Performance Evaluation of the Effect of Binder on Groundnut Shell Briquette

Olatunde Ajani Oyelaran*
Department of Research and Development, Hydraulic Equipment Development Institute, Kano, Nigeria

Bukola Olalekan Bolaji
Department of Mechanical and Mechatronics Engineering, Federal University, Oye-Ekiti, Nigeria

Mufutau Adekojo Waheed
Department of Mechanical Engineering, Federal University of Agriculture, Abeokuta, Nigeria

Michael Femi Adekunle
Department of Forestry, Federal University of Agriculture, Abeokuta, Nigeria

* Corresponding author. E-mail: ajanioyelaran@gmail.com
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Abstract
Densification of biomass is often required to combat the negative handling characteristics of these low bulk density materials. A high-quality densified product is strongly desired, binding agents are usually added to comminuted biomass material to improve the quality of the resulting briquettes. Many materials naturally possess such binding agents; however, they may not be enough or available in a form that can contribute to product binding. The briquettes were prepared from groundnut shell with different cassava starch as binder in varying percentage (5, 10, 15 and 20%) by weight. The prepared briquettes after sun drying for 21 days were subjected to water boiling test for assessing the quality and suitability of briquetted fuel as domestic fuel. The groundnut shell briquettes burnt with good flame and observed 14.47 to 18.46% thermal efficiency while that of wood is 10.31%. The average burning rate of the briquettes ranges between 0.587 and 0.881 kg/hr while that of wood (V) is 1.166 kg/hr. The average specific fuel consumption of the briquettes ranges between 0.067 and 0.267 J/g while that of wood is 0.332 J/g. The boiling time for briquettes is between 14.80 to 23.15 minutes and 13.05 to 19.08 minutes for cold and hot start respectively while for wood are 28.05 and 19.20 minutes for cold and hot starting respectively. Comparatively briquette with 20% binder performs better.

Keywords: *Groundnut shell, Cassava starch gel, Proximate analysis, Water boiling test, Thermal efficiency*

1 Introduction

For most developing countries, biomass chiefly agricultural wastes, has become one of the most promising energy sources. The idea of utilizing the remains from agricultural sectors as primary or secondary energy sources is striking since they are available as free, indigenous and environmentally friendly ones. Furthermore, the decreasing availability of firewood has necessitated the attempts to utilize agricultural wastes efficiently, effectively and sustainably. Some of them, such as coconut shell, wood chip and wood waste, are ready to be use directly as fuel. The majority of them, however, are not

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appropriate for use as fuel without a suitable process since they are they are bulky, uneven and have low energy density. All of these properties make them difficult to handle, transport, store, and utilize in their raw form [1]. Hence, there is the need to subject them to one process of conversion in order to ease these problems. One of the processes through which these residues could be converted to biomass energy is briquetting. Wilaipon [2] described briquetting as a process of compaction of residues into a product of higher density than the original material, while Kaliyan and Morey [1] expressed briquetting as a densification process.

Several kinds of promising fuel-biomass such as soft wood waste [3], maize cob [4], cashew shell waste [5], swine manure [6], coconut oil [7], coconut shell and waste paper admixture [8] and algae [9] were investigated by many researchers. The major parts of agricultural residue in developing countries are use for direct burning. However, direct burning of agricultural residues is extremely inefficient since its thermal efficiency is low. The objective of the present work is to determine the effect of binder on the performance of groundnut shell briquette at different percentage ratio of binder using water boiling test.

2 Materials and Methods

2.1 *Material preparation*

Groundnut shells were collected from the processing sites at Dawanu, Kano - Nigeria. The shells were hammer- milled and sieved. Particles that passed through the 850μm sieves and were retained on the 600μm sieves were used. The groundnut shell was sundried for three days before stocking. Cassava starch was used as the binder in this study. The reason for choosing cassava starch in this research is because of relative availability, ease of preparation and cost.

The groundnut shell and binder were thoroughly mixed in order to obtain a uniformly blended mixture. Mixtures were prepared with four different percentages (5, 10, 15 and 20) of binder with fixed weight of groundnut shell. In each case, fixed quantities of the samples were hand-fed into the briquetting machine and compacted. The dwell time of 5 minutes as in Olorunnisola [8] was used. The machine is a motorized briquetting machine which applied 30MPa of pressure, according to the design of the moulds, twelve (12) briquettes were produced per batch.

