 80cm long

2.2 Methods

2.2.1 Design Considerations

The following factors were considered in the design of the improved stove:

2.2.1.1 Fuel

The moisture content, availability, cost, storage, cleanliness, and convenience of use of the fuel to be used were put into consideration before designing the stove. The moisture content of the fuel to be used is very important as the energy yield of a newly cut wood may be less than half that of dried wood. Wereko-Brobby and Hagen, (1996) stated that the calorific value of a fuel plays a very important role in determining the amount of heat energy given off by the fuel.

2.2.1.2 Costs of Production

The stove was constructed with locally sourced materials to keep the cost as low as possible to make it affordable to low-income earners (Adamu, 2012)

2.2.1.3 Ease of Manufacture and Subsequent Maintenance

The stove was designed such that little technical skills as possessed by road-side welders would be can fabricate and subsequently replace components of the stove (Adamu, 2012)

2.2.1.4 Thermal Efficiency

The thermal efficiency of a cooking stove depends largely on how well the heat generated is transferred from the point of combustion to the pot. The fuel bed to pot distance was kept as close as possible to minimize heat losses and maximize heat transfer. The procedure and formulae used in the calculations were based on the approach use by Adamu, (2012)

The burning rate, *R*, corrected for the moisture content of the fuel was calculated using:

$$R\ (Kghr^{-1}) = \frac{100(Wi - Wf)}{(100+M)t} \text{ ------------------- } (1)$$

Where:

Wi= initial weight of fuel at start of test, kg;

Wf= final weight of fuel at end of test, kg;

M = moisture content of fuel, %;

t = total time taking for burning fuel, s.

The Eindhoven formula was used to determine the efficiency of the stove and the parameter used in the calculation were gotten from the water-boiling test carried out on the stove. The Eindhoven formula for calculating stove efficiency as given by Nwakaire and Ugwuishiwu, (2015) is given in equation 2

$$nf = \frac{MwCp(Tf - Ti)}{MfEf} x100 \text{ ------------------ } (2)$$

Where:
nf=Stove efficiency
Mw=Initial mass of water in the pot kg
Mf=Mass of water evaporated during the experiment (kg)
Cp=Specific heat capacity of water=4.186 (kJ kg–1 ^{o}C)
Ti=Initial temperature of water (°C)
Tf=Final temperature of water (°C)
Ef=Calorific value of fuel =15641.4 (kJ kg–1) (Nwakaire and Ugwuishiwu, 2015)

$$nf = \frac{1.235x4.186(98-36)}{0.04x15641.4} x100$$

$$nf = \frac{5.17x62}{625.66} x100$$

$$nf = \frac{320.54}{625.66} x100$$

nf = 0.512x100
nf = 51.2%

2.2.2 The Briquette Stove Basic Components Design and fabrication

2.2.2.1 The Combubustion chamber

The combustion chamber was made from mild steel plate formed into a cylinder of height 30cm and diameter 14cm. the circumference of the combustion chamber is given by;

$C=\pi D$ -------------------- (3)

Take $\pi=\frac{22}{7}$

$C=\pi\times 14$

C=44cm= 440mm

The volume of the combustion chamber is given by;

$V=\pi D^2h/4$ ------------------ (4)

Take $\pi=\frac{22}{7}$=3.1429

$V= (3.1429\times 30\times 14^2)/4$

$V=4620cm^3=4620000mm^3$

Where C = circumference of the circular top and bottom

D= diameter of the combustion chamber

h = height of the combustion chamber

V = volume of the combustion chamber

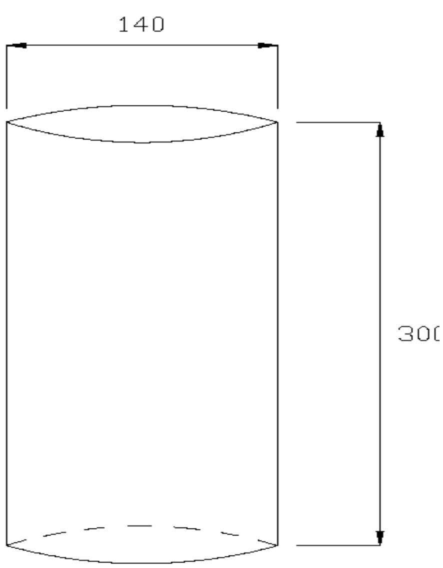

Figure 3.1: The Combustion Chamber

2.2.2.2 The Briquette Pot/Carrier

The briquette pot was formed from mild steel sheet, it is cylindrical in shape and perforated all round to allow passage of air for proper combustion. It has diameter 15cm and height 10cm. using equations 3 and 4, the circumference and volume of the briquette pot can be calculated;

