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Full Length Research Paper

Energy Characterization of Briquettes Produced from Barks of Tropical Hardwoods species

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ABSTRACT: Until recently, bark is treated as a waste, thus, research is directed at studying the utilization of bark residue for briquette production. This study investigated and compared briquettes produced from barks of selected tropical hardwood species using starch as a binding agent. The Bark of *Acacia nilotica* wild ex, *Daniellia oliveri* (Rolfe) Hutch and *Detarium senegalense* J. F. Gmel were grounded and sieve with 1.5 mm sieve. The granulometric fractions were used to produce briquettes by weighing approximate quantities at a constant mixing ratio of 5:1 of bark granules to starch respectively. The starch was prepared with 250 ml of hot water at 100°C to form the prepared stock. The briquette was produced and analyzed with six (6) replicates from each species and combustion related properties such as ash content, volatile matter, fixed carbon and heating value which are important index used in estimating the quality of solid fuel materials such as briquette were assessed using standard methods. The mean ash content, volatile matter, fixed carbon and heating values range from 6.92 ± 0.34 to 4.22 ± 0.17 %; 18.07 ± 0.55 to 12.46 ± 0.82 %; 83.05 ± 0.58 to 78.32 ± 0.78 %, and 32.82 ± 0.13 to 30.02 ± 0.09 % respectively. Based on the result of analysis carried out at a 5 % level of significance, briquette produced *Detarium senegalense* bark gave a significantly better performance as solid fuel material than the other species, the overall efficiency of the briquette produced based on the general proximate analysis follows the trend: and *Detarium senegalense* > *Daniellia oliveri* > *Acacia nilotica.* Thus, and *Detarium senegalense bark* is more efficient for briquette production due to the better performance obtained in all the parameters assessed and a cheaper way of bark residual fuel utilization in rural areas.

Keywords: Bark granules; ash content; volatile matter; carbon content; heating value and briquette production

INTRODUCTION

There had been so much pressure on fossil fuel owing to the rapid population growth in the world that had led to increase demand on fossil fuel for energy production by all the sectors of society. This consequently, impose burden on the existing fossil fuels which were the leading energy sources since last five decades (Yen-Hsiung, 2018). Fossil fuels are of nonrenewable in nature and require millions of years for their replenishment but their limited reserves are running down quickly, also the instability in world petroleum market (In Nigeria for example, the instability in the Middle-East and the unrest in the Niger-Delta oil producing area), which make it difficult to keep balance between the existing reserves and consumption (Ajodo-adebanjoko, 2012).

Fossil fuels also initiates environment hazards since the addition of thousands of tons of carbon, sulphur, nitrogen and other pollutants in the air leads to climate change problems. These adverse effects signify the need to discover novel and economical alternative to fuel. There is therefore, scarcity of energy and there is need to source for alternative form of energy, which is different from convectional types. In order to meet an increasing demand, alternative energy sources like biomass must be used effectively. Tree bark usually refers to all tissues external to and surrounding the vascular cambium of the tree. Generally, it takes up about 9-15 % of a typical log by volume Harkin and Rowe, (1971). In spite of its small proportion, bark plays an important role in a living tree.

Bark has a complex anatomy and complicated chemical composition in order to maintain three main functions: providing nutrient transport from the leaves to the rest of the tree, protecting the sensitive inner cambium from desiccation and shielding from the environment as the primary defense of the tree against wildfire, mechanical injuries caused by heavy wind, and attacks by phytopathogens, phytophagous insects, larger animals, etc. (Hon and Shiraishi; 2000). In the wood industry, bark is a residue in forest mill operations and it is either abandoned or burned as a fuel. In addition to being considered a valuable solid biofuel, bark is also scrutinized for more added-value products that will consider potential specific chemical composition or properties (Demirbas, 2010).

Bark valorization, namely if envisaged within a biorefinery platform, therefore requires a careful examination of composition and processing characteristics. Bark has a similar chemical composition to wood, only that it contains more extractives, higher lignin content, and a smaller amount of holocellulose than wood. The bark chemical components can be separated into fractions with different polarity through sequential extraction using a series of organic solvents and hot water (Harkin and Rowe, 1971; Hon and Shiraishi, 2000). Hardwood species are presently the most important source of wood for pulp production (Patt *et al*., 2006). And therefore, considerable amounts of bark are made available from log debarking, and are separated in the mill as a residual product and used as fuel. In view of the above, considerable interest have been generated on research into characterization of the chemical composition of hardwoods species barks. Among the properties that will qualify the bark of a wood as a potential raw material in the developing biorefinery and chemical industries is the percentage bark abundance. Ogunwusi, (2013) investigates into a number of wood species of high bark abundance so as to meet the ever increasing demand for petrochemical industries. Some of these tree species with high bark abundance are *Acacia nilotica* wild ex linn; *Daniellia oliveri* (Rolfe) Hutch and *Detarium senegalense* J. F. Gmel.

