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Handling and Thermal Characteristics of Briquettes made from Fonio Husk

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ABSTRACT

This study attempted to convert fonio husk, an agricultural waste into a fuel for cooking in households, making its disposal sustainable. Samples of fonio husk and wild acacia nilotica fruits were acquired from dehusking mills in Tafawa Balewa and Muda Lawan market respectively. The fonio husk and gum extracted from the dry acacia fruit were characterized using standard procedures such as ASTM E870 – 82(2013) for proximate analysis, BS 1377 – 2:9.2, 9.3, 9.4 for particle size determination and ASTM D2015-00 for calorific values. Briquettes were produced from mixtures of fonio husk and various concentrations of wild *Acacia nilotica* fruit gum (15 %, 25 % and 35 %) at 3 different compaction pressures (2 MPa, 4 MPa and 6 MPa) using a cylindrical mould (with piston) of 41 mm depth and 37.5 mm inner diameter at a moisture content of 15 %, using a local fabricated machine fitted with a pressure gauge. The briquettes were sun dried for 14 days and subjected to durability test using ASTM D440 – 86 standard procedures for drop shatter for coal, and water absorption test. The moisture content and bulk density of unprocessed fonio husk were determined as 5.81 % and 195.32 kg/m3 respectively, while those of the relaxed briquettes were (5.09 – 5.65 %) and 223.90 – 425.08 kg/m^3 respectively, with volume reduction of 144.63 – 217.63 %. The relaxed densities decreased with increase in binder concentration and compaction pressure. The maximum densities of the briquettes increased with increase in binder concentration and compaction pressure ranging from 565.75 – 823.05 kg/m^3. The impact resistance index of the briquettes ranged from 143 – 333, as against the minimum acceptable value of 1000. The briquettes absorbed 83.33 – 223.08 % water within 5 seconds, beyond which it dispersed. The ignition time and burning rate of the briquettes ranged from 25 – 60 seconds and 10.20 – 22.80g/min respectively. This study concludes that fonio husk is a good briquette material with good densification characteristics and ignition time, but has poor handling characteristics and burning rate. Further study is recommended on other binder materials and processing conditions to improve handling characteristics and burning rate.

Keywords: *Acacia nilotica*, Briquettes, Fonio husk, Waste disposal

INTRODUCTION

Fonio, also called 'Chit' in Zaar dialect of the zaar people of Bauchi state, Nigeria, is one of the oldest indigenous cereals of West Africa (Tokan, *et al.,* 2012; Shamle, *et al.,* 2014). It is the smallest specie of millet, cultivated in many countries of Africa, including Nigeria with an average production rate of 90,000 tons per annum (CIRAD, 2009). Fonio paddy is oval in shape (1.5mm long and 0.9mm wide). The grain is surrounded by a brittle protective shell (the husk), which constitutes 23% of the paddy weight [figure 1b] (Ballogou *et al,* 2013).

Fonio has excellent taste and nutritional value (Ballogou, *et al.,* 2013) and is recommended for children, old and sick people suffering from diabetes or stomach disease. It is therefore used as a staple food and for medicinal purposes in Africa (Jideani, 1990; CIRAD, 2004). It is consumed in various forms including porridge, bread, couscous, tuwo and beer (Jideani, 1999; Tokan *et al.,* 2012; Ndububa, *et al.,* 2016; Ballogou, *et al.,* 2013).

The husk which is usually removed as a waste during processing has not been of much concern until recently with the increasing cultivation and processing mills (CIRAD, 2009). It is gradually drawing attention because of its exceptional problems; it is light, and so can be flown about easily by wind, causing air and land pollution. It is itchy on human skin and cause breathing problems. Unlike husks from other cereals, local farmers report that it performs very low when used as animal feed. More so, it occupies land wastefully, depriving it from being used for economic activities. It is therefore a nuisance that must be gotten rid of immediately to avoid waste accumulation, which is recognized as a problem globally (Ndububa *et al.,* 2016). This can be achieved through waste recycling, a subject of global interest (Atkinson & Sakai, 1993).

Although there are no available reports on studies conducted directly on fonio husk, few have been done on its ash with promising results. In a comparative assessment of the yield of silica from husk ashes of fonio, wheat, and rice, fonio husk had the highest yield of silica with minimal contaminants (Shamle *et al.,* 2014). Silica is being used widely in pharmaceutical products, detergents, adhesives, dental material, ceramic, and adsorbent (Shamle *et al.,* 2014; Brinker & Scherer, 1990; Proctor *et al.,* 1995; Sun & Gong, 2001; Lender & Ruiter, 1990). Fonio husk has also been found to be a good pozzolana material; it was used to replace cement in concrete production up to 10% without affecting its compressive strength (Ndububa *et al.,* 2016).

