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Performance Evaluation of a Modified Briquette Stove

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ABSTRACT

This study was undertaken to modify an existing briquette stove and to evaluate its performance with briquettes produced from a composition of groundnut shell, almond shell and rice husk. The existing stove had several deficiencies and needed modification to perform better. The modified stove was fabricated using locally available and standardized materials. Design principles as stated in literature were taken into consideration and recommendations made by previous researchers were also carefully taken into consideration in order to improve the stove's efficiency. The moisture content of fuel (briquettes) used for testing was found to be 14%. The efficiency of the stove was determined using simple water boiling test. The efficiency was estimated to be 57.2%; time spent to boil 1.580kg of water was 12 minutes from hot start, the specific fuel consumption of stove was found to be 0.577kg/kg. The results obtained from this study compares favourably with similar stoves in existence.

1. INTRODUCTION

Waste disposal from different sectors including industrial and agricultural sectors is a major challenge in developing countries (McAllister, 2015) The absolute measure of agricultural waste produced especially in agriculture cannot be quantified (Alexandar *et al*., 2017) These agricultural wastes are generated from the period of land preparation to planting, harvesting, processing, packaging, transporting and even consuming (Alexandar *et al*., 2017). Many efforts have been made for finding ways to utilize these wastes so as to obtain useful products from them. As the population of the world continues to grow, the demand of humans for energy is becoming difficult for the world's energy leaders to meet (Christoph, 2012). The global rate of energy consumption has about doubled in the last three decades of the previous century (Amoco, 2005). Just in 2004, close to 77.8% of the primary energy consumption was from fossil fuels (32.8% oil, 21.1% natural gas, 24.1% coal), 5.4% from nuclear fuels, 16.5% from renewable resources, of which the main one was hydro (5.5%) and the remaining 11% consisted of non-commercial biomasses such as wood, hay and other types of agricultural biomass which in rural-economics still constitute the main source of energy (Amoco, 2005).

Oil, coal and natural gases represents the major source of energy for homes and industries but however as good as the above listed sources of energy are, they have a lot of adverse effect on the environment and humans which ranges from global environment warming, soil depletion, health hazard, loss of biodiversity, erosion, reduction in agricultural yields, climate change and a host of others due to the production and emissions of dangerous gases from this medium of energy generation (Saidur *et al*, 2011). There is therefore the need to find other sources of domestic fuel other than the use of oil, coal and other natural gases. According to Saidur *et al*, (2011), the use of briquette as a renewable source of energy can contribute to sustainable forest management, there will be neutral CO_2 emission balance, low sulphur emission which usually results in acid rain.

Agricultural residues offer much potential for renewable energy sources in form of biomass (Dairo *et al*., (2018). With advances in the knowledge of biotechnology and bioengineering, some resources, which could have been classified as waste, now form the basis for energy production (McKendry, 2002). According to Christoph (2012), renewable energy technologies are safe source of energy that have much lower environmental impact than conventional energy technologies. Biomass is attracting great attention over the world as a source of renewable energy as well as an alternative for fossil fuels (Dairo *et al*., (2018). The world has relied so much on fossil fuel and this has had a lot of negative impact on the environment. Hence, looking in to the use of agricultural biomass will go a long way to reduce the negative effect of deforestation, help to address the dangerous effect of gases (such as sulphuric gas and carbon monoxide) released from fossil fuels and will also help reduce over dependency on fossil fuel (Amoco, 2005). The potential of biomass energy derived from forest and agricultural residues worldwide is estimated at about 30EJ/year, compared to an annual worldwide energy demand for over 400EJ/year (McKendry, 2002)

Biomass briquetting has to do with the densification of loose biomass material to produce compact solid composites of different sizes with the application of pressure. Briquetting of agricultural residues takes place with the application of pressure, heat and binding agent on the loose materials to produce the briquettes (Alhassan and Olaoye, 2015). Briquettes are often used as a development intervention to replace firewood, charcoal, or other solid fuels. According to Alhassan and Olaoye (2015), briquetting of these agricultural residues such as rice husk, corn stem, millet stems and groundnut shell among others will help to reduce pressure on fuel wood and charcoal production. In the right context, biomass briquettes can thus save time, save money, decrease local deforestation rates and provide income generating opportunity (Alhassan and Olaoye, 2015, Tumurulu *et al,* 2010).

