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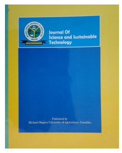

Production and Evaluation of Fuel Characteristics for Briquettes from Different Crop Residues

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ABSTRACT

Briquettes were produced from selected crop residues namely groundnut shells, maize cobs and an ad-mixture of both (composite). The performance characteristics of the briquettes were then evaluated based on fuel efficiency, cooking efficiency, time taken to boil water and fuel consumption rates respectively. The residues were reduced to 2mm particle sizes with a hammer mill and a set of sieves. Gum arabic and water were added in measured quantities based on a design ratio and thoroughly mixed into a thick paste which was fed into a manually operated briquette mould to produce perforated cylindrical briquettes that were sundried into hard pans. The design ratio of dry matter: gum arabic: water was; for type A (maize cob briquettes) 2:0.8:7, for type B (groundnut shell briquettes) 1.2:0.25:3.5 and for type C (composite briquettes) 1.6:0.5:5.5. A laboratory determination of gross calorific value was carried out and the following values were obtained; type A:-,40.924MJ/Kg, type B:-,25.757MJ/Kg and type C:-,39.656MJ/Kg. A specie of firewood, delonix regia wood labelled type D which was used for comparison was found to have a calorific value of 24.340MJ/Kg. On evaluation, the four fuel types A, B, C and D showed fuel efficiency values of 38%, 62%, 41% and 27% respectively. In the same order, cooking efficiency values were estimated to be 14%, 23%, 11% and 10%. In boiling equal volumes of water, it took type A an average of 15mins, type B 20mins, type C 24mins and type D 58mins. Lastly, the rate of fuel consumption was 1.65Kg/hr, 1.14Kg/hr, 1.00Kg/hr and 0.9Kg/hr for types A, B, C and D respectively. Conclusively, it was observed that briquettes produced from selected residues are better substitutes and alternative energy sources compared to wood.

Keywords: Briquettes, gum arabic, delonix regia wood, calorific value, ad-mixture

Introduction

Loss of forest cover is a serious problem around the world particularly in developing countries. One consequence of this loss is that it is becoming increasingly difficult for people in these areas to obtain fuel to cook their food; hence they depend on only wood supply from forest timber. In some of these countries, forest cover has decreased from over 60% to 20% in just a few decades (Baldwin, 1988). Globally, energy cost is no longer a recent challenge though it is a major concern. Kerosene and gas are used for cooking mostly by Nigerian urban dwellers but are so expensive. In most developing countries, wood is the major energy source used mainly for cooking in rural communities, and this has depleted to a great extent (Adeniyi et al, 2014).

The persistent energy challenges have resulted in making researchers across the globe to seek alternative sources of energy that are not only environmentally friendly but cost effective. One of such alternatives is the making briquettes for heating (Tornubari, 2019). Briquetting is the bringing together of carbonaceous materials mostly agricultural wastes with or without binder via compaction (Nasrin et al, 2008 and Chen et al, 2013). Various researchers have used different materials to produce briquettes across the globe, (E.C. Mbamala 2019) used palm kernel shell, (Tornubari, 2019) used African pear, rice husk by (Gbabo et al, 2018), coffee husks and pulp (Merete et al, 2014) to mention a few. Briquetting of biomass has numerous advantages, which include waste management and control of global warming through the limited use of fossil fuel (Deng et al, 2009). Also, long time exposure to smoke from wood during cooking has health implications, which can be reduced by using briquettes (Akuma and Charles, 2017).

Groundnut shells and maize cobs are by-products of agricultural produce after harvest with very high calorific values having tendencies to conserve heat and can be utilized as alternative sources of energy for cooking. Large quantities of these by-products are lying waste on farmlands and residential areas hence the potentials of the by-products can be explored.

This research was carried out in order to resolve the problem of deforestation to avoid cutting of trees that serve as crop and soil cover from direct impact of rainfall and sunshine; encourage wild life reservation and resort centres in forest reserve; provide affordable and easily accessible means of cooking and heating in households and for commercial purposes; convert crop residues to useful products to avoid environmental pollution and to produce efficient, durable and light weight briquettes that can serve various purposes.

