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Physical and combustion properties of charcoal briquettes from neem wood residues

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A b s t r a c t. This study examines the effect of binder type and blending ratio on the physical and combustion properties of charcoal briquettes produced from wood residues of neem (*Azadirachta indica* A. Juss). Wood residues which included slabs, edgings and cut-offs were carbonized using a carbolite furnace, model MTF 12/388. The carbonized sample (charcoal powder) was bonded with gum arabic and cassava starch, and briquettes produced in this way were assessed. The briquettes were also analyzed for volatile matter, fixed carbon, ash content and heating value. Variation in binder type and blending ratio significantly influenced compressed density and durability rating of the briquettes. Similarly, variations in blending ratio for briquette volatile matter, fixed carbon, ash and heating value were significant ($P < 0.05$). All the properties investigated showed that gum arabic bonded briquettes have better physical and combustion qualities than starch bonded briquettes. For quality specification, the best gum arabic bonded briquette was obtained when the blending ratio was 10:3 while the best starch bonded briquette was obtained at the blending ratio of 5:1.

K e y w o r d s: wood residue, neem, charcoal briquettes, combustion properties, blending ratio

INTRODUCTION

The concept of biomass waste or residue utilization will continue to be a topical issue in developing countries of the world. Large quantity of agro and forestry based residues are generated on yearly basis. The major agro based residues come from rice husk, coffee husk, maize stalk and husk, sugarcane bagasse, jute sticks, silk cotton pods, groundnut shells (Shri, 2008). The same could be said of residues from wood based biomass. Considerable amount of residue is generated during wood harvesting and processing operations. For example, Hakkila and Parikka (2002) reported that wood residues account for between 15 and 60% by volume in sawmills, and between 40 and 70% by volume in plywood industries in Nigeria and many developing countries. A majority of these residues are in form of barks, sawdust, slabs, cut-offs, cull logs etc. In industrialized countries, availability of these residues in abundant supply at the wood processing mills made them an economically attractive source of energy in wood industries. USDA (2002) reported that about 84% of the wood and wood waste fuel used in the United States is consumed by industry, electric power producers, and commercial businesses. The economic downturn coupled with the moribund state of many wood based industries makes this practically impossible in developing countries. For example, out of many wood based industries in Nigeria, sawmill industry appears to be the most active, while other are either moribund or are operating far below capacity (Aruofor, 2000).

The biomass residues generated by the wood based industry in most developing countries have potential to replace energy sources such as firewood in domestic energy need (Suarez *et al.*, 2000). However, only a small proportion of the residues are being used as fuel because of their high moisture, high polymorphism and low energy density. These troublesome characteristics increase costs of transport, handling and storage, making the use of biomass as a fuel impractical (Nasrin *et al.*, 2008). Some of these drawbacks can be overcome through densification of biomass residues for briquette production.

Densification or briquetting is the process of compacting the biomass residue into a uniform solid fuel called briquettes. It has higher density and energy content and less moisture compared to its raw materials. Briquetting of biomass can be done using various techniques, either with or without binder addition. Biomass briquettes are mostly used for cooking, heating, barbequing and camping in countries

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such as USA, EU, Australia, Japan, Korea and Taiwan. In the developing countries, biomass briquettes are mainly for household usage only. These investigations become necessary in view of the recent interest in the use of neem wood for structural and construction works (Akpan, 2007; Gladstone, 2003). Though neem wood is listed among the fuel wood species, it is not among the main species exploited for fuel (Njiti and Kemcha, 2002). This could be attributed to its sporadic burning and low energy value per volume. It is thus expected that the briquetting of neem wood residues will help in im- proving the energy value of the residues, thereby increasing the option for domestic fuel supply in the savannah region where the tree is predominant.

The aim of this study was to examine the effect of binder type and blending ratio on the physical and combustion properties of charcoal briquettes from the wood residue of neem (*Azadirachta indica* A. Juss).