It should be noted however that the ash is a by-product of combustion of the fonio husk. It is therefore important that the energy in the husk be extracted before the ash is used for other purposes. This is especially needful when Nigeria is bedeviled by serious 'energy poverty' to the extent that 86% and 42% of its rural and urban populations respectively still depend on wood for their daily energy needs (Oyedepo, 2012; Olufemi, *et al.,* 2012). This has resulted in the gradual depletion of the forest resources causing environmental problems such as desert encroachment, erosion and global warming (Mwampamba, *et al.,* 2013). There is therefore a dare need for a substitute to wood and charcoal as fuels for cooking, in order to reduce the pressure on the nation's forest resources.

However, fonio husk, like many other agricultural residues, is not appropriate for use directly as a fuel without further processing due to difficulty in handling (storage and transportation) resulting from low density, low energy density, and high moisture content (Wilaipon, 2002; Ndiema, *et al,* 2002). One promising technology that has been used extensively to improve the fuel and handling characteristics of these residues is briquetting. This is the densification of loose biomass material to produce compact solid composites with the application of pressure (Talukdar, *et al,* 2014).

This study therefore investigated the possibility of converting the fonio husk into a fuel for cooking which may provide a renewable alternative source of energy that will eventually reduce wood and charcoal consumption. This has the potential to reduce pollution and over dependence on wood for fuel, thereby reducing deforestation. More so, it will encourage the cultivation of fonio to meet its increasing demand.

The objectives of this study were therefore to:

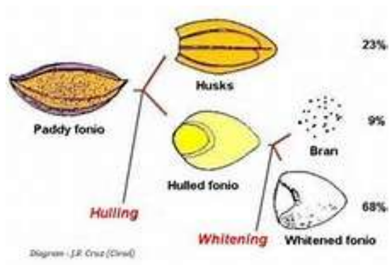
1. Produce briquettes from fonio husk using wild acacia nilotica fruit gum as binder;
2. Determine the influence of binder concentration and compaction pressure on thermal and handling characteristics of the briquettes.

MATERIALS AND METHODS

Materials Preparation and Briquette Production

The sample of fonio husk (FH) was obtained from a fonio mill in Tafawa Balewa, Tafawa Balewa Local Government Area of Bauchi State, Nigeria (Figure 1 a). Dry wild acacia nilotica fruits (Figure 1c) were bought from Muda Lawan market in Bauchi, Nigeria. Both the FH and acacia nilotica fruits were further sun-dried for 7 days. The acacia nilotica fruit was slightly pounded in a mortar (taking care not to crush the seed) and sifted subsequently to extract the gum in powder form. The FH and wild acacia nilotica fruit gum (ANG) were then characterized using appropriate procedures: moisture content was determined Using ASTM E870-82(2013) standard procedure. The particle size of fonio husk was determined using BS1377 – 2:9.2, 9.3 and 9.4 test procedures. Proximate analysis of FH, ANG and briquettes were done using ASTM E870 - 82(2013) and calorific values were determined using ASTM D2015-00 standard procedures.

Briquettes were then produced from a mixture of FH and ANG (binder). The binder ratio was varied from 15 %, 25 % and 35 % by weight of husk. The ANG was dissolved in warm water and allowed to gellatize before mixing with the FH. Water was added until the moisture content was 15% to make the mix suitable for briquetting. A cylindrical mould made of steel (41 mm deep and 37.5 mm inner diameter) and a piston in a locally fabricated machine fitted with a pressure gauge were used in making briquettes at 3 different die pressures (6 MPa, 4 MPa and 2 MPa) with a dwell time of 20 seconds. The briquettes were sun dried for 14 days before being subjected to various tests.

(a) Fonio husk at dump site (b) Composition of fonio paddy


(c) Wild acacia nilotica fruit

Figure 1: Briquetting Materials

Physical and Handling Characteristics of the Briquettes

The dimensions of the briquettes (height, H and diameter, D) were determined immediately after ejection from the mould by measuring with a digital vernier caliper. The masses of the briquettes were determined by measuring with a digital spring balance. The maximum densities of the briquettes were determined immediately after ejection from the mould. The relaxed densities were determined after 14 days of sun drying. Relaxed density is the density of the briquette after drying, also referred to as spring back density (Efomah and Gbabo, 2015). Densities were determined using equation 1.

$$\rho = \frac{M}{V} \qquad (1)$$

Where $V = \pi R^2 H$; ρ = density of briquette; M = mass of briquette; V = Volume of briquette; R = radius of briquette ($\frac{D}{2}$);