A briquette stove is an equipment that generates heat by burning solid compacted wood or agricultural residues in form of briquettes. It does this by steadily feeding fuel into a burning pot area from a storage container, thereby creating a constant flame that requires little or no physical adjustments (Orhevba and Okoro, 2015). A briquette stove which makes use of wastes generated from agricultural residues will therefore help to reduce problems of environmental pollution and pressure on tree felling.

The aim of this study therefore, is to modify an existing briquette stove which will use briquette fuel made from different ratios of agricultural biomass (wastes). This stove will also reduce health hazard resulting from smoke emissions as it comes with a chimney which helps to eject the smoke safely.

2. MATERIALS AND METHODS

2.1. Materials

The briquette stove was fabricated using locally available and standardized materials. Galvanized iron (1.0mm and 1.5m x 2.4m half sheet) and 5cm diameter metal pipe 80cm long were used for the fabrication. The tools and equipment used for this study include hand shear, wire brush, vice, hammer, compass, tri-square, anvil. Folding method was used for joining instead of using the conventional welding method and this was done in order to make the work neat. The briquette stove was subjected to test using briquette fuel made from agricultural residues (rice husk, groundnut shell and almond shell).

2.2. Methods

2.2.1. Design considerations

The original item had the following deficiencies (Plate 1):

- Too much space was given to the insulation chamber thereby giving little space for proper combustion of fuel in the combustion chamber.
- The fuel to pot distance seemed too much thereby leading to less heat getting to the combustion chamber
- An insulation material with less insulation property was used
- Mild steel (2mm) was used thereby making the previous stove very heavy
- No provision was given for easy replacement of any of its component part.

All these were put into consideration in the design of the improved briquette stove.

Plate 1: The existing stove

2.2.1.1. Fuel

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.

2.2.1.2. Costs of production

The stove and the briquette fuel were made with locally sourced materials to keep the cost as low as possible in order to make it affordable to low-income earners

2.2.1.3. Ease of manufacture and maintenance

The stove was designed such that little technical skills as possessed by road-side welders is enough to 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 briquette pot to cooking pot distance was kept as close as possible to minimize heat losses and maximize heat transfer, this was an improvement from the original stove whose briquette pot to cooking pot distance was too much. The procedure and formulae used in the calculations were based on the approach used by Adamu (2012).

The burning rate, R, corrected for the moisture content of the fuel was calculated using Equation 1.

$$R = \frac{100(W_i - W_f)}{(100+M)t} \quad (1)$$

Where:
W_i = Initial weight of the fuel at start of test (kg)
W_f = Final weight of fuel at the end of test (kg)
M = Moisture content of fuel (%)
t = Total time taken for burning fuel (hr)

The Eindhoven formula was used to determine the efficiency of the stove and the parameters used in the calculation were obtained 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 shown in Equation 2.

$$n_f = \frac{M_w\, C_p(T_f - T_i)}{M_f E_f} \times 100 \quad (2)$$

Where:
n_f = stove efficiency
M_w = Initial mass of water in the pot (kg)
M_f = Mass of water evaporated during the experiment (kg)
C_p = Specific heat capacity of water = 4.186 $kJkg^{-1o}C$
T_i = Initial temperature of water (^oC)
T_f = Final temperature of water (^oC)
E_f = Calorific value of fuel = 15641.4 kJ/kg

2.2.2. Design and fabrication of the briquette stove

The stove is made up of various components and parts. The procedure and formulae used in the calculations were based on the approach reported by Adamu (2012) with minor adjustments.

2.2.2.1. The combustion chamber

The combustion chamber was made from mild-steel plate formed into a cylinder of height 21.5cm and diameter 28.2cm (Figure 1). The circumference of the combustion chamber is given by:

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

$\pi = \frac{22}{7}$
$C = \pi \times 28.2$
$C = \frac{22}{7} \times 28.2$
C = 88.6cm = 886mm.

The volume of the combustion chamber is given by:

$$V = \pi D^2 \frac{h}{4} \tag{4}$$

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.