$C=\pi D$ --------------------- (3)

$C = {}^{22}/_{7}\times 15$

C =47.14cm = 471.4mm

From

$V=\pi D^2h/4$ ------------------ (4)

$V = \frac{({}^{22}/_{7}\times(15)^2\times 10)}{4}$

$V = 7071.43\div 4$

$V = 1767.86cm^3 = 1767860mm^3$

Where C = circumference of the circular top and bottom
D= diameter of the briquette pot
h = height of the briquette pot
V = volume of the briquette pot
Take $\pi=\frac{22}{7}$

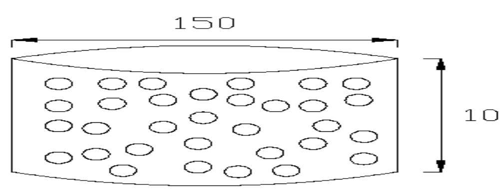

Figure 2.2: The Briquette Pot/Carrier

2.2.2.3 Insulating Material

Fibre glass wool was used to insulate the wall of the combustion chamber. It is an insulating material made from fibres of glass arranged using a binder into a texture similar to wool. The process traps many small pockets of air between the glass and these small air pockets result in high thermal insulation properties. Because of its thermal and acoustic properties, it isone of the most widely used forms of insulation. It is known for its light weight, high tensile strength and exceptional resilience. It has maximum service temperature of about 250^{o}C (Natindco, 2015)

The insulating process is shown in plate I:

Plate I: The stove wall insulation process

2.2.2.4 Stove Body

The body is made of mild steel sheet formed into a cylinder with the following dimensions:

Height=30cm

Diameter=28cm

The inner cylinder and the outer cylinder forms a heat conservation chamber with wall thickness of 7cm which was filled with fiber glass wool to minimise heat loss by conduction. Plate II shows the combustion chamber of the fabricated stove;

Plate II: The combustion chamber

2.2.2.5 Chimney

This is made from mild steel pipe. It extends from the heat conservation chamber through the insulated wall to the atmosphere and serves as channel through which burnt gases are expelled.

ISSN 2348 – 7968

2.2.2.6 Base

Serves as seat for the combustion chamber and also houses the briquette pot, it is shown in plate III

Plate III: Picture of the briquette pot

Plate IV shows the full pictorial view of the briquette stove;