Compaction ratio of the briquettes was determined using equation 3 (Oladeji, 2010).

$$Compaction\ Ratio(CR) = \frac{Maximum\ Density\ (Md)}{Initial\ Density\ (Id)} \qquad (3)$$

Relaxation Ratio was calculated as shown in equation 4 (Oladeji, 2010).

$$Relaxation\ Ratio(RR) = \frac{Maximum\ Density\ (Md)}{Relaxed\ Density\ (Rd)} \qquad (4)$$

The percent volume reduction (%VR) was determined using equation 5

$$\%VR = \frac{Relaxed\ Density\ (Rd)}{Bulk\ Density\ of\ Unprocessed\ husk\ (Hd)} \qquad (5)$$

The axial and lateral expansion rates of the briquettes (%AE and %LE) were determined using equations 6 and 7 respectively.

$$\%AE = \frac{H_f - H_i}{H_i} \times 100 \qquad (6)$$

$$\%LE = \frac{D_f - D_i}{D_i} \times 100 \qquad (7)$$

Where H_i = Initial height of briquette; H_f = Final height of briquette; D_i = Initial diameter of briquette; D_f = Final diameter of briquette.

The impact resistances of the briquettes were studied by adopting the ASTM D440 – 86 standard procedures for drop shatter for coal; Shattering resistance of briquettes was measured by dropping a briquette sample 10 times from a height of 2 m on concrete surface

(Gadge *et al*; 2000; Wakchaire & Mani, 2011). The number of pieces into which the briquette broke was recorded. An impact resistance index (IRI) was chosen to enable the researchers study the impact resistance of the briquettes. The pieces of briquette after the first drop that weighed less than 5 % of the initial weight was not included in the IRI calculation (Yadong and Henry, 2000). The IRI was then calculated using equation 8.

$$IRI = \frac{N}{n} \times 100 \qquad (8)$$

Where N = number of drops; n = total number of pieces that weigh up to 5 % or more of the initial weight of the briquette after N drops.

For 10 drops as stated earlier, the minimum acceptable IRI is therefore 1000. Any briquette that scored less than this was considered to have failed. In order to study the weight loss, the number of drops was increased to 30. The per cent weight loss after 10 – 30 drops were calculated for each briquette and recorded.

Resistance to water penetration is expressed as a percentage of water absorbed by briquettes when immersed in water at 27°c for 30 seconds (Gadge *et al*; 2000; Wakchaure & Mani, 2011). It is also referred to as the porosity index (PI) of the briquette. This was determined with the help of equation 9 (Montgomery, 1978)

$$PI = \frac{Mass\ of\ Wet\ Briquette\ (MWB) - Mass\ of\ Dry\ Briquette\ (MDB)}{Mass\ of\ Dry\ Briquette\ (MDB)} \times 100 \qquad (9)$$

The time taken for the briquettes to disperse in water was also studied. A briquette was immersed in water at 27°c and allowed to disperse completely. The onset dispersion time, 50 % dispersion time and 100 % dispersion time were recorded for each briquette.

Thermal Characteristics of the Briquettes

Proximate analysis, calorific value test and combustion rates of briquettes were done to assess the effectiveness of the briquettes as cooking fuel. For proximate analysis and calorific value determination, ASTM E870 - 82(2013) and ASTM D2015-00 standard procedures were adopted respectively.

To determine ignition time, the briquettes were dried at 105°C for effective combustion. A dried briquette was ignited at the edge with a Bunsen burner and the time taken for each briquette to catch fire was recorded in seconds. In order to determine the burning rate (which is mass loss per unit time), a simple test as proposed by Talukdar, *et al;* (2014) and Chaney, *et a;* (2010) were adopted; A briquette was placed on a steel wire mesh grid resting on three supports to allow free flow of air. Now the whole system was placed on a mass balance. The briquette was ignited from top and mass loss data was taken at intervals of 10 seconds.

RESULTS AND DISCUSSION

Characterization of Materials

Table 1 shows the result of proximate analysis of fonio husk (FH) and wild acacia nilotica fruit gum (ANG). It shows that FH and ANG have moisture contents of 5.81and 4.63 respectively, which are less than the acceptable limit for briquetting of 8 – 12 % (Eriksson and Prior, 1990). This is why the moisture content of the FH/ANG mixture was raised to 15 % before briquetting was done.