Before promoting the use of any new type of product for fuel, it is expedient to have good understanding of its performance. Design, operation and efficiency the of thermo-chemical conversion system are largely depends upon the basic characteristic properties such as; moisture content, elemental composition and bulk density, particle size and porosity etc. Biomass residues have large variations in their characteristics properties thus require a well-established data of the biomass residues which may helpful in setting up of systems for their better conversion. Basic characteristic features which are important for designing a biomass conversion unit includes proximate analysis (ash content, moisture content, volatile matter and fixed carbon), Ultimate analysis or elemental compositions (carbon, hydrogen, oxygen, sulphur, calcium, nitrogen etc.) and heating value determination. Proper evaluation of these properties consequently enhances the overall plant efficiency. Briquetting process has been investigated by several researchers (Grover, 1996; Ajueyitsi and Adegoke, 2003; Battacharya *et al*., 2002). The objectives of this study were therefore to produce briquettes from bark residue of *Acacia nilotica* wild ex linn*; Daniellia oliveri* (Rolfe) Hutch and *Detarium senegalense* J. F. Gmel. This study will also highlight some other characterization such as the proximate analysis of the bark residual briquette and ultimate analysis of the bark residue used in the production of the briquette.

MATERIALS AND METHODS

Location of study

The briquette' production was carried out at Forest Products laboratory Auburn University, Alabama, USA. The experiment and the laboratory test were carried out at Forestry Research Institutes of Nigeria (FRIN), Jericho, Ibadan, located on Latitude 7^{o}23'48.287.5 N and Longitude 3^{o}51'48.96.0 E (FRIN meteorological station, 2013).

Briquettes preparation

Bark residues of *Acacia nilotica* wild ex, *Daniellia oliveri* (Rolfe) Hutch and *Detarium senegalense* J. F. Gmel were collected from Bodija plank market Ibadan during conversion of the logs. The bark residues were crushed mechanically and sundried to reduce their moisture content, sieved with 0.5mm mesh size and stored in ziplock bag prior to use. Cassava starch was used as binder. The feedstock's and binder were prepared at mixing ratio 5:1 of bark granules to starch respectively.

The cassava starch powder was mixed with 30ml of cold water and prepared by stirring thoroughly the mixture of starch powder to 250ml of hot water at 103 ± 2^{0}C to form prepared stock. The prepared stock was then blended with the sieved bark residue and introduced into the manual mould where it was compressed manually. The briquettes produced were removed and oven dried. Six (6) replicates were produced from each of the bark granules obtained from the sampled wood species. A total numbers of 18 briquettes were produced from the wood species altogether.

Proximate analysis

Determination of percentage ash content (PAC)

The PAC was determined as described by Emerhi, (2011) and Ogwu *et al.* (2014). 2g of the briquette sample was converted to ash in the muffle furnace at a temperature of 550°C for 4hrs and the resulting ash was then weighed after cooling. The PAC was determined by the formula:

$$PAC = \frac{B}{D} \times 100$$

Where, B= Weight of ash
D= initial Weight of sample.

Determination of percentage volatile matter (PVM)

The PVM was determined according to the method described by Emerhi, (2011) and Ogwu *et al.* (2014). 2g of briquettes sample was measured into a crucible and then oven dried at 103°C to constant weight. The briquettes were then kept in the furnace at a temperature of 550°C for 10 minutes and weighed after cooling and the PVM was determined using the Formula:

$$PVM = \frac{B - C}{B} \times 100$$

Where;
B = is the weight of oven dried sample
C = is the weight of sample after 10min in the furnace at 550°C.

Determination of percentage fixed carbon (PFC)

The PFC was estimated by subtraction (Emerhi, 2011; Ogwu *et al.,* 2014). The sum of percentage volatile matter (PVM) and Percentage ash content (PAC) was subtracted from 100.

$$\%FC = 100 - (\%PVM + \%PAC)$$

Where;
%PFC = Percentage Fixed Carbon
%PVM = Percentage Volatile Matter
%PAC = Percentage Ash Content

Determination of heat value (HV)

This was calculated using the formula:

$$HV = 2.326(147.6C + 144V)MJ/Kg$$

Where;
C = is the Percentage Fixed Carbon
V= is the Percentage Volatile Matter (Emerhi, 2011).

Statistical analysis

Data generated were expressed as mean ± standard deviation of six (6) replicate analyses and also subjected to Analysis of Variance (ANOVA) and subsequently Duncan test was used to separate mean where differences exist.

RESULTS AND DISCUSSION

Ash content

Table 1 presents the mean percentage values of the ash content for the briquette produced from the three tropical hardwood species used. The result shows that briquette produced from *Acacia nilotica* bark residue had the highest ash content with a mean value of 6.92%which is significantly higher ($p < 0.05$) than those produced from bark residue of *Detarium senegalense* with the mean value of 4.22%. Briquettes produced from *Detarium senegalense* had a significantly lower ash content compared to the other sampled species (Table 2).

