DENSIFICATION CHARACTERISTICS OF SOME NON-TIMBER FOREST TREE RESIDUES FOR FUEL

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ABSTRACT

A study was undertaken to determine the densification characteristics of three non-timber forest tree residues, namely Bush Mango (Irvingia), Achi (Brachystegia eurycoma) and Para Rubber (Hevea brasiliensis) shells for fuel. The shells were reduced with a hammer mill to 1.00 mm, 2.00 mm and 4.75 mm particle size and densified by mixing with starch with a densification apparatus at optimum temperature and pressure of 100°C and 200 MPa, respectively. Mechanical properties of the densified samples determined were shatter resistance and durability index. Higher heating value (HHV) of Rubber, B. eurycoma and Irvingia shells were 15.97, 13.0 and 13.10 MJ/kg, respectively. Bulk density of the samples were arranged in the descending order of B. eurycoma (587 kg/m³), Rubber (520 kg/m³) and Irvingia (517 kg/m³). The densified rubber shell had the most favourable energy properties as fuel due to its high calorific values and volatile matter content. It also had the least fixed carbon and ash contents. There was no significant difference in the calorific value and volatile matter contents of the Irvingia and B. eurycoma shells. The densified rubber shell had the highest shatter resistance at various temperatures and pressures investigated. The densified rubber shell is recommended for use as fuel due to its high calorific and durability values.

Keywords: *Biomass, densification, calorific value, residues and densification properties.*

1. INTRODUCTION

Biomass densification is the bonding together of biomass product, by pressure and heat of densifying machine utilizing the natural resins in biomass product or by application of a binder (Grover and Mishra, 1996). Densified biomass formed under high pressure and temperature, with a bulk density of 5–7 times that of loose material can significantly decrease transportation and storage costs and have a positive impact on the combustion characteristics (Brandt, 1989).

Annually, large quantities of biomass residues are produced as a result of forestry activities, timber production, food production and agro-industrial processes. Severe economic constraints for utilization of these residues include low bulk densities resulting in high storage and handling costs. Combustion characteristics of the bulk material are a further constraint in many cases (Brandt, 1989).

Some of these biomass residues include: *Irvingia spp, Brachystegia eurycoma* and *Hevea brasiliensis* shells which are left after extracting the useful parts. *Irvingia gabonensis* and *Irvingia wombolu,* the bush mango is the source of "*Ogbono"* the *Irvingia* kernel which is popularly used as soup thickener in most West and Central African countries. The popularity of the kernels in local and international markets has highlighted its potentials as a true commercial crop, and this has resulted in more intensive collection of *Irvingia* fruits from the forests (Ladipo, 2000). *Brachystegia eurycoma* belongs to the family of *Caesalpiniaceae,* phylum spermatophyte and order *fabaceae*. It is a dicotyledonous plant, classified as legume and grows commonly along river banks. It flowers between April and May and fruit between September and January of each year, the fruits are very conspicuous and persistently woody. The seed flour of *Brachystegia eurycoma* have gelation properties and imports a gummy texture when used in soup, which is a desirable attribute necessary for the eating of *gari*, pounded yam etc (Uhegbu *et al*., 2009). *Hevea brasiliensis*, a member of the *Euphorbiaceae* family, is the major commercial source of natural rubber (NR). NR is a latex polymer with high elasticity, flexibility, and resilience that has played a critical role in the world economy since 1876 (Rahman *et al*., 2013). Rubber is an indispensable commodity used in the manufacture of over 50,000 products world-wide (Probhakarn, 2010). Approximately 2,500 plant species synthesize rubber (Mootbroek and Cornish, 2000), but *Hevea brasiliensis* also known as para rubber tree, is the primary commercial source for natural rubber (NR) production.

Densification of these residues would enable the following advantages: (i) it helps to reduce -deforestation by providing a substitute for fuel wood, (ii) it increases the net calorific value per unit volume, (iii) the denser product is easy to transport and store, (iv) the process helps in solving the problem of residue disposal, (v) the fuel produced is uniform in size and quality and cleaner

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burning and (vi) reduced smoke improves the health risks of women/kitchen workers. Hindrances to biomass densification include: (i) briquettes tend to disintegrate rapidly, making it impossible to transport or use them in a humid atmosphere, (ii) it is not cheaper than firewood for cooking in developing countries and fear of failed ventures (Bhattacharya, 2003) and (iii) high cost associated with some of the densification processes (Clarke and Preto, 2015).