Table 1: Proximate Analysis of FH and ANG

Parameter	FH	ANG
% Moisture content	5.81	4.63
% Ash content	6.96	4.06
% Fixed carbon	22.69	31.04
%Volatile Matter	64.54	60.27
% Calorific Value (MJ/kg)	8.64	11.23

The bulk density of raw FH was determined as 195.32 kg/m^3 while the particle size was found to be in the range of 0.06 – 2.00 mm. This shows that FH is suitable for briquetting in its raw state without further size reduction.

The densities of the uncompressed mixtures of FH and different binder concentrations are given in table 2. The densities varied from 496.69 kg/m^3 to 662.25 kg/m^3. The densities increased with increase in binder concentration, indicating that the pores in the residue reduced with increase in the ANG concentration; this made more mass of the material available per unit volume' making it good for briquetting.

Table 2: Initial Densities of Uncompressed Mixtures of Fonio Husk and Binders (kg/m^3)

Binder Ratio		
15%	**25%**	**35%**
496.69	607.06	662.25

Physical and Handling Characteristics of the Briquettes

The maximum densities of the briquettes at different binder ratios and compaction pressures varied from 565.75 kg/m^3 to 823.05 kg/m^3 (Figure 2). The densities increased with increase in binder concentration and compaction pressure. These densities are higher than the densities of the uncompressed mixtures of FH and ANG. This shows that the major objective of briquetting (densification of the residue) was achieved with fonio husk. This result is similar to the one obtained by Bamgboye and Bolufawi (2014) for sorghum residue briquettes, in which densities varied from 789 kg/m^3 to 1372 kg/m^3.

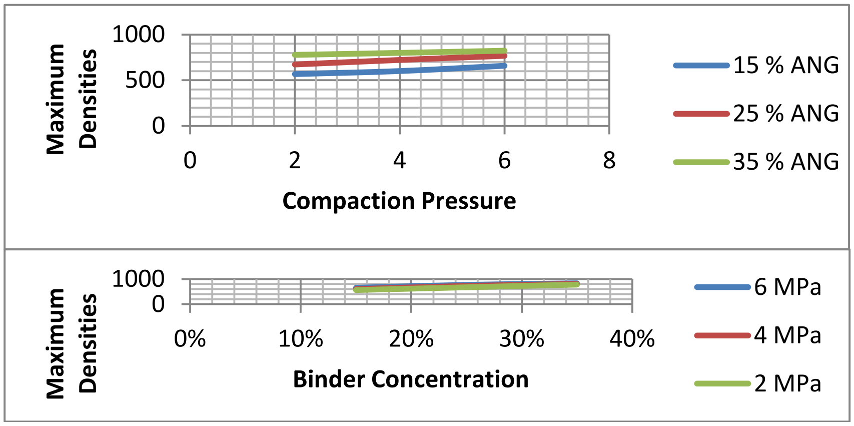


Figure 2: Maximum Densities of Briquettes (kg/m^3)

The relaxed densities of the FH briquettes are presented in figure 3. The densities varied from 223.90 kg/m^3 to 425.08 kg/m^3. These values were observed to be higher than the density of the unprocessed fonio residue of 195.32 kg/m^3. The densities increased with increase in binder ratio and compaction pressure. The increase in relaxed density resulting from an increase in compaction pressure could be due to the compactness of the material as pressure increased, and the reduction in elastic recovery during relaxation of the formed briquette (Bamgboye and Bolufawi, 2014).

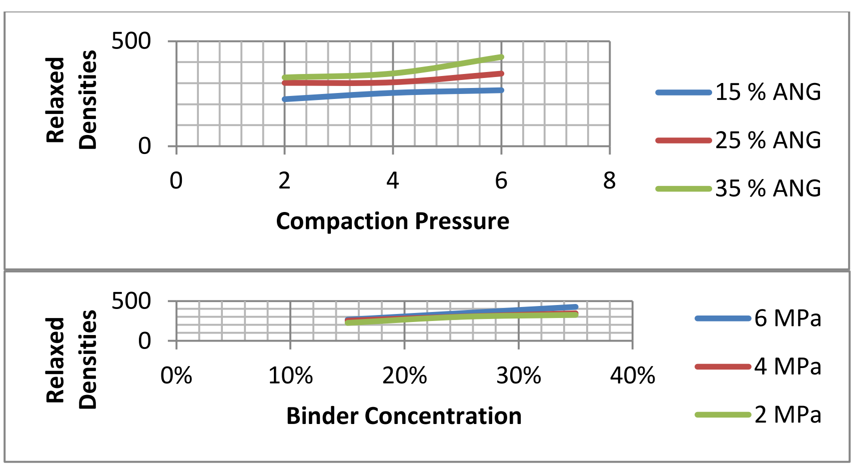


Figure 3: Relaxed Densities of Briquettes (kg/m^3)

The per cent axial and lateral expansion of the briquettes after 14 days of production are shown in figures 4 and 5. The per cent axial expansion varied from 6.28 % to 18.89 %, while the per cent lateral expansion varied from 3.12 % to 5.67 %. Both the axial and lateral expansions were observed to decrease with increasing binder ratio and compaction pressure probably due to more plastic deformation taking place at higher pressures. This also is an indicator of the acceptability of FH as a good briquette material. The briquettes however expanded more in the axial direction than in the lateral direction.