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

V = (3.1429 x 21.5 x 28.2^2)/4

V = 53720cm^3 = 537208mm^3

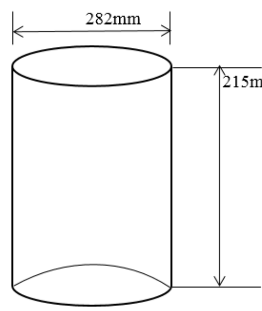

Figure 1: The combustion chamber

2.2.2.2. The briquette pot carrier

The briquette pot carrier was formed from galvanized iron sheet, it is cylindrical in shape and perforated all round to allow passage of air for proper combustion. It has diameter 29.8cm and height 10cm. Equation 5 was used to calculate the circumference and volume of the briquette pot.

$$C = \pi D \tag{5}$$

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

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

C = $\frac{22}{7}$ x 29.8

C = 93.76cm = 937.6.mm

V = $\pi D^2 h/4$

$V = \frac{(\frac{22}{7} \times (29.8)^2 \times 10)}{4}$

V = 27910.21/4

V = 6977.55cm^3 = 69775.5mm^3

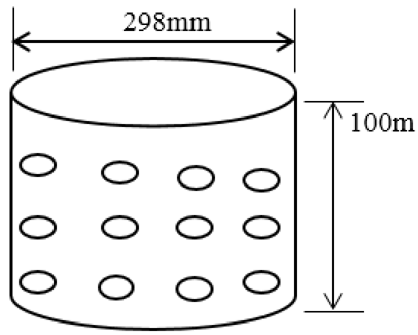

Figure 2: The briquette pot carrier

2.2.2.3. Insulating material

The material used for insulation is the plaster of Paris (POP), a quick setting gypsum plaster consisting of a fine, white powder, calcium sulphate hemihydrate ($CaSO_4.2H_2O$) which hardens when moistened and allowed to dry. Plaster of Paris is prepared by heating calcium sulphated dehydrate on gypsum, to 120º–180 º (248º – 356º F). According to Gesa *et al.* (2014), P.O.P exhibits one of the best insulation properties with thermal conductivity of 0.1185W/mK and thermal resistivity of 8.4388 mK/W.

2.2.2.4. Stove body

The body was 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 fibre glass wool to minimise heat loss by conduction. The dimensions of Orhevba and Okoro (2015) were modified based on the deficiencies observed.

Plate 2: Complete setup of the briquette stove



(a) Combustion chamber cover (b) Briquette pot (c) Ash packer

Plate 3: Parts of the briquette stove

2.2.2.5. Chimney

The chimney was made from two mild-steel pipes of 50mm diameter and height of 670mm. It extends from the heat conservation chamber through the insulated wall to the atmosphere and serves as channel through which burnt gases are expelled.

2.2.2.6. Base

The base serves as seat for the combustion chamber and also houses the briquette pot.

The briquettes used in testing the stove are shown in plate 5 while the conceptual diagrams of the stove are shown in Figure 3.