Materials and Methods

Materials

Briquettes were produced in the departmental processing laboratory shed of Ahmadu Bello University, Zaria. Materials used for briquette production include:

1. Groundnut shells
2. Maize cobs
3. Molten gum Arabic (Binder for agglomeration)
4. Water

Method

Production Processes for the Briquettes

Residues of groundnut shells and maize cobs were ground with a hammer mill and sieved to a required particle size of 2mm. Measured quantities of gum Arabic and water were added to the ground residues and thoroughly mixed in separate bowls labelled A, B and C.

Bowl A contained maize cob sample while bowls B and C had groundnut shells and composite samples respectively. The composite sample was an ad-mixture of maize cobs and groundnut shells in the ratio 4:1. A locally fabricated briquette mould was used in producing the briquettes manually. The cavity of the mould was filled with samples from the labelled bowls and levelled off at the top to obtain smooth surfaces. Then via a lever (foot press) twelve plungers aided the ejection of the already formed briquettes from the mould onto a flat surface for sun drying to reduce existing moisture content to a minimum of 8% in maize cobs and 5% in groundnut shells and composite briquettes. These moisture content levels aided efficient combustion and minimum smoking of the briquettes during the water boiling test.

Dry and wet bulb thermometers were used to take temperatures on a daily basis and values were recorded. Drying of briquettes to their respective permissible and optimum moisture contents took a total of two weeks due to the atmospheric conditions at the period of drying. Production of briquettes was done during rainy season hence the extremely humid weather condition slowed down the drying process which should have taken less days if briquettes were not gaining moisture during the drying process.

Figures 1 and 2 show the ejection of briquettes from mould and types of briquettes produced respectively.