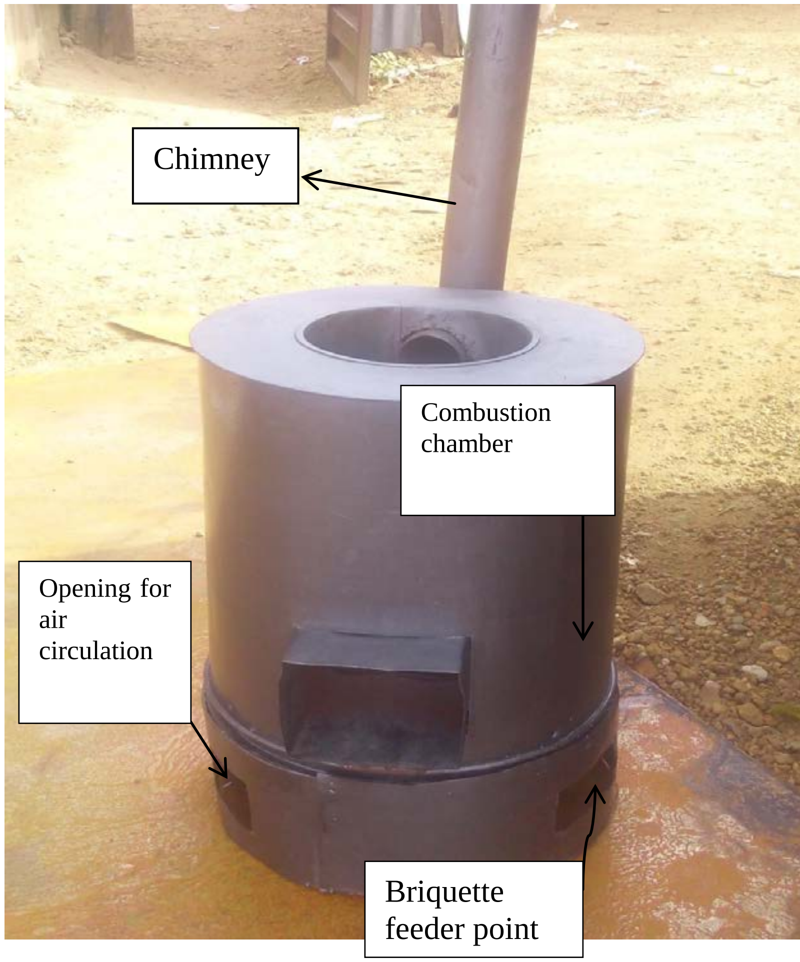

Plate IV: Complete setup of the briquette stove

Plate V shows the briquettes used for testing the stove

Plate V: Briquettes used for testing the stove

2.2.4 Heat Transfer Process in the Stove

Heat is transferred from the heat source to the pot mainly by convection using air as medium and partly by conduction through the combustion chamber metal wall. When air is heated it expands and become less dense. The less dense warm gas then floats up through the more dense cold liquids and gases; in the process heat is transferred upwards and delivered to the cooking pot. Because the heat produced is confined in a partially close chamber, less heat is lost to the environment and because the heat produced by the burning fuel is not utilized totally as it is generated, hot air tends to accumulate in the combustion chamber thereby delivering more heat to the cooking pot than produced by the burning fuel.

2.2.5 Performance evaluation

Water boiling test was conducted on the briquette stove. The efficiency of the stove, briquette fuel burning rate, specific fuel consumption and time spent in cooking were determined using the results from the water boiling test. The tests were conducted in an open environment.

2.2.6 Test Procedure

The briquettes were arranged in the briquette chamber. The apparatus used for the tests include one medium-size aluminum pot, a weighing balance, a stopwatch, lighter and thermometer. The stove and pot were thoroughly cleaned and dried. The performance evaluation of the cook stove was carried out in order to examine its burning rate and efficiency. The quantity of briquettes to be used was weighed and recorded. It was therefore ensured that there was sufficient briquette fuel of the same biomass source and moisture content available for the tests, the already weighed briquette fuel(0.354kg) were arranged inside the briquette chamber and about 10ml which is equivalent to 0.01Liter and $0.00001m^3$ in volume of kerosene was sprinkled on the briquette to initiate burning for the test. The pot was placed on the stove the moment the briquettes started burning. The time of the day, the environmental conditions (ambient temperature) and the initial temperature of the water was recorded. The temperature of the water was recorded at intervals of five (5) minutes until the moment the water came to a vigorous boil. The pot was then removed from the stove and the fire immediately put out with the help of dry sand. The final weight of the remaining water, charcoal and the final temperature of water were then measured and recorded and were used for the calculations.

2.2.7 Tests on Burning Rate

Tests on burning rate were carried out with the briquette fuel stove. The final weight of fuel at the end of the test and the time taken to burn was recorded.

From equation 1:

R (Kghr^{-1})

$$= \frac{100(Wi - Wf)}{(100 + M)t} \quad ------------------- (1)$$

Where:

Wi= initial weight of fuel at start of test= 0.516kg

Wf= final weight of fuel at end of test= 0.354kg

M = moisture content of fuel= 13.3%;

t = total time taking for burning fuel=0.38hr

$$R = \frac{100(0.361 - 0.212)}{(100 + 13.3)0.38}$$

R=0.45Kg/hr

2.2.8 Water Boiling Tests

According to Olawole and Cyril (2008).water boiling tests (WBTs) are simple and short simulations of standard cooking procedures. They measure the fuel consumed and time required for simulated cooking. Water boiling tests are usually employed to examine the performance of stove under different operating conditions to an expected stove performance. It is used by stove designers, researchers and field workers for quick contrast of the performance of stoves. The data obtained in the tests were used to compute the thermal efficiency, fuel consumption, cooking time of the stove and the specific fuel consumption (SFC) using the following equations: (5)