MATERIAL AND METHODS

The materials used for this study were wood residues obtained from the trees of *Azadirachta indica*. The residues included slabs, edgings and cut-offs generated at the wood workshop of the University of Maiduguri, NE Nigeria. The residues were carbonized in a laboratory furnace (Carbolite furnace, model: MTF 12/388) in the absence of air and at temperature up to 450°C. The charcoal produced was grinded into powder and air dried at room temperature to attain equilibrium moisture content. The press used for the briquetting consisted of a wooden frame fitted with a hydraulic jack (Dahlam and Forst, 2001) while the mould was made of PVC pipe of 28 cm (height) x10.4 cm (diameter) perforated to about 1/3rd of the height and equipped with wooden disks to cover both ends.

For each batch of briquettes, the charcoal powder was mixed with either cassava starch or gum arabic (gum extract from *Acacia senegal* L.) until a uniform mixture was obtained. The percentages of binder used in the mixture were 10, 20, 30, and 40%. Thus, the charcoal-binder blends in each charge were in ratios of 10:1, 5:1, 10:3 and 5:2. The mixture was then hand-fed into the mould, covered at both ends with the wooden disks, and compacted at a pressure of 10.70 kg cm^{-2} for 5 min before the briquette was removed. At each level of binder, 15 briquettes were produced.

The physical properties which included the compressed density, dimensional stability, relaxed density and relaxation ratio were determined in accordance with the method described by Olorunnisola (2007). Four briquettes were randomly selected from each production batch for the tests. The mean compressed density of the briquettes was determined immediately after removal from the mould as a ratio of measured mass (g) over calculated volume (cm^3). To determine dimensional stability, the length of four representative briquettes was measured at 0, 30, 60 and 1440 and 10,080 min intervals. The relaxed density and relaxation ratio of the briquettes was determined after 19 days of sun-drying at an ambient temperature and relative humidity of 22 ± 3°C and 75 ± 5%, respectively. The durability of the briquettes was determined in accordance with the chartered index described by Suparin *et al*. (2008). The briquette samples were dropped repeatedly from a height of 1.5 m onto a metal base. The fraction of the briquette that remained unshattered was used as an index of briquette durability in percentage.

The combustion properties which included percentage volatile matter, fixed carbon and ash contents of four representative samples were determined based on ASTM Standard E711-87 (2004), while the heating value was determined by the Gouthal formula.

For volatile matter determination, 1g of the briquette was placed in a crucible of known mass and oven-dried to constant mass, after which it was heated in the furnace at temperature of 600°C for 10 min. The volatile matter was then expressed as the percentage loss in mass to the oven dried mass of the sample. The percentage ash content followed the same procedure as volatile matter, except that the sample was heated in the furnace for 3 h. The percentage fixed carbon was calculated using the equation below:

$$FC = 100 - (V + A), \quad (1)$$

where: FC (%) – fixed carbon, V (%) – volatile matter, A (%) – ash, while the heating value (HV) (MJ kg^{-1}) was calculated by using the equation stated below:

$$HV = 2.326(147.6FC + 144V). \quad (2)$$

RESULTS AND DISCUSSION

The experimental results of the compressed density, relaxed density, the relaxation ratios and durability rating of the briquettes are presented in Table 1. From these results it is apparent that the difference in binder type and blending ratio had a marked effect on the compressed density of the briquettes ($P < 0.05$), but did not significantly influence their relaxed density and ultimately their relaxation ratio ($P > 0.05$). Relaxed density *ie* density of the briquette after removal from the press) is one of the parameters characterising briquette. The gum arabic bonded briquette had average compressed density of 0.639 g cm^{-3} and relaxed density of 0.459 g cm^{-3}, while starch bonded briquettes had compressed and relaxed density of 0.462 and 0.359 g cm^{-3}, respectively. This gave the relaxation ratio values of 1.39 and 1.29 for the two briquette types, respectively. Though gum arabic bonded briquettes compressed better than starch bonded briquettes, the difference is not significant when their relaxation ratio is considered. The implication of this result is that both binders gave a relatively stable briquette. Meanwhile, the optimum compressed density and relaxed density was attained when the charcoal-binder blend ratio was 10:3