2.2 *Proximate analysis*

The moisture content investigations were determined according to ASTM [10] method. The volatile matter contents and ash contents of the samples were determined according to ASTM [11] and ASTM [12] standards, respectively. In addition, the fixed carbon content was computed by difference.

Moisture determination

1g of sample is put in the crucible. The crucible without cover was then placed in an oven with controlled temperature at 107±3°C for 1 hour. Thereafter, the crucible with sample was taken out from the oven and covered. It was allowed to cool down in a desiccator. The weight of sample was determined again when it reached the room temperature, both initial (W_b) and final (W_b) weights were recorded. The moisture content was calculated using equation (1). Three experiments were carried out and the average result calculated.

$$\text{Moisture Content (MC)\%} = \frac{W_a - W_b}{W_a} \qquad (1)$$

Volatile Matter Determination

1 gram sample was measured into known weight VM bottle with lid. The bottle was then transferred into a high temperature carborlite furnace already set at 900°C and heated for 7 minutes. Then, the VM bottle was taken out from the furnace and it was allowed to cool down in the desiccator. The weight of sample was determined again when it reached the room temperature, both initial (W_i) and final (W_f) weights were recorded. The volatile matter content was calculated using equation (2). Three experiments were carried out and the average result calculated.

$$\text{Volatile Matter Percentage (VM)} = \frac{W_i - W_f}{W_i} \qquad (2)$$

Ash Determination

1 gram of groundnut shell sample was measured into

known weighted ash tray with lid. The sample was then transferred into a high temperature carborlite furnace already set at 825°C and heated for 1 hour. Then, the ash tray is taken out from the furnace and it is cooled in the desiccator until it reaches room temperature, both initial (W_i) and final (W_f) weights were recorded. The ash content was calculated using equation (3). Three experiments were carried out and the average result calculated.

$$\text{Ash Content (AC), \%} = \frac{W_f}{W_i} \quad (3)$$

Fixed carbon

The fixed carbon (FC) indicates the heating value of the biomass. This is obtained by subtracting the percentages of moisture, volatile matter and ash from 100. As shown in equation (4).

$$FC = 100 - (MC + VM + AC) \quad (4)$$

2.3 *The water boiling test (WBT)*

The interesting thing about the energy content of a briquette is how much of the energy in the briquette can actually be utilized. If the same test is carried out on each briquette and firewood, a good evaluation can be made. The test is known as the Water Boiling Test and was used for assessing the briquettes with each other. The modified version of the WBT, which was developed for the Shell Household Energy Programme based on the procedures proposed by VITA [13] and Baldwin [14] was used in this work. It consists of three phases.

Phase 1: High Power (Cold start)

Procedure

The timer was prepared, but not started until the fire was started. The amount of water was determined by placing the pot on the scale and adding water until the total weight of pot and water together is 2 kg. The weight of the pot with the water was recorded. A thermometer was placed into the pot to take the initial water temperature and recorded. Pre-measured recorded fuel sample was placed in the stove and fire was started using kerosene as the starting material.

As the fire was started the pot containing the water was placed on the stove. The timer was started and readings of the water temperature were taken at two and half minutes intervals. The fire was controlled by means of bringing the water in the pot rapidly to boil without waste of the fuel used. When the water in the pot reached the boiling temperature as shown by the thermometer, the following were done:

a) The time the water in the pot reached the local boiling point was recorded along with the temperature.
b) All fuel sample were removed from the stove and the flames extinguished by blowing the ends and knocking all loose ash off the ends of the fuel into the container for collecting the ash for weighing.
c) The weight of unburnt fuel, removed from the stove was determined and recorded.
d) The pot with hot water was weighed and the weight recorded.
e) The ash from the stove was extracted and weighed with the ash knocked off the fuel and the weight recorded.

Phase 2: High Power (Hot start)

The second phase of the test, high power (hot start) was continued within 10 minutes after the completion of the first test high power (cold start) on the same stove.

Procedure

The timer was reset, but not started until the fire was started, the pot was refilled with 1.7 kg of fresh cold water which was two-third full of the pot which give a total weight of the pot and water as 2 kg. The weight of the pot with water and water's initial temperature were recorded. The fire was rekindled using kerosene, as the fire was started the pot was placed on the stove with the water. The timer was started and readings of the temperature were taken at every two and half minute intervals. When the boiling temperature was reached, the following were done rapidly:

a) The unburnt fuels were removed from the fire and the loose ash knocked out the unburnt fuels were weighed and recorded

b) The water temperature was taken and recorded.

c) The pot with the water was weighed and recorded.