$$SFC = \frac{Mf}{Mc} - (5)$$

Where

Mc= mass of water evaporated=1.235 - 1.191= 0.044Kg

Mf= mass of burnt fuel=0.361 – 0.212= 0.149Kg

SFC=specific fuel consumption

$$SFC = \frac{0.149}{0.044}$$

SFC = 3.39Kg/Kg

2.2.9 Time Spent in Cooking

The time spent in boiling in boiling the water calculated using the relationship below:

Time Spent =

$$\frac{Total\ time\ in\ boiling}{Total\ mass\ of\ boiled\ water} = \frac{Tc}{Mf} - - - - - - - - - - - - - - (6)$$

Tc= Total time spent in boiling.

Mf=Mass of boiled water.

Workings:

$$\text{Time Spent} = \frac{23}{1.235} = 18.6\text{min/kg}$$

3.0 RESULTS AND DISCUSSION

3.1Results

Tables 3.1 and 3.2 show the results from the water boiling tests.

Table 3.1: Results for Boiling of Water

Parameters	Values
Ambient Temperature	36°C
Initial Temperature of Water	36°C
Final Temperature of Water	98°C
Time Spent	23mins
Weight of Empty Pot	0.5kg
Initial weight of fuel	0.361Kg
Final weight of Fuel	0.212Kg
Weight of used Fuel	0.149Kg
Initial weight of the Water	1.235K
Final weight of the Water	1.191Kg
Total weight of Water Evaporated	0.044Kg

Table 3.2: Change in Temperature of the water at 5mins interval

Time (mins)	**Temperature(°C)**
0	36
5	40
10	62
15	75
20	92
25	98

Table 3.3 shows the efficiency of the briquette stove, burning rate of the briquette fuel, specific fuel consumption (S.F.C), and cooking time as calculated using the parameters obtained during the performance evaluation test(water boiling test).

Table 3.3: Values obtained from the tests carried out

Parameter	unit	Value
Efficiency	%	51.2
Burning rate	Kg/hr	0.45
S.F.C	Kg/Kg	3.39
Time spent	Min/Kg	18.6

3. 2 Discussion

The change in temperature with time at five minute interval during the water boiling test was taken and recorded as shown in Table 3.1. The stove efficiency(%), burning rate (kg h^{-1}), specific fuel consumption (Kg/Kg) and time spent in cooking under the water boiling test scenario calculated to be 51.2, 0.45, 0.38, and 18.6 respectively. It was observed that the water started boiling at 22 min at temperature of 96°C during the water boiling test process. Plates I – V show the pictorial view of the briquette stove at the various stages of construction, and the briquettes used for the testing.

Adamu (2012) reported an efficiency of 75.5% for briquette fuel which is slightly higher than the efficiency of the briquette stove designed in this project work; this difference may be attributed to difference in biomass used. Woodchips would have higher heat of combustion than rice husk and corn cob. However, the efficiency of the dual source stove when tested with kerosene as source of fuel was found to be 27.85% which is far lower than that of the briquette stove designed in this research work. Nwakaire and Ugwuishiwu (2015) reported a lower stove efficiency value of 20.75% for a natural cross draft gasifier stove using rice husk briquettes as energy source. The lower value suggests that the designed stove for this study is within performance range.

4.0 CONCLUSIONS

The briquette stove was designed and fabricated using locally available materials; mild steel sheet was used for the construction of the combustion chamber, briquette pot, stove body and stove base and mild steel pipe for the construction of the chimney. Performance evaluation was carried out to determine the efficiency of the stove, its fuel burning rate, time taken to cook food and the specific fuel consumption (SFC) of the stove using a simple water boiling test.

The result from the test shows that the designed stove for this study is within performance range. The briquette used has minimal smoke emission and the smoke emitted was properly channeled out through the chimney making the stove safe for domestic cooking. The stove designed if adopted for cooking in urban and rural homes will go a long way in reducing environmental risks resulting from over dependent and excessive use of tree products and fossil fuels for domestic cooking.

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