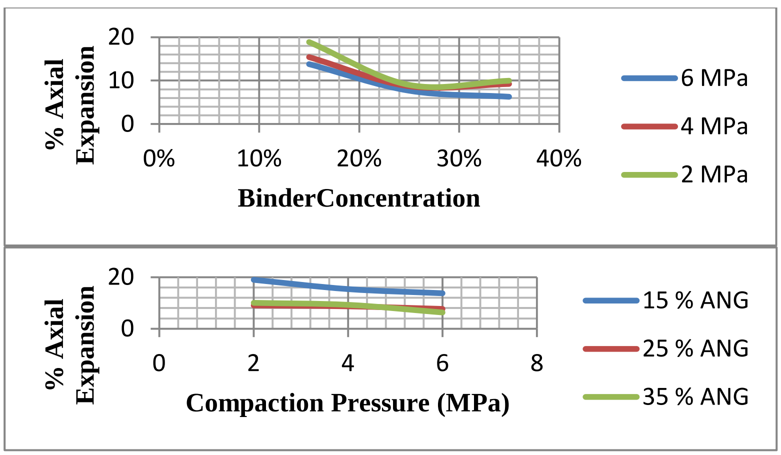


Figure 4: Axial Expansion of Briquettes

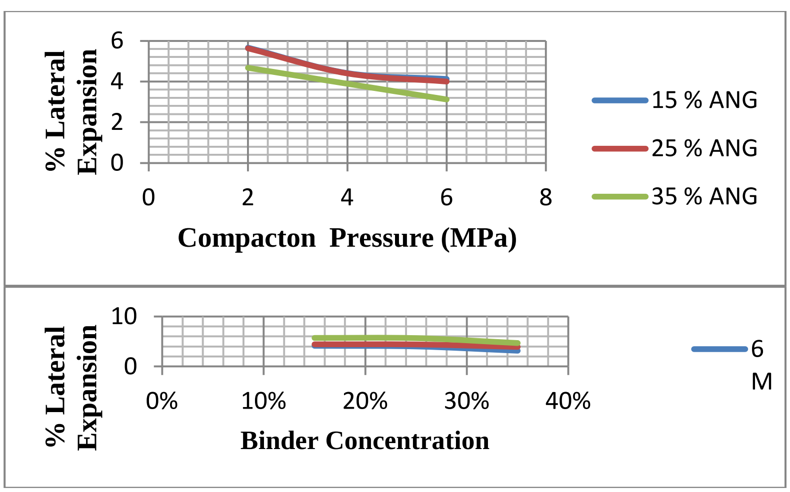


Figure 5: Lateral Expansion of Briquettes

Table 3: Compaction Ratio of Briquettes

Compaction Pressure (MPa)	Binder Ratio 15%	25%	35%
6	1.32	1.26	1.24
4	1.21	1.19	1.21
2	1.14	1.11	1.17

The compaction ratios of the briquettes are shown in table 7 for different binder ratios and compaction pressures. The least value of the compaction ratios was 1.11, while the highest value was 1.32. It was observed that the compaction ratio increased with compaction pressure and binder ratio. This shows that more voids were expelled as the compaction pressure increased. The result indicates low volume displacement due the briquettes offering more resistance to compaction probably due to fewer voids in them. This result is less than what was obtained by Bamgboye and Bolufawi (2014) for guinea corn residue briquettes, in which the compaction ratios varied from 3.194 to 9.730.

The relaxation ratios of the briquettes varied between 1.94 and 2.53 (table 8), decreasing with increasing binder ratio and compaction pressure to indicate that plastic deformation took place more at high pressure and the binder held better with increasing concentration; The low relaxation ratio indicates better stability. This result is good, as the values compare well with the results of some previous studies such as 2.22 for rice husk and 1.70 for corn corb briquettes (Oladeji, 2010), 1.80 for coconut husk (Olorinishola, 2007) and 2.25 for coconut husk (Oladeji *et al.*, 2009).