Some works have been previously done on biomass densification which include: rice husk based charcoal briquettes (Jindaporn and Songchai, 2007); briquetting of two species of corncob from white and yellow maize and mixed with cassava starch gel which acts as a binding agent (Oladeji, 2011); briquetting of cashew shell, rice husk and grass without any binding material (Sengar *et al*., 2012); densification of rice husk (Ahiduzzaman, 2007) and utilization of corncob, melon shell and cassava peel for briquetting and the heating value calculated for briquettes from corncob, melon shell and cassava peel were 20890 kJ/kg, 21887 kJ/kg and 12765 kJ/kg, respectively. Hence, findings showed that briquettes produced from corncob and melon shell have more positive attributes of biomass fuel than cassava peel briquette (Oladeji and Lucas, 2010). Consequently, the densification characteristics of some biomass as reported by Thoreson *et al.* (2012) include the durability rating of corn briquettes which was found to be 46% while Adetogun *et al.* (2014) published that maize cob of different particle sizes have density values ranging between 150 kg/m^3 and 270 kg/m^3; volatile matter values ranging between 5782% and 62.91%; fixed carbon values ranging between 5.75% and 8.28%; ash content values ranging between 1.06% and 1.23% and heating value ranging between 20.93 MJ/kg and 24.97 MJ/kg. RETSASIA (2005) reported that the heating values of palm kernel cake (PKC) and sawdust are 19.53 MJ/kg and 18.94 MJ/kg, respectively while FAO (2003) noted the ash content values of PKC and sawdust to be 2.35% and 1.63%, respectively.

These three biomass residues (*Hevea brasiliensis*, *Irvingia spp* and *Brachystegia eurycoma* shells) are however bulky and transportating them will bring about the increase in transportation cost. However, as the world population is increasing day by day, agricultural activities increase to meet the need of man. Agricultural residues are increasingly produced from food and feed crop of which some are threats to human health while large resources are also channeled for disposal. The objective of this work is to study the densification characteristics of *Hevea brasiliensis*, *Irvingia spp* and *Brachystegia eurycoma* shells for use as fuel.

2. MATERIALS AND METHODS

2.1 *The Samples*

The shell residues of the three non-timber forest trees *(Brachystegia eurycoma, Irvingia gabonensis* and *Hevea brasiliensis)* were sourced locally from Umudike environment. *B. eurycoma shells* and *Irvingia* shells labelled as A and C in Fig. 1, respectively, were both sourced from Ahaba Imenyi Isuikwuato, Abia State, Nigeria. Rubber shells labelled as B in Fig. 1 were sourced from Michael Okpara University of Agriculture Umudike rubber plantation.

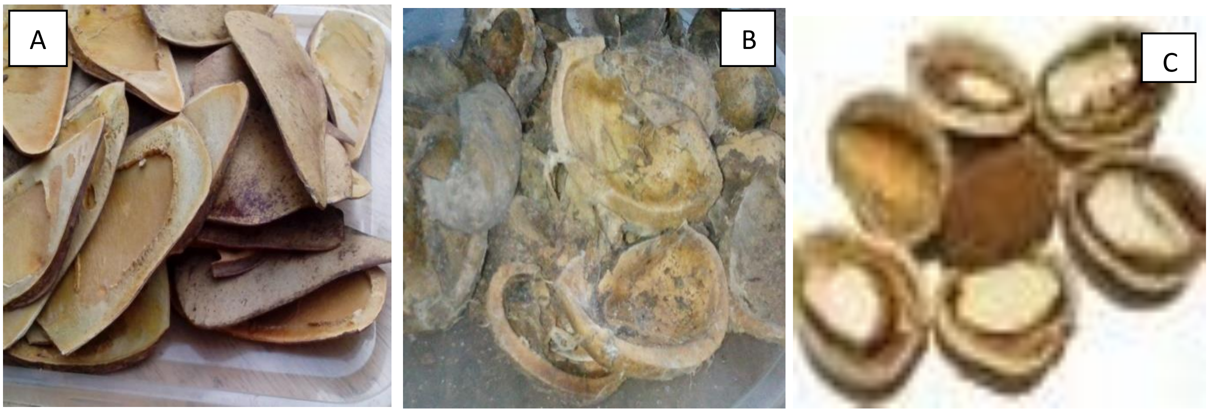


Figure 1. Pictures of B. eurycoma shells (A), rubber shells (B) and irvingia shells (C).