T a b l e 1. Effects of binder type and blending ratio on the physical properties of the briquettes

Variables			Parameters			
			Compressed density* (g cm^{-3})	Relaxed density* (g cm^{-3})	Relaxation ratio*	Durability rating* (%)*
Binder type						
Gum Arabic			0.640	0.532	1.21	98.74
Starch			0.506	0.420	1.22	83.26
Blending ratio						
Charcoal	:	Binder				
10	:	1	0.546b	0.411ab	1.33a	86.64c
5	:	1	0.585ab	0.496a	1.18ab	87.95b
10	:	3	0.668a	0.596a	1.12b	89.66b
5	:	2	0.493c	0.401b	1.23a	99.75a
Charcoal	:	Gum Arabic				
10	:	1	0.605	0.458	1.32	97.05
5	:	1	0.670	5.62	1.19	98.63
10	:	3	0.750	0.676	1.11	99.27
5	:	2	0.533	0.431	1.24	100.00
Charcoal	:	Starch				
10	:	1	0.487	0.363	1.34	76.23
5	:	1	0.500	0.429	1.17	77.27
10	:	3	0.585	0.516	1.13	80.04
5	:	2	0.453	0.371	1.22	99.50
Significance level						
Binder type			P = 0.001	P = 0.064	P = 0.416	P = 0.001
Blending ratio			P = 0.004	P = 0.137	P = 0.121	P = 0.001

*Means of 4 replicate samples. Values with the same alphabet in each column are not significantly different at $\alpha = 0.05$ using Duncan multiple range test.

by mass in both briquette types. This is clearly evident in the least relaxation ratio obtained at this level. This behaviour has also been seen in briquette with a biobinder (Ivanov *et al*., 2003), briquette with a starch binder (Jindaporn *et al*., 2005), and fuel briquette from waste paper and coconut husk admixture (Olorunnisola, 2007).

When the durability rating of the briquettes was carried out, it was discovered that the type of binder used and the blending ratio remarkably influenced the durability rating of the briquettes ($P < 0.05$). Durability rating of 98.74% obtained in gum arabic bonded briquettes was significantly higher than 83.26% obtained in starch bonded briquettes (Table 1). It is expected that gum arabic bonded briquettes will withstand mechanical handling better than starch bonded briquettes. The reason for this might be because gum arabic bonded briquettes compressed better than starch bonded briquettes, as exemplified by higher mass per unit volume and lower relaxed density. Meanwhile, when the blending ratio was varied, durability rating increased with increase in binder fraction of the briquette. Thus, it could be inferred that durability of a briquette is a function of compressed density (Hussain *et al*., 2002; Wilaipon, 2007) and variation in binder level (Bisana and Laxamana, 2008). Increase in compressed density and binder level enhances durability while moisture content reduces it (Olorunnisola, 2007).

The results of the stability test reflect the trend observed in compressed and relaxed density of the briquettes. The observed linear expansions were generally minimal. Gum arabic bonded briquettes showed better stability than starch bonded briquettes (Fig. 1a, b). When the stability trend was viewed along the blending ratios, briquettes produced with charcoal-binder ratio of 5:1 and 10:3 in both briquette types were observed to exhibit the best stability. Thus, briquette produced with 10:3 charcoal-binder blend produced the