Table 4: Relaxation Ratio of Briquettes

Compaction Pressure (MPa)	Binder Ratio 15%	25%	35%
6	2.47	2.21	1.94
4	2.36	2.37	2.30
2	2.53	2.23	2.37

The per cent volume reduction of FH due to briquetting is shown in figure 6. It varies between 114.63 % and 217.63 %, and it increased with both compaction pressure and binder ratio. The rate of increase of per cent volume reduction is however higher with increase in binder concentration than compaction pressure. The result suggests that FH is good for briquetting, especially with 35 % ANG concentration.

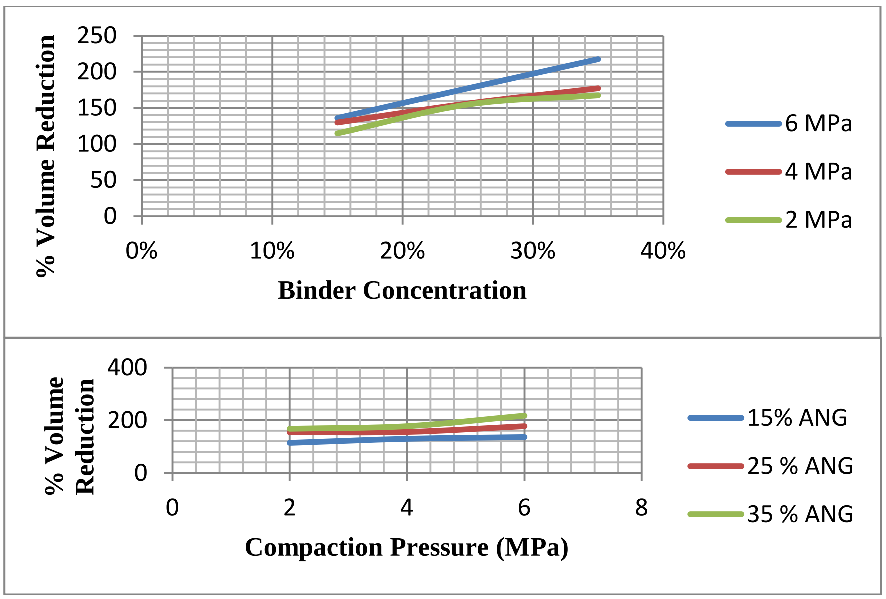


Figure 6: % Volume Reduction of Briquettes

The impact resistance index of the briquettes is presented in table 10. It varied between 143 and 333. It shows that all the briquettes failed the durability test, since all the values fell below the lowest acceptable value of 1000 set earlier. The weight loss of the briquettes is shown in table 11. The table shows that at 15 % and 25 % binder concentrations all the briquettes lost more than 90 % of their weights at 10 drops, and lost all at 20 drops. Although the briquettes with 35 % binder ratio exhibited better durability, they lost between 65.22 – 95.24 % of their weights at 10 drops and up to 97.82 % at 30 drops. This result shows that the FH briquettes with ANG as binder has very low durability and are likely to fail during storage and transportation. Further studies on other binder materials may be needful in this regard.

Table 5: Impact Resistance Index of Briquettes

Compaction Pressure (MPa)	Binder Ratio 15%	25%	35%
6	250	167	143
4	257	143	200
2	260	143	333

Table 6: Weight Loss of Briquettes after 10 – 30 drops

Compaction Pressure (MPa)	Binder Ratio(%) / No. of Drops								
	15%			25%			35%		
	10	20	30	10	20	30	10	20	30
6	96.88	100	-	96.67	100	-	95.24	97.62	97.82
4	93.75	100	-	96.88	100	-	94.74	97.37	97.75
2	96.88	100	-	97.35	100	-	65.22	95.65	95.68

The per cent water absorption of the briquettes after 5 seconds of immersion in water is presented in table 12. It varied between 83.33 – 223.08 %. It decreased with increase in binder ratio, but increased with increasing compaction pressure. This indicates that hygroscopic properties of the briquettes improve with increase in binder ratio, but the influence of compaction pressure requires further investigation.