Phase 3: Low Power (Simmering)

The hot start high power test was continued with the flame reduced and the water simmered for additional 45 minutes at a temperature between 3-4°C below the boiling point. When the 45 minutes was reached, the following were done rapidly:

a) All fuel sample were removed from the stove and the flame extinguished by blowing on the ends and knocking all loose ash off the ends of the fuel into the container for collecting the ash for weighing.

b) The unburnt fuel, removed from the stove was weighed and the weight recorded.

c) The pot with water was weighed and recorded.

d) The ash from the stove was extracted and weighed with the ash knocked off the fuel and the weight recorded.

The following was used for the experiment Wood (V), Groundnut shell with 5% binder (W), Groundnut shell with 10% binder (X), Groundnut shell with 15% binder (Y), Groundnut shell with 20% binder (Z). Equations (8) to (11) were used to calculate mass of fuel that was used to bring the water to boiling point, equivalent dry wood consumed, water vaporized (water loss), Water remaining at the end of water boiling test, time taken for test and Temperature difference respectively.

The same procedure is repeated on the samples of briquettes made with the various groundnut shell and binder varied proportions. Fuel samples of similar size of average dimension 193 mm × 37 mm × 45 mm were used for the test in order to minimize variation due to fuel differences. This size is in accordance to Olle and Olof [15] who states that: the type and size of fuel can affect the outcome of the stove performance tests. In order to minimize the variation that is potentially introduced by variations in fuel characteristics VITA [13] recommends taking the following precautions:

a) Use only wood that has been thoroughly air-dried. Drying is accelerated by ensuring wood is stored in a way that allows air to circulate through it.

b) Different sizes of wood have different burning characteristics. While stove users may not have the ability to optimize fuel size, use only similar sizes of wood to minimize this source of variation throughout the world.

Due to the lack of adequate turn - down ability of the three stones stove to maintain a desired temperature without the fire going out, the minimum amount of fuel sample necessary to keep the fire from dying completely was used. The following was used for the experiment Wood (V), Groundnut shell briquette with 5% binder (W), Groundnut shell briquette with 10% binder (X), Groundnut shell briquette with 15% binder (Y), Groundnut shell briquette with 20% binder (Z).

The fuel sample outputs to be analyzed include:

a) Thermal efficiency (η): This is the ratio of the work done by heating and evaporating water to the energy of the fuel consumed. This is given by [16]

$$\eta = \frac{C_{pw} \times (P_i - P_e) \times (T_f - T_i) + H_L \times (P_i - P_f)}{f_m \times H_f} \quad (5)$$

b) Burning Rate (R_b): This is a measure of the rate of wood consumption while bringing the water to a boil. It is calculated by dividing the equivalent dry wood consumed by the time of the test.

$$R_b = \frac{f_m}{t_f - t_i} \quad (6)$$

c) Specific fuel consumption (F_{sc}): This is a measure of the amount of wood required to produce one gram of boiling water or maintain one gram of boiling water within 3°C of the boiling point.

$$F_{sc} = \frac{f_d}{P_f - P_e} \quad (7)$$

$$f_m = f_i - f_f \quad (8)$$

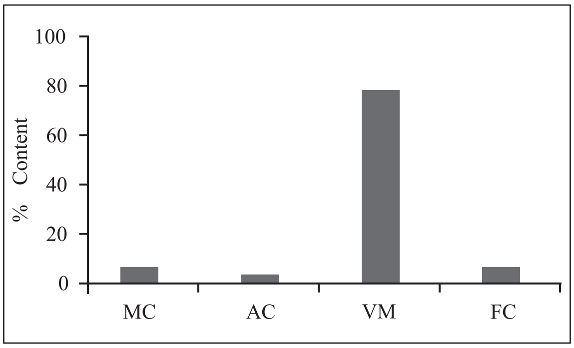

Figure 1: Result of proximate analysis of groundnut shell.

$$f_d = f_i - f_f - \Delta C \quad (9)$$

$$W_v = P_i - P_e \quad (10)$$

$$W_r = P_f - P_e \quad (11)$$

$$\Delta\theta = t_f - t_i \quad (12)$$

$$\Delta T = T_f - T_i \quad (13)$$

3 Results and Discussion

3.1 *Proximate analysis*

As observed from Figure 1 the moisture content (MC), volatile matter (VM), ash content (AC) and fixed carbon (FC) of the grinded groundnut shell are 11.51, 77.93, 3.60 and 6.96% respectively. The moisture content of the groundnut shell is within the limits of 15% recommended by Grover and Mishra [17] and Kaliyan and Morey [1] for agro-residues. The average moisture content of the briquettes was 9.13%. The moisture content of the briquettes obtained in this study are also satisfactory as they are within the limits recommended by Yang et al. [18], which stated that the difference between the moisture content of agro-residues and their briquettes ideally should be in the region of about 2%.