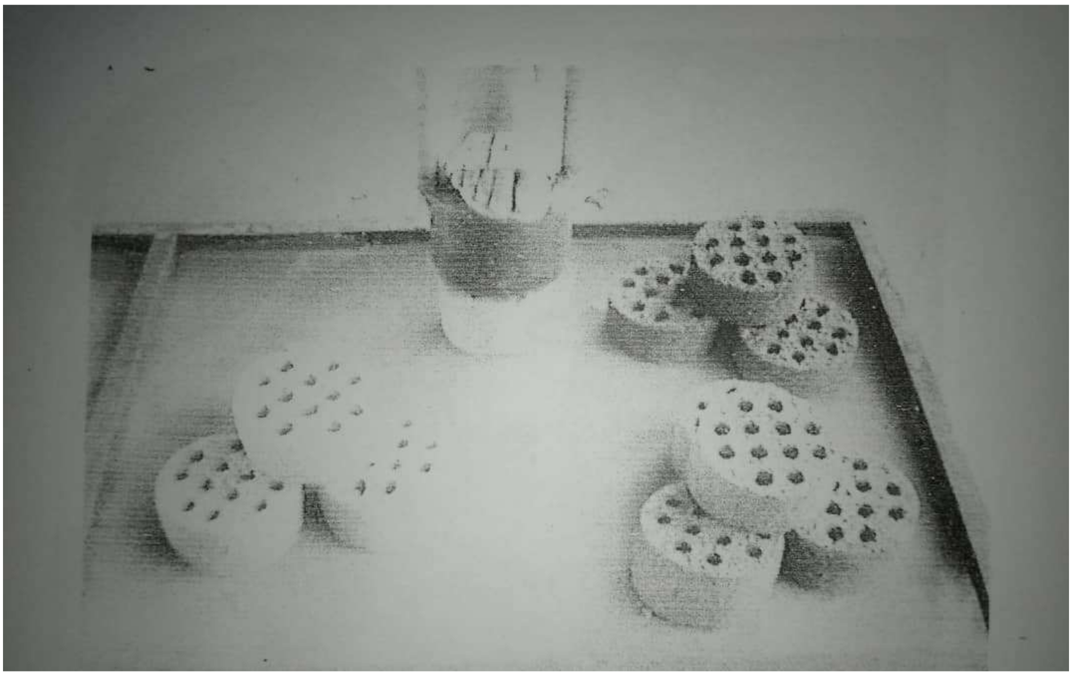

Fig 1: Ejection of briquettes from mould

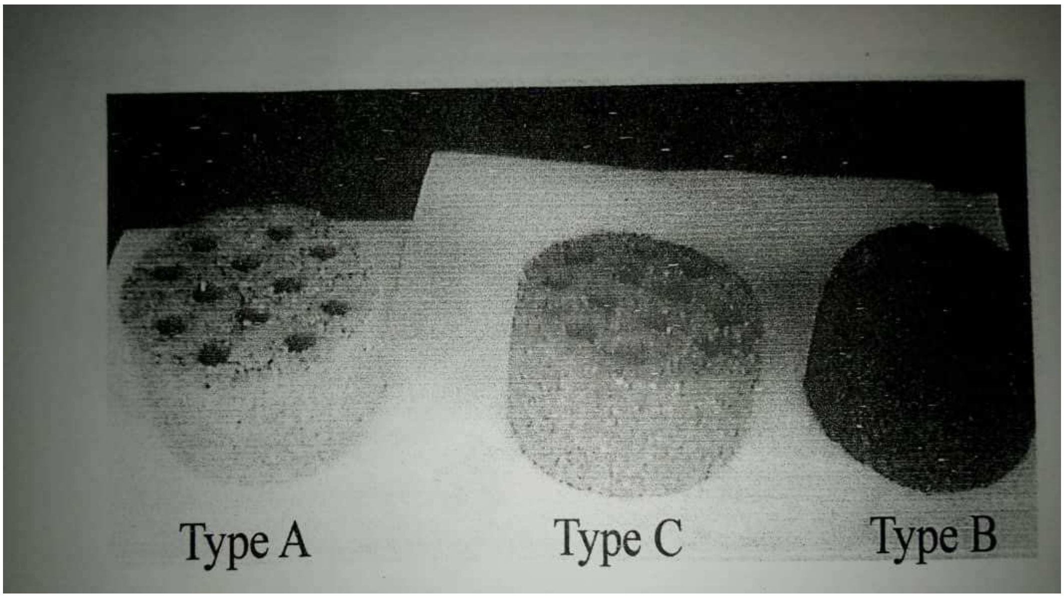

Fig 2: Types of briquettes produced

Test Apparatus for Calorific Value Determination

Various apparatus were used to conduct the calorimetric experiment which includes:

1. Mehler Cook bomb calorimeter and accessories
2. Oxygen cylinder in mobile trolley with valves and pressure gauge assembly
3. Weighing balance (CB3)
4. Beckmann thermometer (0.01^{0}C scale division)
5. Mercury-in-glass tube thermometer (-10^{0}C to 110^{0}C)
6. Empty gelatin capsules
7. Measuring cylinder (1000cm^3)
8. Pipette (1ml)
9. Stop clock

Test Procedure on Calorimetry

The interior of the bomb calorimeter including the supports and crucible were cleaned and dried before starting and 1ml of distilled water was pipetted into the bomb. Empty gelatin capsules were weighed to values ranging from 0.0939g to 0.0990g for different values of briquettes and their replicates. About 0.0860g to 0.2185g of dry samples ground to fine powder was added to the lower half of the capsules. The cover immediately replaced and re-weighed.

A 0.0025g of fuse wire was fixed across the terminals of the bomb. 0.0045g of dry cotton was attached to the fuse wire and to the capsule. The capsule was carefully set in the crucible while the bomb was carefully closed using a special vice and spanner and it was then connected to the oxygen cylinder for charging. Oxygen was added slowly to the bomb so that the capsule will not be blown out of the crucible (the design of the bomb is such that oxygen is diverted onto the sides of the bomb to minimize disturbances of the crucible, but sonic velocities can be generated). The allowable pressure charged into the calorimeter was between 20 and 25 atmospheres.

The calorimeter vessel was properly placed in the water jacket which was at room temperature and 2900g of water was added to the calorimeter vessel. This ensured a total submerge of the bomb leaving only the electrical terminals suspended. The temperature of the water was lowered by 2 to 3^{0}C below room temperature and the bomb was carefully put in place with the electrical wire connections made. The oxygen cylinder – bomb connection was carefully checked to ensure no leakage. The thermometer and stirrer were arranged so as not to touch either the bomb or the vessel then stirrer was switched on. When it was noticed that the temperature was rising quite steadily and the stirrer had been running for 2 minutes, a series of readings at one-minute intervals were taken.

At the end of the fifth minute, the firing circuit was closed for two seconds then the bomb was deserted for the next 20 seconds. The one-minute readings were continued until the temperature passed through a maximum value. At the end of the second 5th minute, the bomb was removed, placed on the vice and the pressure in the bomb was released slowly and uniformly over a period of one minute. Adequate care was exercised when doing this (the pressure was released by unscrewing the check valve a short distance and pressing down the bomb). The bomb was opened, observed for combustion, rinsed out, cleaned and dried. The bomb calorimeter apparatus is presented in figure 3.