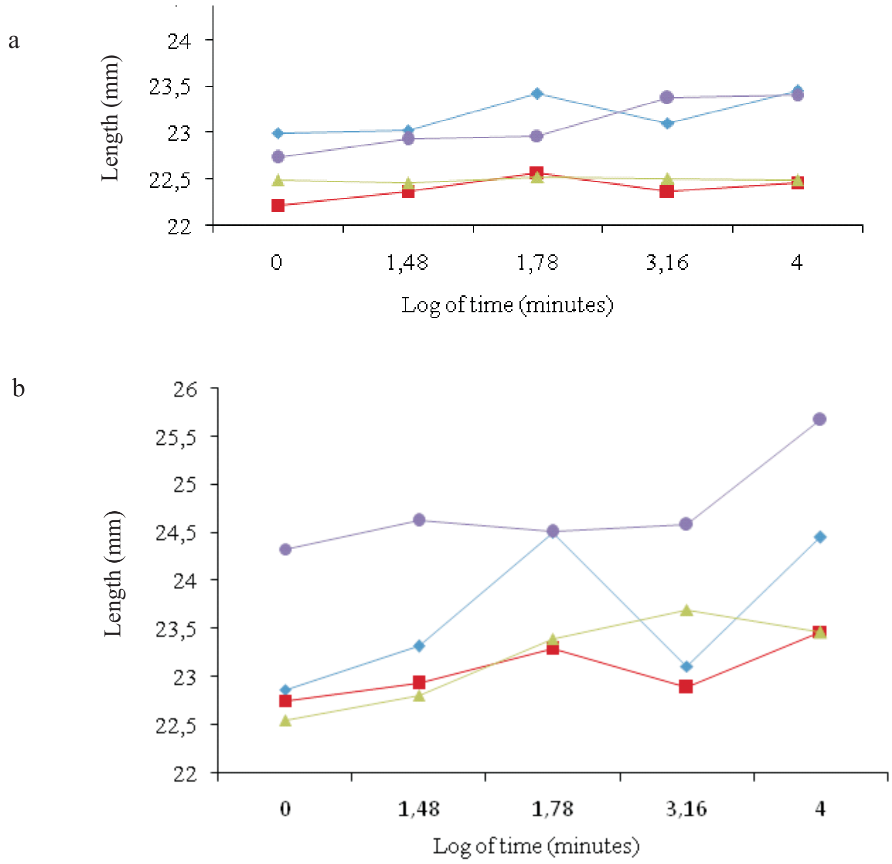

Fig. 1. Linear expansion of gum arabic (a) and strach (b) bonded briquette at varying time and binder level: ◆ – 10%, ■ – 20%, ▲ – 30%, and ● – 40%.

most stabilising effect, followed by briquettes with 5:1 charcoal binder blend. This confirms that stability of the briquette is a function of the binder levels and compressed density (Suparin *et al*., 2008).

Meanwhile, the results of the volatile matter presented in Table 2 show that binder type and blending ratio had a marked effect on the volatile matter of briquettes with P values of 0.001 and 0.036, respectively. The percentage volatile matter in gum arabic bonded briquettes was higher than that obtained in starch bonded briquettes. The volatile matter of gum arabic bonded briquette increased from 10.63 to 13.0%, while it increased from 10 to 12% in starch bonded briquette. These values fall within the 9.0-25.8% range obtained in carbonizate produced from Velenje lignite at varying temperature (Zapusek *et al*., 2003). In terms of quality specification, the low volatile matter recorded implies that the briquettes might not be easy to ignite, but once ignited they will burn smoothly with clean flame without smoke. The fuels related to smokeless grade are known to contain no more than 20% volatile substances (Ivanov *et al*., 2003).

Consistent with previous tests, the percentage fixed carbon in gum arabic bonded briquettes was slightly higher than in starch bonded briquettes, with mean values of 84.38 and 84.31%, respectively (Table 2). The highest percentage fixed carbon of 85.25% was obtained when the charcoal-gum arabic blend was 5:1 in contrast to 85.20% obtained when the charcoal-starch ratio was 10:3. The difference in value obtained could be attributed to the difference in compressed densities of the two briquette types. Nevertheless, the percentage fixed carbon obtained was within the 84.7-96.9% range obtained in carbonisate produced from Velenje lignite at varying temperature (Zapusek *et al*., 2003). It is expected that the high percentage of fixed carbon and its smokeless flame will enhance the heat value and combustion duration of the briquette.