Plate 4: Stove base

Plate 5: Briquettes

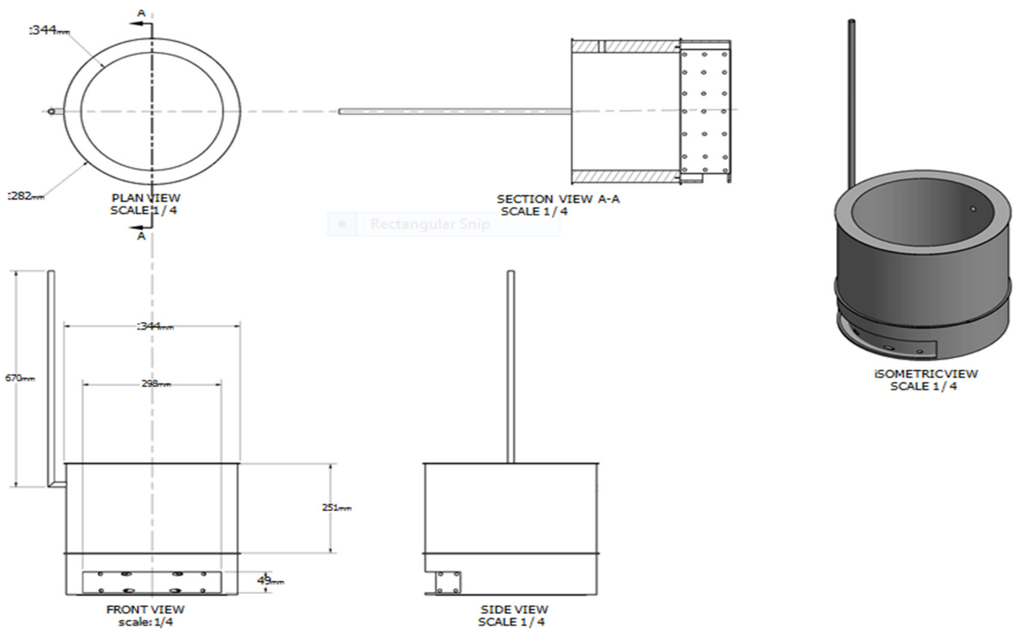

Figure 3: Conceptual diagrams of the stove

3. RESULTS AND DISCUSSION

The ambient, initial and final temperatures of the water used for the test were 24.60, 21.50 and 98.60ºC respectively. Table 1 shows the temperature at every four minutes during the water boiling test.

Table 1: Change in temperature of water at four minutes interval

Time (mins)	Temperature (ºC)
0	21.5
4	38.9
8	62.5
12	98.6

The stove efficiency, burning rate and time spent were obtained as follow:

$$n_f = \frac{1.580 \times 4.186[98.6 - 21.5]}{0.057 \times 15641.4} \times 100 = \frac{509.93}{891.6} \times 100$$

$$= 0.572 \times 100 = 57.2\%$$

Burning rate:

$$R = \frac{100(0.540 - 0.441)}{(100 + 14.0) \times 0.2}$$

$$= \frac{100 \times 0.099}{114.0 \times 0.2} = \frac{9.9}{22.8}$$

$$R = 0.434 \text{kg/hr}$$

Water boiling test:

$$SFC = \frac{M_f}{MC} = \frac{0.0571}{0.099} = 0.577 \text{kg/kg}$$

Time spent in cooking:

$$\text{Time spent} = \frac{Total\ time\ in\ boiling}{Total\ mass\ of\ boiling\ water} = \frac{TC}{M_f} = \frac{12}{1.580} = 7.59 \text{min/kg}$$

Table 2 shows the result obtained for the efficiency of the briquette stove, burning rate of fuel, specific fuel consumption (S.F.C) and the cooking time evaluated using parameters obtained during the performance evaluation tests (Water boiling test).

Table 2: Results of test carried out

Parameter	Unit	Value
Efficiency	%	57.2
Burning rate	kg/hr	0.434
Specific fuel consumption	kg/kg	0.577
Time spent in cooking	min/kg	7.59

The fuel used for testing the briquette stove was briquette obtained from agricultural residues mixed in the following proportions; 20-70% for groundnut shell, 10-40% for almond shell, 10-30% for rice husk, 2-20% for binder, 5% for filler (clay) and 3% for water. The peak calorific value produced by this blend of composites was 29994.49 kcal/kg and the lowest calorific value obtained was 23701.47 kcal/kg. The change in temperature with time at four minutes interval during the water boiling test was taken (Table 1). The stove efficiency (%), burning rate (kg/hr), specific fuel consumption (kg/kg) and time spent in cooking (mins) under the water boiling experiment was calculated and recorded to be 57.2%, 0.437(kg/hr), 0.577(kg/kg) and 7.59mins respectively. The hot start method of fuel ignition was adopted before commencement of the test and observations made was that the water started boiling at exactly 12 minutes at a temperature of 98.6^{o}C. Adamu (2012) reported an efficiency of 75.5%. This value is higher than the efficiency of the briquette stove designed in this study, this difference may probably be attributed to the difference in biomass used. However, the efficiency of the stove when tested with kerosene as source of fuel was found to be 27.85% which is lower than that of the stove designed in this study. Nwakaire and Ugwuishiwu (2015) reported a lower stove efficiency value of 20.75%. Thus, the designed stove in this study falls within performance range.

4. CONCLUSION

The briquette stove was designed and locally available materials were used for its fabrication. Folding method was used for joining and there were no weld joints on the stove. Performance evaluation was carried out on the stove with the briquette fuel produced from three different agricultural residues (groundnut shell, almond shell and rice husk); their mixing ratio ranged from 20-70% groundnut shell, 10-40% almond shell and 10-30% for rice husk. Other components were added to improve the quality of the briquettes and they include: 2-20% for binder, 5% clay and 3% of water. The result obtained from the performance evaluation test shows that it is within the performance range when compared with previous studies.

5. ACKNOWLEDGMENT

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6. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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