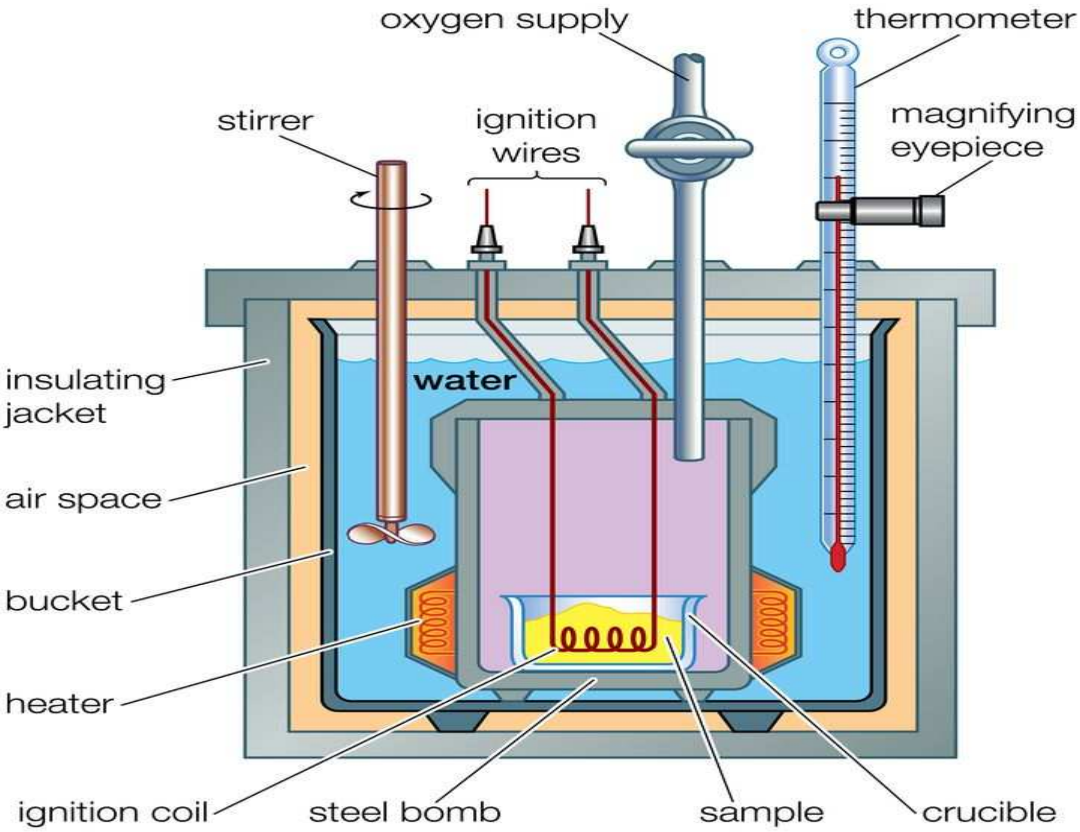

Figure 3: A bomb calorimeter apparatus (Encyclopaedia Britannica/UIG/Getty Images)

Determination of heat energy

Heat energy liberated by the fuel was determined using equation 1 as adopted by Adegoke (1999).

$$Q_f = M_f H \qquad (1)$$

Where;

Q_f = heat energy liberated by fuel (kJ)
M_f = mass of fuel (g)
H = calorific value of fuel (MJ/kg)

Evaluation of Fuel Characteristics for Briquette from different crop Residues

After successful production and determination of calorific values of briquettes, a further evaluation of their fuel characteristics was carried out. Two litres of water was poured into four similar pots provided each of 0.25m diameter and 0.5mm thickness respectively. These pots were placed on similar stoves as obtained from (Ndirika, 2002) having a sample of fuel in them. The initial temperature of water was taken at a value of 28^0C and the time it took each fuel sample to boil water was recorded. The amount of fuel burnt and the quantity of water evaporated were measured. The measurements were then used to estimate fuel efficiencies, cooking efficiencies, boiling times and fuel consumption rates which served as determinants for evaluating the characteristics of the fuel samples. Figures 4 and 5 show the water boiling operation in progress.