3.2 *Average thermal efficiency for fuel samples*

The average thermal efficiencies (Figure 2) of the various fuel samples were estimated using equation 1 with data obtained from the WBT in Tables 1 to 7 for high

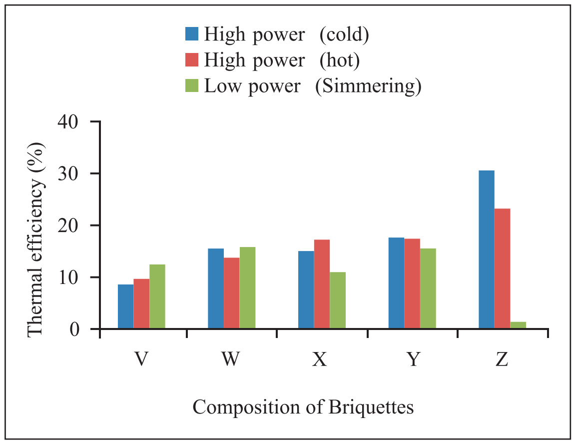

Figure 2: Comparative results of thermal efficiency of briquettes.

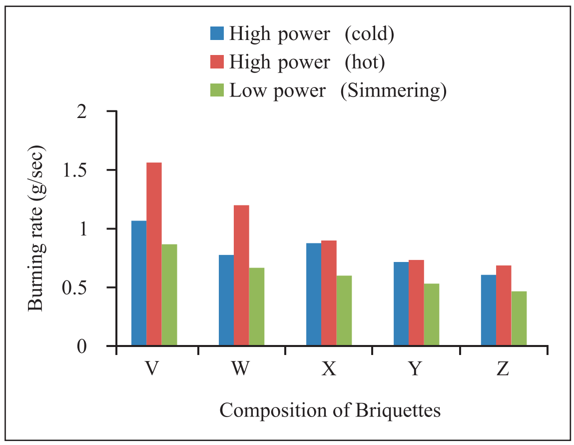

Figure 3: Comparative results of burning rate of briquettes.

power (cold start), high power (hot start) and low power (simmering). Comparison of the average thermal efficiencies of each of the briquettes and wood as in Figure 1 show that briquette Z with 20% binder has the highest value of 18.46%, briquette Y with 15% binder is 16.93%, briquette X with 10% binder is 14.47% and briquette W with 5% binder is 15.08% and firewood V, 10.31%.

3.3 *Average burning rate of fuel samples*

The average burning rates (Figure 3) of the various fuel samples were estimated using equation 2 with data obtained from the WBT in Table 1 to 7. The average

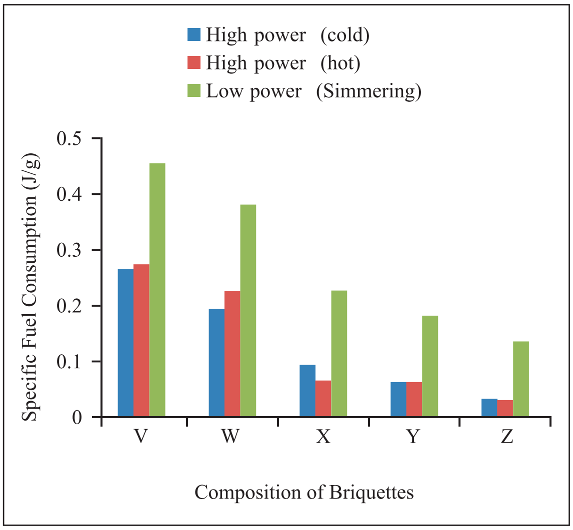

Figure 4: Comparative results of specific fuel consumption of briquettes.

burning rates values for all five fuel samples at high power (cold start), high power (hot start) and low power (simmering). The burning of the briquettes was steady and it produced red hot charcoal. Comparison of the performance between the average burning rates of the briquettes shows that briquette Z with 20% binder is 0.587 kg/hr with the lowest burning rate, briquette Y with 15% binder is 0.661 kg/hr, briquette X with 10% is 0.792 kg/hr, briquette W with 5% binder is 0.881 kg/hr while fire wood (V) is 1.166 kg/hr. From the results obtained it can be seen that burning rate decreases with increase in binder.