Ground samples of *B. eurycoma, Irvingia* and rubber shells in the proportion of 0.70 kg, 0.30 kg and 0.50 kg, respectively, were taken and poured on the topmost sieve of 4.75 mm; the sieve with biggest mesh size and then covered. It was fitted to the shaker and allowed to shake for five minutes after which the various samples on the different sieve sizes were collected for particle size analysis.

2.2 *Densification of Samples*

Twenty grammes of the three biomass ground samples using hammer mill were mixed with a cassava starch as binder of viscosity 8740 MPa.s at 20 g of the samples and

10 ml of the binder. The heating band was switched on and the thermostat was set at 100°C before the samples were poured into the densification apparatus.

The densification was done at 200 MPa after which the densified samples were collected from the chamber at the base of the apparatus used in Kaliyan and Morey (2009a) shown in figure 2A while figure 2B shows examples of densified samples.

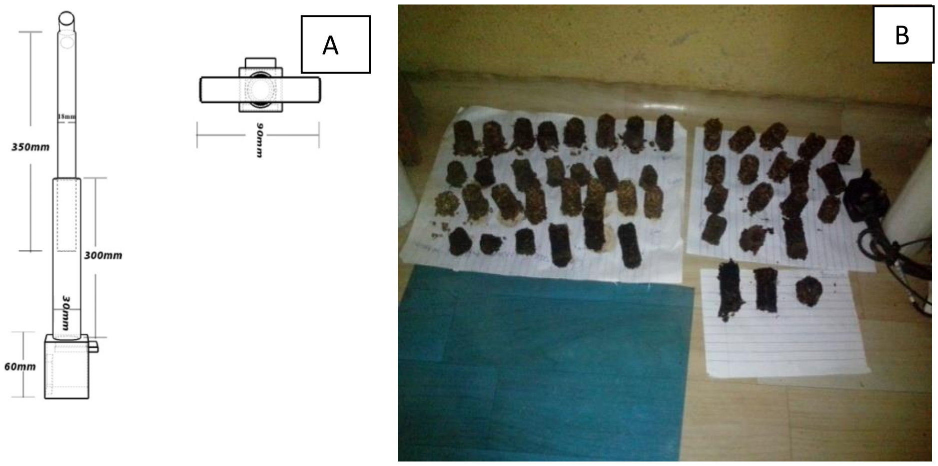


Figure 2. Densification apparatus (A) and densified samples (B)

2.3 Analysis of the Densified Biomass

Twenty grammes of the ground residual samples were mixed with a binder (cassava starch) and put in a container. Using a press at different varying pressures, the samples were densified separately. The densified biomass samples were used to determine the various properties: density, hardness, durability and calorific value.

2.4 Hardness of densified biomass samples

The shatter resistance of densified samples was determined by weighing initially (w_1) and then raised individually to a height of 1 metre each and allowed to drop on the concrete floor as used by Sengar *et al.* (2012). The samples were weighed after dropping (w_2) to determine the weight loss as:

$$WL\% = \frac{w_1 - w_2}{w_1} \times \frac{100}{1} \quad (1)$$

Therefore, percentage shatter resistance is:

$$\%SR = 100 - \%WL \quad (2)$$

where,

WL = Weight loss (%)

SR = Shatter resistance (%)

w_1 = initial weight of sample (g)