Figure 4: Briquettes set up in stoves

Figure 5: Water boiling operation in progress

Determination of Fuel Efficiency

The efficiency of a fuel sample was determined using equation 2 as adopted by Prasad and Verhaart, (1983).

$$\eta_f = \frac{m_{w.i} \times C_{p.w} \times (t_c - t_i) + m_{w.evap} \times H_L}{m_f \times H_f} \quad (2)$$

Where;

η_f= fuel efficiency (%)
$m_{w.i}$= initial amount of water in the pot (Kg)
$C_{p.w}$= specific heat of water (4.2KJ/Kg^{0}C)
t_c= temperature of boiling water (^{0}C)
t_i= initial temperature of water (^{0}C)
$m_{w.evap}$= amount of water evaporated during experiment (Kg)
$H_L = amo$unt of evaporation water at atmospheric temperature and 100^{0}C (2260KJ/Kg)
m_f= amount of fuel burnt (Kg)
H_f= combustion value of fuel used (MJ/Kg)

Determination of Cooking Efficiency

Cooking efficiency was determined using equation 3 as adopted by Danshehu et al, (1996)

$$\eta_c = \frac{M_w h_L}{M_f C_f} \quad (3)$$

Where;
η_c= cooking efficiency (%)
M_w= mass of water evaporated (Kg/hr)
h_L= heat evaporation of water at atmospheric pressure and 100^0C (2260KJ/Kg)
M_f= fuel consumption rate (Kg/hr)
C_f= heat value of fuel (MJ/Kg)

Determination of Boiling Time

The time taken to boil two litres of water was determined using equation 4 as adopted by Danshehu *et al* (1996).

$$T_s = \frac{T}{W_b} \qquad (4)$$

Where;
T_s= boiling time (mins/Kg)
T= total time spent in boiling (mins)
W_b= total weight of boiled water (Kg)

Determination of Fuel Consumption Rate

The rate at which briquettes were burnt was estimated using equation 5 as adopted by Danshehu *et al* (1996).

$$M_f = \frac{W_i - W_f}{t} \qquad (5)$$

Where;
M_f= fuel consumption rate (Kg/hr)
W_i = initial weight of fuel before combustion (Kg)
W_f= final weight of fuel after combustion (Kg)
t= total boiling time (hr)

Statistical Analysis

The statistical tool used in the analysis of this work is the analysis of variance based on the two-way classification method with the F-distribution table at 5% significant level. This tool was used to compare the sample means of fuel efficiency, cooking efficiency, boiling time and fuel consumption rate for briquette samples and firewood in order to determine whether there is any significant difference between the fuel samples.

Results and Discussion

Using equation 1, maize cob briquettes (type A) exhibited a calorific value of 40.924MJ/kg, groundnut shell briquettes (type B) produced a calorific value of 25.757MJ/kg while the composite briquettes (type C) and delonix regia wood had calorific values of 39.656MJ/kg and 24.340MJ/kg respectively. These results are similar to the calorific values of sawdust obtained by (Chinyere et al, 2014) which ranges from 38.30MJ/kg to 47.05MJ/kg and that of groundnut shell as in (Oyelaran et al, 2015) from 19.51MJ/kg to 19.92MJ/kg which shows that calorific value decreases as the quantity of groundnut shells increases. A detailed pictorial representation of this is shown in fig 1.

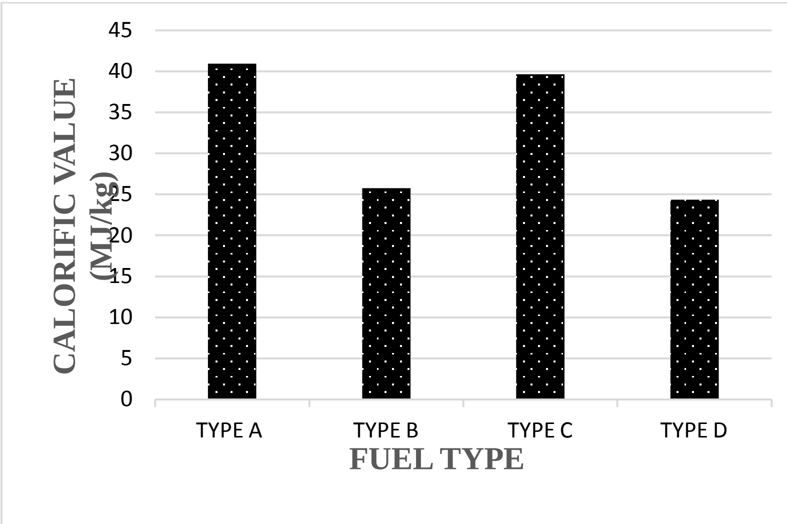

Figure 6. Calorific Value of Briquettes

Details of Production

During the production of briquettes, some critical values were measured and recorded in table 2.