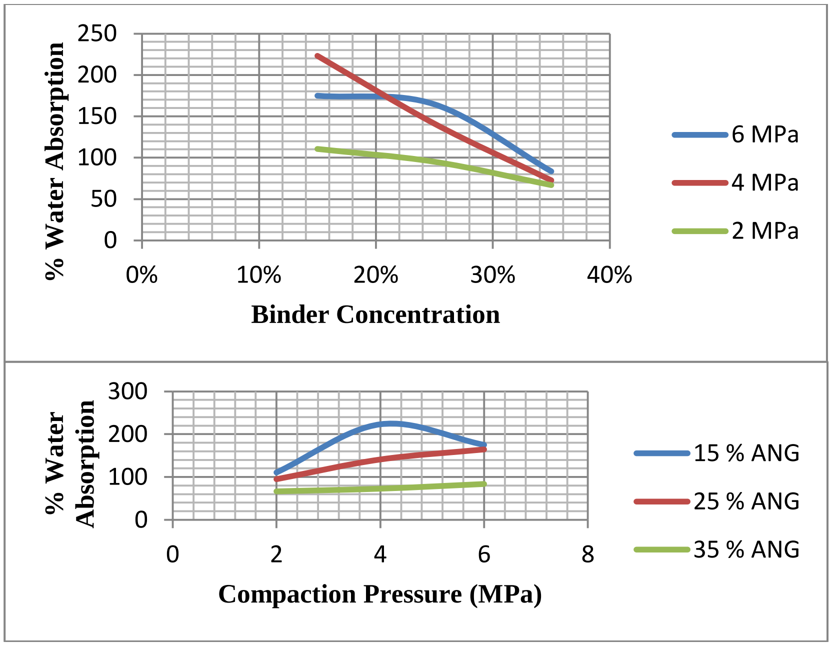


Figure 7: Water Absorption of Briquettes

All the briquettes became too soft to be carried out of the water when immersed beyond 5 seconds. Moreover, all the briquettes started dispersing in water within 29 seconds. The 100 % dispersion time varied between 30 – 150 seconds. Both the onset and 100 % dispersion time were irregular with variations in compaction pressure and binder concentration. This result is better than the one obtained by Wilaipon (2004) for Maize cob briquettes where onset and 100% dispersion time was less than one minute. The cause of low water penetration resistance may be a subject of further study, since the two materials FH and ANG seem to be new in this area of study

Table 7: Dispersion Time of Briquettes in Water (s)

Compaction Pressure (MPa)	Binder Ratio(%) / Dispersion Time (s)								
	15% Onset	50%	100%	25% Onset	50%	100%	35% Onset	50%	100%
6	8	20	40	11	25	40	25	42	111
4	12	18	56	12	15	20	15	40	110
2	10	15	30	12	16	40	29	65	150

Thermal Properties of the Briquettes

The proximate analysis for the briquettes produced at different binder ratios and compaction pressures are shown in table 8. The table shows that the moisture content of the briquettes varied between 5.02 % (least) and 5.67 % (Highest), resulting in a reduction in moisture content of 2.410% – 13.597%. The table also shows that the calorific value of the briquettes varied from 8.937 MJ/kg to 9.225 MJ/kg. This further shows that briquetting has resulted in 3.678 % – 7 .019 % increase in calorific value. The reduction in moisture content may be attributed to compaction, which causes a reduction in the pores in the husk which hold water. On the other hand, the increase in calorific value could be the result of the addition of the binder, which has a higher calorific value of 11.23MJ/kg.

The ignition time of the briquettes ranged between 25 seconds and 60 seconds. It increased with increase in binder concentration and compaction pressure (Figure 8). The rate of increase is however higher with increasing compaction pressure. This trend could be attributed to reducing porosity of the briquettes as the binder ratio and compaction pressure increased. This result compares well with the findings of Davis and Davis (2013) for briquettes made from water hyacinth and phytoplankton scum as binder.

Table 8: Proximate Analysis of Briquettes

Binder Concentration	Parameter	Compaction Pressure		
		2 MPa	4 MPa	6 MPa
15 %	Moisture Content (%)	5.62	5.67	5.65
	Ash Content (%)	6.61	6.58	6.56
	Fixed Carbon (%)	25.35	25.28	25.34
	Volatile Matter (%)	62.42	62.47	62.45
	Calorific Value (MJ/kg)	8.937	8.956	8.967
25 %	Moisture Content (%)	5.33	5.26	5.32
	Ash Content (%)	6.33	6.32	6.34

	Fixed Carbon (%)	27.13	27.21	27.62
	Volatile Matter (%)	61.21	61.21	61.32
	Calorific Value (MJ/kg)	8.984	8.986	8.990
35 %	Moisture Content (%)	5.13	5.02	5.11
	Ash Content (%)	6.14	6.09	6.13
	Fixed Carbon (%)	28.20	28.02	28.13
	Volatile Matter (%)	60.53	60.87	60.53
	Calorific Value (MJ/kg)	9.026	9.032	9.225