When the percentage ash content of the briquettes was considered, it was discovered that the type of binder used does not significantly influence the ash content of the briquette (P = 0.144). However, variation in blending ratio significantly influenced the ash content of the briquette (P = 0.001). The ash content of 4.95% obtained in starch bonded briquette was higher than the 4.47% value obtained in gum arabic bonded briquette. The lowest ash content in gum arabic and starch bonded briquettes was obtained when the blending ratio was 10:3 and 5:1, respectively. The low ash recorded is a reflection of the high heating value obtained in the two briquette types. Similar low percentage ash content has been reported for briquettes from oil palm biomass

T a b l e 2. Effects of binder type and blending ratio on the combustion properties of the briquettes

Variables			Parameters			
			Volatile matter	Fixed carbon	Ash	Heating value
				(%)		(MJ kg^{-1})
				Binder type		
Gum Arabic			11.53	84.38	4.47	32.83
Starch			10.75	84.31	4.95	32.54
				Blending ratio		
Charcoal	:	Binder				
10	:	1	11.00ab	83.25b	5.75a	32.27b
5	:	1	11.32a	84.88a	3.81b	32.93a
10	:	3	11.78a	85.10a	3.88b	33.17a
5	:	2	10.75b	83.88b	5.38a	32.40b
Charcoal	:	Gum Arabic				
10	:	1	11.0	83.75	5.25	32.44
5	:	1	10.63	85.25	4.11	32.83
10	:	3	13.00	85.00	3.50	33.54
5	:	2	11.50	83.50	5.00	32.52
Charcoal	:	Starch				
10	:	1	11.00	82.75	6.25	32.09
5	:	1	12.00	84.50	3.50	33.03
10	:	3	10.55	85.20	4.25	32.79
5	:	2	10.00	84.25	5.75	32.27
				Significance level		
Binder type			P = 0.001	P = 0.078	P = 0.144	P = 0.115
Blending ratio			P = 0.036	P = 0.063	P = 0.001	P = 0.001

*Explanations as in Table 1.

(Nasrin *et al*., 2008) and briquettes from lignite with biobinders (Ivanov *et al.*, 2003). Ash content in the briquette normally causes an increase in the combustion remnant in the form of ash, thereby lowering the heating effect of the briquette.

Meanwhile, heating value is the most important combustion property for determining the suitability of a material as fuel. It gives the indication of the quantity of fuel required to generate a specific amount of energy. The summation of the previous tests was reflected in the heating value. The slightly higher heating value of 32.83 MJ kg^{-1} obtained in gum arabic bonded briquette compared to 32.54 MJ kg^{-1} obtained in starch bonded briquette could be attributed to its higher compressed density, volatile matter, fixed carbon and low ash content. Variation in blending ratio was discovered to significantly influence the heating values of the briquettes. The heating value reached the peak (33.54 MJ kg^{-1}) when the charcoal-gum arabic blend was 10:3 compared to the highest value of 33.03 MJ kg^{-1} obtained when 5:1 charcoal-starch blend was used (Table 2). These values were found to be higher than 18.89 MJ kg^{-1} obtained in banana peel briquette (Wilaipon, 2008), 14.1 MJ kg^{-1} in maize cob briquette (Wilaipon, 2007), and 24-27 MJ kg^{-1} for lignites with biobinder (Ivanov *et al*., 2003). In terms of quality specification, this shows that an excellent charcoal briquette can be produced from the wood residue of *Azadirachta indica* and the fact that the materials used *ie* the press, mould and binders are cheap and require low technology, and make the production cost-effective.

CONCLUSIONS

1. The physical and combustion properties of the briquettes were found to be influenced by the type of binder and the blending ratio used.

2. In terms of quality specification, the best gum arabic bonded briquette was obtained when the blending ratio was 10:3 while the best starch bonded briquette was obtained when the blending ratio was 5:1.

3. The results obtained on the physical and combustion properties show that both binder types can produce high quality charcoal briquette with high durability rating and heating value.

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