A total of 41 briquettes were produced in the departmental shed at a room temperature of 30^{0}C, it took approximately four hours to produce the briquettes using a manually operated foot press- briquette machine.

Table 2: Measurements taken during production

Measured Parameter	**Briquette Source**		
	Maize Cobs	Groundnut Shells	Composite
Number of briquettes produced	16	12	13
Qty. of water (litres)	7.0	3.5	5.5
Qty. of residue (kg)	2.0	1.2	1.6
Weight of gum Arabic (kg)	0.8	0.25	0.5
Mix ratio (residue:binder:water)	2:0.8:7	1.2:0.25:3.5	1.6:0.5:5.5
Time taken (hrs)	1.5	1	1
Moisture Content (kg/kg)	10	6	4

Room temperature= 30^0C; Wet bulb temperature= 27.5^0C; Total no. of briquettes produced= 41

Cost Analysis of fuel samples

A summary of the cost incurred in the production of briquette samples is shown in table 3.

The average weight of one unit of briquette sample is 0.2kg and costs N43 which by comparison with the cost of firewood or charcoal is cheaper and more durable in the sense that it burns for a longer period and serves its purpose. It is also easier to ignite and smokes less than other fuel sources earlier mentioned.

Table 3: Production cost of briquettes

Fuel Source	**Weight of Fuel (kg)**	**Rate (N/kg)**	**Total Cost (N)**
Maize Cob	3.0	200	600
Groundnut Shell	1.8	200	360
Gum Arabic	2.0	400	800

Total cost of production = N1760
Total number of briquettes = 41
Weight of one briquette sample = 0.16kg - 0.2kg
Average cost of one briquette = N43

Estimation of Briquettes Consumed during Evaluation

Some quantity of water was boiled and the weight of fuel was measured before and after boiling in order to estimate the weight of fuel used. The cost was then estimated from the rate of each fuel sample. The cost of fuel required to boil 2 litres of water has been estimated and it clearly shows that the 1Kg briquette is equivalent to 2.25Kg of firewood which simply implies that more money is required to achieve a heating/cooking process when using firewood as compared with briquette, this is clearly shown in table 4.

Table 4: Cost of fuel required to boil 2 litres of water during test operation

Fuel Used	Weight of fuel (kg)	Rate (N)	Total Cost (N)
Firewood	0.90	300	270
Maize cob briquettes	0.40	450	180
G/nut shell briquettes	0.38	450	170
Composite briquettes	0.40	450	180

Fuel Efficiency

Analysis of variance of briquettes based on the two-way classification method is shown in table 5. The sources of variation were basically difference in fuel efficiencies and fuel samples which were observed to vary along rows and columns respectively. From the table, it can be seen that there is a high significant difference between the briquettes as well as in their efficiencies with calculated F-ratios of 466.43 and 9.22 respectively as against table F-ratios of 4.76 and 5.14 at 5% significance levels. This result can be compared with that of (Chinyere et al, 2014) where fuel efficiency values were significant at 5% significance level with corn starch as a binder of sawdust briquettes.

Table 5: Analysis of variance in fuel efficiency of briquettes

Source of variation	Sum of squares	Degree of freedom	Mean squares	Calculated F-ratio	Table F-ratio
Fuel efficiency	26.17	2	13.09	9.22**	5.14
Briquettes	1987.00	3	662.33	466.43**	4.76
Error	8.50	6	1.42		
Total	2021.67	11			

** Highly significant at 5% significance level

During boiling operation, type B (groundnut shell) and type C (composite briquettes) burnt slowly, were smokeless and boiled water faster than type A and firewood. These efficiency characteristics have been clearly shown in Fig 2, where type B briquette was observed to have the highest mean value of fuel efficiency (62%) while type A and type C had efficiency values of 38% and 41% respectively with that of firewood being as low as 27%.