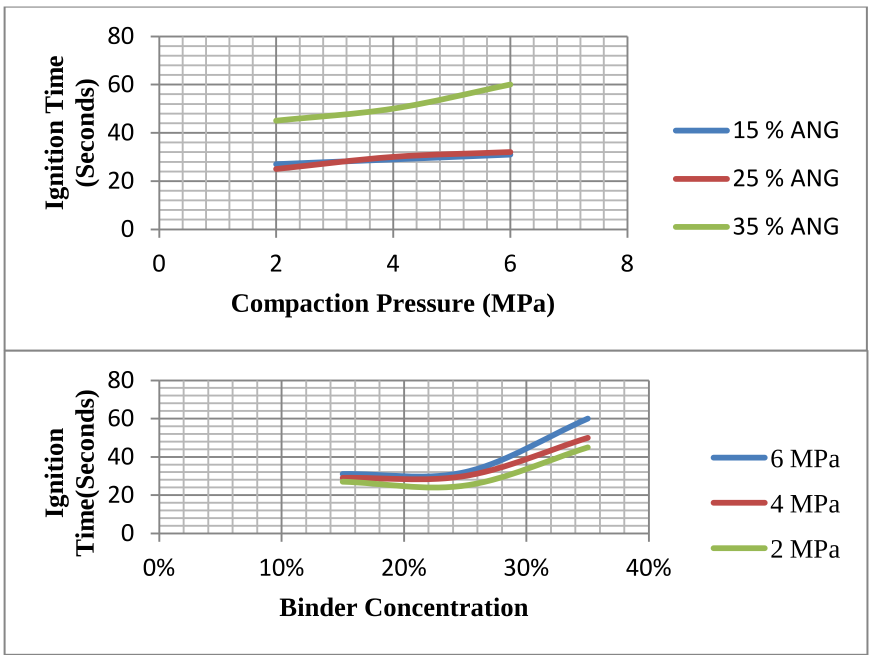


Figure 8: Ignition Time of Briquettes.

The burning rate of the briquettes (Figure 9) varied between 10.20 g/min (for briquette of 35 % binder ratio and 6 MPa compaction pressure) and 22.80 g/min (for briquette of 15 % binder ratio and 2 MPa compaction pressure). This is relatively high as compared to 1.6 – 2.0 g/min for briquettes produced from rice bran and palm kernel shells (Mohammed and Olugbade, 2015). It was further observed that the burning rate reduced with increasing compaction pressure and binder ratio. This trend can also be attributed to the reduction of voids in the briquette as the binder ratio and compaction pressure increased, indicating that further compaction and/or increase in binder ratio can be used to further reduce the burning rate.

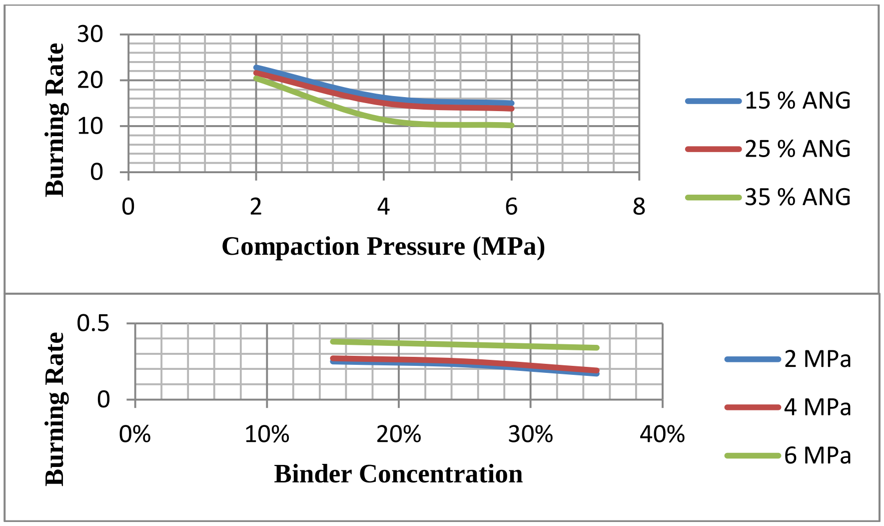


Figure 9: Burning Rate of Briquettes.

CONCLUSION

Briquettes have been successfully produced with fonio husk using wild acacia nilotica fruit gum as binder at various concentrations (15 – 35 %) and compaction pressures (2 – 6 MPa). Fonio husk has proven to be a good briquetting material with good densification characteristics, comparable to other agricultural residues.

The FH briquette with ANG as binder has poor Shatter and water penetration resistance, making it unreliable in storage and transportation. Further study is recommended to determine the actual factors responsible for the briquettes' poor handling characteristics. Other binder materials, compaction pressures, and processing conditions may be investigated.

The ignition time of the fonio husk briquette is good and comparable to other agricultural wastes. However, it requires a binder of other material component with higher calorific value to improve its heat output and burning rate.

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