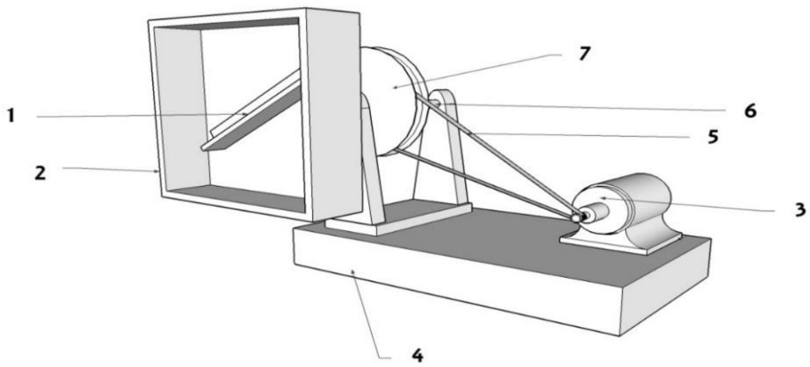
W_2 = final weight of sample (g)

2.5 Durability of densified biomass samples

This was done using tumbling test. The weights of the samples were taken before tumbling (w_1) and after tumbling (w_2). The cuboids, formed by angle iron frame having dimensions of 30 cm x 30 cm x 45 cm and fixed over hollow shaft diagonally was used to conduct the tumbling test. The samples were respectively put inside the cuboids and rotated for 15 minutes. The durability tester used is for pellets and crumbles as used in ASABE (2011). After 15 minutes of tumbling action, the samples were taken out, weighed, and percent loss was calculated by using the formula provided for shatter resistance in hardness test as given in Equ. (2). While durability was calculated as:

$$DI = 100 - \%WL \quad (3)$$

Though Equ. (2) and (3) may look alike, the processes are different.



Legend

1-Beater

2-Box

3-Electric motor

4-Base

5-Belt

6-Shaft

7-Driven pulley

Figure 3. Durability tester

2.6 Calorific value of densified biomass samples

Heating values of the densified samples were determined at the National Centre for Energy Research Development, University of Nigeria Nsukka, Enugu State using XRY-1A bomb calorimeter. The samples were prepared in hot air at an oven temperature of 80 - 100°C for 24 hours in a grit manner. Less than 1 gramme of sample was filled into a cup and 10 cm of the nichrome wire (ignition wire) was measured and also about 10 ml of distilled water into the bomb calorimeter. After all these, the lid of the bomb was securely covered and the calorific value of the samples were determined after burning. This was done by replicating each of the three samples used three times.

After pressing, the pellets were reweighed and placed in the bomb calorimeter following the guidelines of the manufacturer. Energy content of *B. eurycoma*, *irvingia* and rubber shells were determined in triplicates. However, the energy released from the condensation of the liquid after heating is termed the higher heating value.

The lower heating values (LHV) were determined by subtracting the heat of condensation of the water from the higher heating values (HHV) of the samples.

In this study, the correlation that exist between the HHV and LHV according to Sokhansanj (2011) is:

$$LHV = HHV(1-M) - 2.447M \quad (4)$$

where,

LHV = lower heating value (MJ/kg)

HHV = higher heating value (MJ/kg)

M = mass fraction of percentage moisture content

2.447 = constant, latent heat of vapourization of water in MJ/kg.

The analysis for all the results obtained were carried out with Microsoft Excel (Microsoft Office XP Professional, 2007) and Genstat using DNMRT and F-LSD.

3. RESULTS AND DISCUSSION

3.1 Particle Size of the Ground Samples

The samples that passed through the 4.75 mm sieve and retained on the 2.00 mm sieve are the 4.75 mm size and those retained on 1.00 mm sieve are 2.00 mm while those collected in the pan below are the 1.00 mm size which were used. Figure 4 shows the percentage distribution of the particle sizes among the samples and which depends on the hammer mill used. However, wheat straw, barley straw, corn stover and switchgrass were each densified at 0.8 mm, 1.6 mm and 3.2 mm differently (Mani *et al,* 2006). Cassava root was densified at 1 mm, 4 mm and 10 mm (Warajanont and Soponpongpipat, 2013), and Arzola *et al.* (2012) published that palm kernel shell was densified at 1.6 mm, 3.65 mm and 5.7 mm respectively and Adetogun *et al.* (2014) densified maize cob at 2.36 mm, 4.75 mm and 6.30 mm partcle sizes respectively. This shows that the particle sizes used are within the range.