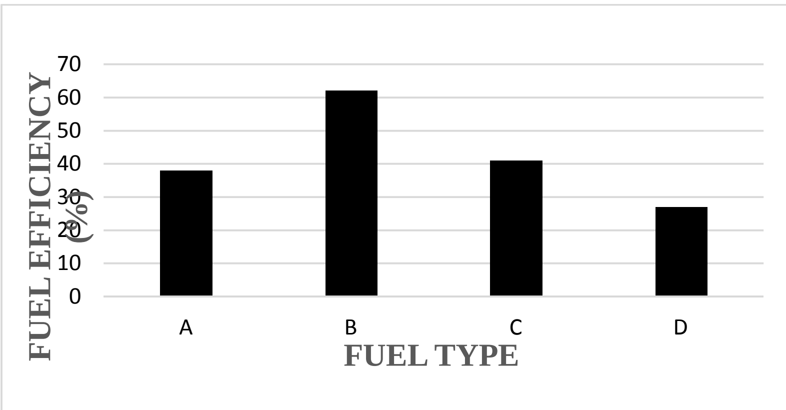

Figure 7. Fuel Efficiencies of Briquettes

Cooking Efficiency

From table 6, at a calculated F-ratio of 160.16 and a table F-ratio of 4.76, a remarkable significant difference was observed between briquettes. On the other hand, there is no significant difference in the cooking efficiencies both at 5% significant levels.

Table 6: Analysis of variance in cooking efficiency of briquettes

Source of variation	Sum of squares	Degree of freedom	Mean squares	Calculated F-ratio	Table F-ratio
Cooking efficiency	6.50	2	3.25	4.67^{NS}	5.14
Briquettes	336.33	3	112.11	160^{**}	4.76
Error	4.17	6	0.69		
Total	347.00	11			

NS: Not Significant at 5% significance level
** Highly significant at 5% significance level

Although there is no significant difference in this result due to the little discrepancy in the recorded values, the average cooking efficiency obtained for groundnut shell briquette (23%) is observed as the highest value, produced less smoke and soot as compared with the other fuel types as shown in figure 3. The smoking of maize cobs and composite briquettes is a beneficial characteristic which can serve as a means of preserving food not meant for immediate use hence type A and type C briquettes are equally recommendable for use. This can be compared with the results obtained from (E.C Mbamala, 2019).

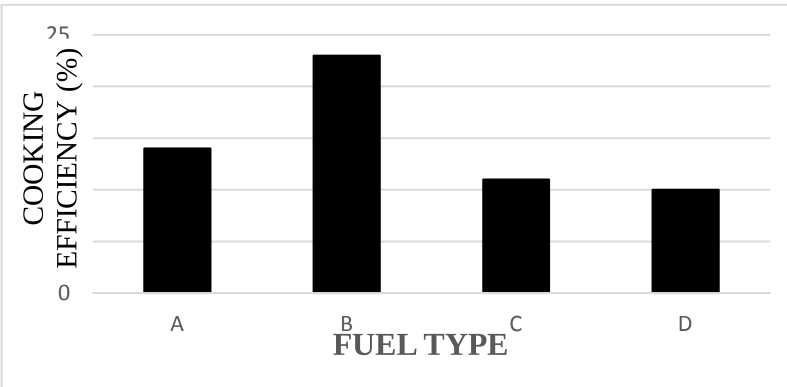

Figure 8. Cooking Efficiencies of Briquettes
Boiling Time

All the briquette samples boiled equal quantities of water in less than 30 minutes with type A briquette being the quickest at 15 minutes. At 5% significance level and a calculated and table F-ratio of 923.96 and 4.76 respectively, an extremely high significant difference can be observed between the briquettes in table 7.

Table 7: Analysis of variance in boiling time of briquettes

Source of variation	Sum of squares	Degree of freedom	Mean squares	Calculated F-ratio	Table F-ratio
Boiling time	16.67	2	8.34	6.84**	5.14
Briquettes	3381.67	3	1127.22	923.96**	4.76
Error	7.33	6	1.22		
Total	3405.67	11			

** Highly significant at 5% significance level

Delonix regia wood (sample D) took a whooping 58 minutes to bring an equal volume of water to boil. The difference between the slowest briquette (type C) which took 24 minutes and firewood is so high and incomparable in speed as shown in fig 4.