3.4 *Average specific consumption for fuel samples*

The average specific fuel consumption (Figure 4) of the various fuel samples were estimated using equation 3 with data obtained from the WBT in Table 1 to 7. The average specific fuel consumption values for all five fuel samples at high power (cold start), high power (hot start) and low power (simmering). Comparison of the performance between the average specific fuel consumption of the briquettes showed that briquette (Z) with 20% binder is 0.067 J/g with the lowest specific fuel consumption, briquette (Y) with 15% binder is 0.103 J/g, briquette (X) with 10% binder is 0.128 J/g, briquette (W) with 5% binder is 0.267 J/g and fire wood (V) is 0.332 J/g.

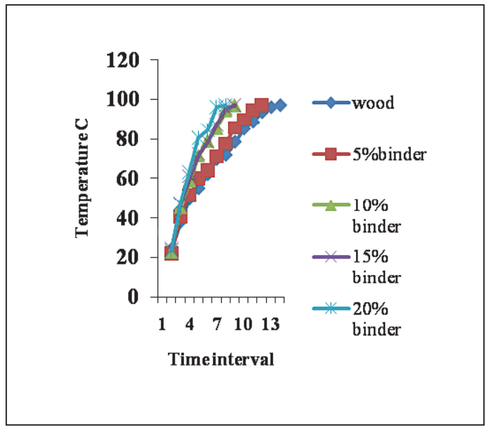

Figure 5: Comparative results of water boiling test (Cold start) for fuel samples.

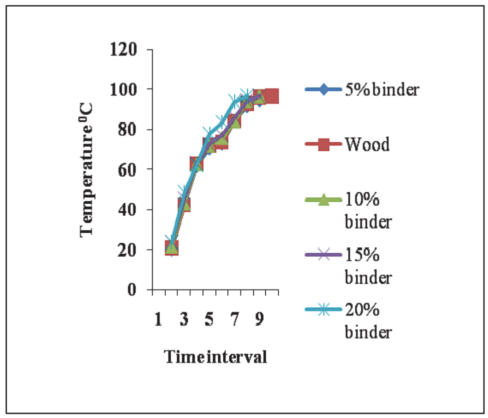

Figure 6: Comparative results of water boiling test (Hot start) for fuel samples.

Boiling time

Readings of the values for the water boiling test in Table 1 and 2 for the various fuel samples were used to plot a graph of temperature against time as shown in Figure 5 and 6. Repeating the test with a hot stove Figure 6 helps to identify differences in performance of the briquettes when the stove is hot or cold. From the plotted graphs it was observed that the briquettes with 20% binder (Z) has the fastest rate of boiling water in both cases, followed by that with 15% binder (Y). The time in which the local boiling temperatures were attained during the Water Boiling Test for each of the fuel samples along with their simmering durations are shown in Table 8.

Table 1: Experimental results of water boiling test (Cold start) for fuel samples

Time (min)	V Temp °C	W Temp °C	X Temp °C	Y Temp °C	X Temp °C
0	24.0	22.0	23.0	24.0	23.5
2.5	38.0	40.5	45.5	47.0	47.5
5.0	49.5	51.5	59.0	61.0	63.0
7.5	55.0	60.0	71.5	72.5	80.5
10.0	62.0	64.0	79.0	78.5	84.5
12.5	69.5	71.0	85.5	87.0	96.0
15.0	72.0	77.5	94.5	95.5	97.0
17.5	78.5	85.5	97.0	97.0	
20.0	85.0	89.5			
22.5	88.5	94.5			
25.0	93.5	97.0			
27.5	96.0				
30.0	97				

Table 2: Experimental results of water boiling test (Hot start) for fuel samples

Time (min)	W Temp °C	A Temp °C	B Temp °C	C Temp °C	D Temp °C
0	20.5	21.0	22.0	24.0	24.0
2.5	42.5	42.5	43.5	46.0	49.0
5.0	62.0	63.0	63.0	63.5	62.5
7.5	71.0	72.5	72.5	73.0	78.0
10.0	73.5	74.0	76.0	77.5	84.0
12.5	84.5	84.5	84.5	86.5	94.0
15.0	92.0	93.0	94.5	94.5	97
17.5	95.0	96.5	97.0	97	
20.0	97.0	97.0			