3.2 The Density of the Densified Samples

The *Irvingia* shells have densities of 121.7 kg/m^3 and 517 kg/m^3 for ground and densified samples, respectively. *B. eurycoma* shells have densities of 431.3 kg/m^3 and 587 kg/m^3 for ground and densified samples, respectively while that of rubber shells are 247.33 kg/m^3 and 520 kg/m^3 for ground and densified samples, respectively. *Irvingia* shells recorded the lowest densities before compaction and also the most affected by compaction in terms of increase in density which may be as a result of the fibrous nature of the biomass sample while *B. eurycoma* shells recorded the highest densities before compaction and the least affected by compaction in terms of increase in density as the densities of the three samples after compaction were seen not to be significantly different as shown in Table 1. This invariably shows that the densities of the densified samples are dependent on the biomass samples and the densification apparatus/system used.

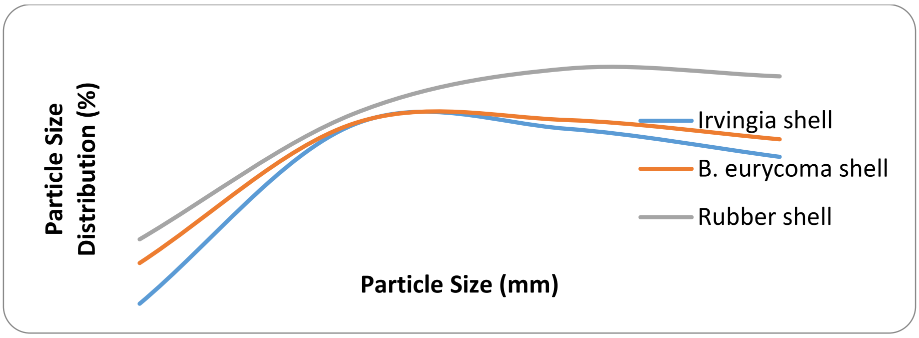


Figure 4. Percentage particle size distribution of the samples

The densities of the samples are below that of rice husk according to Ahiduzzaman (2007) which was densified from 117.0 kg/m³ to 825 kg/m³ using the screw extrusion process. High density briquettes tend to have longer burning time and release more heat (Huang, 2014). That means that the higher the bulk density, the higher the burning time and the heat content.

Table 1. Summary of energy properties of densified samples

Property	*Irvingia* Shell	*B. eurycoma* Shell	Rubber Shell	Mean	$LSD_{0.05}$
Density (kg/m³)	517ᵃ	587ᵃ	520ᵃ	541	Ns
Volatile matter (%)	69.13ᵃ	50.33ᵇ	75.03ᶜ	64.83	2.463***
Ash Content (%)	5.10ᵃ	13.57ᵇ	4.80ᵃ	7.82	1.911***
Fixed Carbon (%)	12.37ᵃ	22.03ᵇ	7.17ᶜ	13.86	3.542***
HHV (MJ/kg)	13.10ᵃ	13.00ᵇ	15.97ᶜ	14.02	0.067***
LHV (MJ/kg)	11.00ᵃ	10.87ᵇ	13.60ᶜ	11.82	0.067***

Note: Means that have the same alphabet on a row are statistically the same while means with different alphabets are significantly different at 5% level of probability.

ns = not significant

*** = significant at 0.1% or P<0.001.

3.3 Hardness and Durability Index of Densified Biomass Samples

At 50°C and 200 MPa, it was discovered that the densified samples were of low quality as more pressure is required to eject the samples due to adhesive force on the instrument and they tend to break up since the binder was not properly activated by heat, hence, the shatter resistance of the samples are: *Irvingia* shell (87.73%), *B. eurycoma* shell (81.67%) and rubber shell (97.00%), respectively and are highly significant as shown in Table 2. The shatter resistance of the samples when densified at 100°C and 200 MPa; 100°C and 100 MPa were not significantly different.

However, the durability index of the three biomass samples at 50°C and 200 MPa are: *Irvingia* shell; 79.33%, *B. eurycoma* shell; 84.27% and rubber shell; 87.43% respectively are significantly different as compared to the durability index of the samples when densified at 100°C and 200 MPa; 100°C and 100 MPa which have no significant difference as shown in Table 2. Hence, the reason to densify at 100°C and 200 MPa.