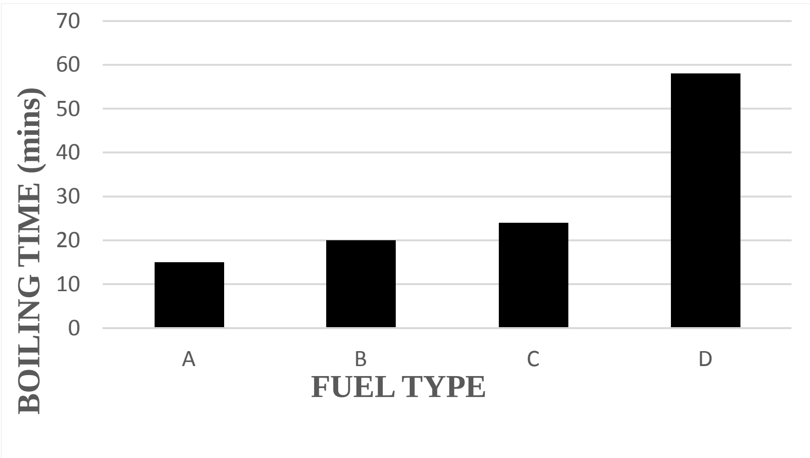

Figure 9. Boiling time of Briquettes

Fuel Consumption Rate

The ratio of the amount of fuel burnt to the time taken to boil water simply defines the rate of fuel consumption. Firewood was observed to burn at the slowest rate which implies that the sample was not used up as fast as the briquettes though it took a longer time to bring water to boil as discussed earlier. Table 8 shows a high significant difference at 5% significant level between the briquettes with a calculated F-ratio and table F-ratio of 57.1 and 4.76 respectively.

Table 8: Analysis of variance in fuel consumption of briquettes

Source of variation	Sum of squares	Degree of freedom	Mean squares	Calculated F-ratio	Table F-ratio
Fuel consumption rate	0.05	2	0.0249	4.50^{NS}	5.14
Briquettes	0.95	3	0.3157	57.1**	4.76
Error	0.03	6	0.0055		
Total	1.03	11			

NS: Not Significant at 5% significance level
** Highly significant at 5% significance level

In fig 5, it is clearly shown how the fuel consumption rate values are within a short range (this is similar to the values obtained by Oyelaran et al, 2015) and can be inferred from the ANOVA table above where there was no significant difference in the rates obtained. The quantity of type A briquette utilized to bring water to boil was the largest but does not differ much from the wood sample and type A also required little time to bring water to boil. Therefore, the briquette samples are more dependable than wood.

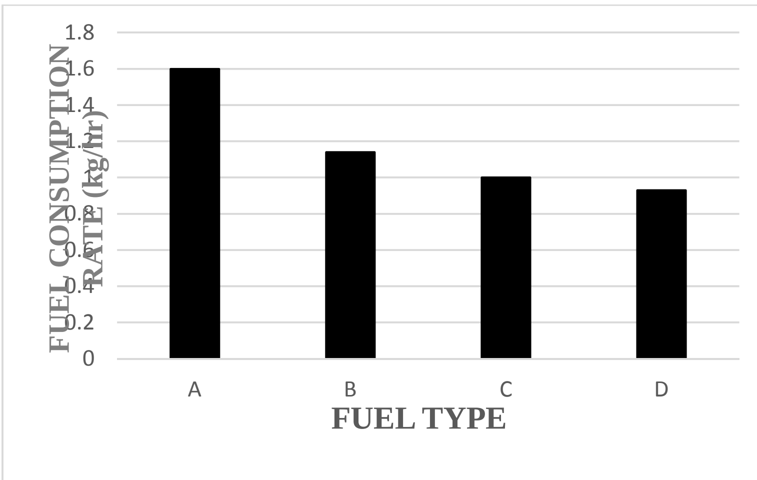

Figure 10. Fuel Consumption of Briquettes

Conclusion

From the research undertaken and the evaluations conducted, it clearly shows how briquettes made from groundnut shells and maize cobs can be recommended as alternative sources of fuel for cooking and heating purposes as compared with firewood globally due to their high calorific values, efficiencies, availability, waste recycling ability, affordability and portability. This places briquettes above other energy sources such as firewood, kerosene, charcoal and cooking gas.

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