Table 3: Water boiling test values for firewood (V)

	Cold Start	Hot Start	Simmering
f_i	0.70	0.80	0.70
f_f	0.20	0.30	0.055
P_i	2.00	2.00	2.00
P_f	1.90	1.85	1.40
f_m	0.50	0.50	0.65
Δ°C	0.075	0.075	0.150
f_d	0.425	0.425	0.500
T_i	21,5°C	22.00°C	97°C
T_f	97°C	97°C	94°C
ΔT	75.5°C	74°C	-3°C

Table 4: Water boiling test values for briquette with 5% binder (W)

	Cold Start	Hot Start	Simmering
f_i	0.60	0.60	0.70
f_f	0.30	0.25	0.20
P_i	2.00	2.00	2.00
P_f	1.85	1.85	1.35
f_m	0.30	0.35	0.50
Δ°C	0.05	0.05	0.10
f_d	0.30	0.35	0.40
T_i	22	21	97
T_f	97	97	94
ΔT	75	76	-3

Table 5: Water boiling test values for briquette with 10% binder (X)

	Cold Start	Hot Start	Simmering
f_i	0.65	0.65	0.65
f_f	0.40	0.45	0.20
P_i	2.00	2.00	1.85
P_f	1.90	1.85	1.40
f_m	0.25	0.25	0.45
Δ°C	0.10	0.10	0.20
f_d	0.15	0.10	0.25
T_i	23	23	97
T_f	97	97	94
ΔT	74	74	-3

Table 6: Water boiling test values for briquette with 15% binder (Y)

	Cold Start	Hot Start	Simmering
f_i	0.65	0.65	0.65
f_f	0.40	0.45	0.20
P_i	2.00	2.00	1.85
P_f	1.90	1.85	1.40
f_m	0.25	0.25	0.45
Δ°C	0.10	0.10	0.20
f_d	0.15	0.10	0.25
T_i	23	23	97
T_f	97	97	94
ΔT	74	74	-3

Table 7: Water boiling test values for briquette with 20% binder (Z)

	Cold Start	Hot Start	Simmering
f_i	0.70	0.70	0.70
f_f	0.55	0.55	0.35
P_i	2.00	2.00	1.90
P_f	1.80	1.90	1.40
f_m	0.15	0.15	0.35
Δ°C	0.10	0.10	0.20
f_d	0.15	0.20	23
T_i	22	23	97
T_f	97	97	94
ΔT	75	74	-3

Table 8: Result of average fuel samples boiling point time and simmering duration

Sample	Boiling time cold start (minutes)	Boiling time hot start (minutes)	Boiling time simmering start (minutes)
V	28.05	19.20	45
W	23.15	19.08	45
X	17.10	16.70	45
Y	16.75	16.35	45
Z	14.80	13.05	45

4 Conclusions

Cassava starch gel as binder in groundnut shell briquettes has enhanced the burning rates, specific fuel consumption and thermal efficiencies of the briquettes as evident in this research work. The observed increased in briquette properties with increase in starch content could be attributed to the adhesive role the starch played in the briquettes [8,19].

The burning rate, specific fuel consumption and thermal efficiency of the briquette range from 0.587 to 0.881 kg/hr, 0.067 to 0.267 J/g and 14.47 to 18.46% respectively. While burning rate, specific fuel consumption and thermal efficiencies of wood used in the test are 1.166 kg/hr, 0.332 J/g and 10.31% respectively. The overall performances show that 20% binder have the most outstanding result. It was found that the amount of binder used have significant influence on the properties of the briquettes. So the groundnut shell briquettes will provide better alternatives to fossil fuel for firing heating and melting devices in the areas where groundnut is grown. The increasingly use of these wastes in composite briquette form, will help in solving disposal problem apart from providing good alternatives to fossil fuel.

Nomenclature

P_e = Dry mass of pot (g)
P_i = Initial mass of pot and cold water (g)
P_f = Final mass of pot and hot water (g)
W_r = Water remaining at the end of water boiling test (g)
W_v = Water vaporized
f_m = Mass of fuel (kg)
T_i = Initial temperature of water (°C)
T_f = Final temperature of water (°C)
f_i = Initial mass of fuel (g)
f_f = Final mass of fuel (g)
f_m = Mass of fuel that was used to bring the water to boil (g)
f_d = Equivalent dry wood consumed (g)
C_w = Specific heat capacity for water (J/g°C)
ΔT = Temperature difference in water boiling test (°C)

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