The three samples have very high shatter resistance. These samples were seen to be very durable in comparison with corn stover briquettes with durability rating of 46% as published by Thoreson *et al.* (2012). According to Kaliyan and Morey (2009b), 150 MPa was the pressure used to densify corn stover and switch grass. This shows that these samples under study require higher pressure to be densified.

Table 2. Mechanical properties of the densified biomass samples

Temperature & Pressure	Properties	*Irvingia* Shell	*B. eurycoma* Shell	Rubber Shell	Mean	$LSD_{0.05}$
100^{o}C & 200 MPa	Shatter Resistance	99.20^{a}	99.03^{a}	99.20^{a}	99.14	Ns
	Durability index	99.07^{a}	99.50^{a}	97.00^{a}	98.52	Ns
50^{o}C & 200 MPa	Shatter Resistance	87.73^{a}	81.67^{b}	97.00^{c}	88.80	3.152**
	Durability index	79.33^{a}	84.27^{b}	87.43^{c}	83.68	2.263**
100^{o}C & 100 MPa	Shatter Resistance	82.10^{a}	79.40^{a}	82.60^{a}	81.37	Ns
	Durability index	70.30^{a}	72.93^{a}	66.93^{a}	70.06	Ns

Note: Means that have the same alphabet on a row are statistically the same while means with different alphabets are significantly different at 5% level of probability.

ns = not significant;

** = significant at P<0.01.

3.4 Calorific Values of Densified Samples

3.4.1 Higher heating value (HHV) of samples

The higher heat value of the three biomass samples is 13.10 MJ/kg for *Irvingia* shell, 13.00 MJ/kg for *B. eurycoma* shell and 15.97 MJ/kg for rubber shell as shown in Table 1. The rubber shell has the highest heat value when densified as *Irvingia* shell and *B. eurycoma* are almost of the same higher heat value. In comparison with other biomass samples, Ebeling and Jenkins (1985) published that the HHV of the following samples are: walnut shell (20.18 MJ/kg), peanut hull (18.64 MJ/kg) and rice hull (16.14 MJ/kg) while Jaafar and Ahmad (2011) published the HHV of raw palm kernel shell as 18.81 MJ/kg and Uemura *et al* (2010) for raw palm kernel shell as 19.78 MJ/kg. This shows that the HHV of the samples are lower than these biomass samples in comparison but *Irvingia* shell before densification which is in the same range with them. The higher the HHV the easier and better the samples will be burned.

3.4.2 Lower heating value (LHV) of samples

The lower heat value of the biomass samples is: *Irvingia* shell; 11.00 MJ/kg, *B. eurycoma* shell; 10.87 MJ/kg and rubber shell; 13.60 MJ/kg respectively. Compared to the LHV content of some biomass samples according to Ebeling and Jenkins (1985), walnut shell (19.02 MJ/kg), peanut hull (17.53 MJ/kg) and rice hull (15.27 MJ/kg), the samples under study have lower LHV content but *Irvingia* shell before densification. The higher the LHV, the higher the combustion energy and LHV is dependent on moisture content: as higher the moisture content of the sample, the lower the LHV because as heat liberated during the chemical reactions is absorbed by the evaporation process.

CONCLUSION

The energy properties of the densified samples were significantly different at 5% level of significance but the ash content of the densified *irvingia* shell, the HHV and LHV of densified rubber shells which were not significant at 5% level. Results obtained showed that rubber had the highest volatile matter content and calorific values while B. eurycoma recorded the highest density value. Rubber recorded the lowest ash and fixed carbon contents. The densified residue with the most favourable energy properties is the rubber shell followed by *irvingia* shells and then *B. eurycoma* shells. It was seen that lower ash content is inversely proportional to the calorific value.

The particle size for densification should not be too fine to prevent clogging during densification and not to be too coarse to avoid disintegration which shows that 2.00 mm particle size is ideal for densification among these particle sizes. *Irvingia* shells have almost proportionate distribution of the particle sizes and this shows that of equal mass of the samples, *irvingia* shells will have higher quantity of durable densified samples. The optimum temperature and pressure for densification was found to be 100^{o}C and 200 MPa, respectively.

It is recommended that the samples be densified at 100^{o}C temperature and pressure of 200 MPa of which rubber shell is the sample with the most favourable energy properties.

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