Ash is the noncombustible inorganic component of biomass and it has a significant influence on heat transfer to the surface of a solid fuel material. Ash is also considered an impurity that reduces burning efficiency due to its noncombustible nature; therefore, solid fuel materials with low ash content are considered better suited for thermal utilization than those with higher ash content. These values are within the range of 3.30% to 7.21% obtained for other biomass as reported by Omoniyi and Olorunnisola, (2014) in the study on bagasse though at variance with the values obtained by Tembe *et al*., (2014) in the study on rice husk, groundnut shells and sawdust form *Daniella oliveri.* The combustion volume and efficiency may however be affected by the relatively higher surface area of the bark residue used in this case as well as higher ash content which might have led to relatively increased dust emissions (Raju *et al*., 2014). Also according to Danon, (1998) low ash content will give high heating value and high ash content will give

Table 1: The mean percentage ash content for the briquettes produced from the wood samples.

Wood samples	Mean (%)
Daniellia oliveri b	5.98 ± 0.26a
Detarium senegalense	4.22 ± 0.17c
Acacia nilotica	6.92 ± 0.34b

Mean with same alphabet are not significantly different from each other at p < 0.

Table 2: Analysis of variance for percentage ash content

SV	DF	SS	MS	F-cal	F-tab
Treatment	2	2 24.778	12.389	87.451*	3.682
Error	15	2.125	0.142		
Total	17	26.903			

*Significant at p <0.05

Table 3: The mean percentage volatile matter of the briquettes produced from bark of wood species.

Wood samples	Mean (%)
Daniellia oliveri	14.24 ± 0.66c
Detarium senegalense	18.07 ± 0..55a
Acacia nilotica	12.46 ± 0.82b

Mean with same alphabet are not significantly different from each other at p <0 .05.

Table 4: Analysis of variance for percentage volatile matter.

SV	DF	SS	MS	F-cal	F-tab
Treatment	2	96.778	48.389	24.194*	3.682
Error	15	30.000	2.000		
Total	17	126.778			

*Significant at p <0.05

low heating value. This therefore follows that briquette produced from the sawdust of the three sampled hardwood species have great potential for use as a solid fuel material. However, among the three wood species used in this study, from *Detarium senegalense* bark residue will gives the highest heating value and thus better efficiency as a solid fuel material compared to the other species.

Percentage volatile matter

The result of the mean percentage volatile matter of the briquette produced from the bark residue of the three sampled wood species is presented in (Table 3). The result shows that briquette produced from *Detarium senegalense had* the highest mean value of 18.07% which is significantly higher (p < 0.05) when compared with *Acacia nilotica* and *Daniellia oliveri* (with a value of 12.46 % and 14.24 % respectively (Table 4). The presence of volatile matter in a solid fuel material is an added advantage, as it enhances the combustion of solid fuel material. The volatile matter represents the briquette's yield on the carbonization process to provide more data on combustion properties of the materials and provides a basis for its use as a solid fuel material. Low grade solid fuel materials tend to have low volatile content that results into incomplete combustion which may lead to significant release of smoke and toxic gases which are not desirable from the environmental point of view. Sotande *et al*., (2010) also reported that low volatile matter of briquettes supports low ignition and high volatile matter supports burning of fuel, however the percentage volatile matter reported in this study is on the lower side compared to that reported for briquettes made from some hard wood species like *Afzelia africana, Terminalia superba, Melicia excelsa* made from combinations different types of binders. However, briquettes produced from *Detarium senegalense* will support burning of fuel the most thus, have better efficiency as a solid fuel material when compared with the briquettes produced from *Acacia nilotica* and Daniellia *oliveri.*

Percentage fixed carbon

Table 5 shows the mean value of percentage fixed carbon of the briquette produced from three wood species used. The result shows the briquette produced from *Acacia nilotica* had the highest mean fixed carbon of 81.92% which is statistically comparable (p<0.05) to that produced from *Daniellia oliveri* with mean fixed carbon of 80.58% and *Detarium senegalense* which has the lowest with the mean fixed carbon of 79.08% statistically comparable with that of *Acacia nilotica*. The fixed carbon content of a solid fuel material is the amount of carbon left in the material after the volatile materials are eliminated (Table 6). It is used as an estimate of the amount of coke that will be produced from a sample of solid fuel material like coal. Charcoal possessing high volatile matter tends to have lower fixed carbon, the advantage of this is that lower fixed carbon solid fuel materials tends to be harder, heavier easier to ignite than those that contain higher fixed carbon (Raju *et al.,* 2014). However, the result of the fixed carbon content in this study further implies that the briquettes produced from the bark granules of all the sampled wood species is suitable for domestic applications as a fixed carbon requirement of 86.7 % is recommended for briquettes produced for domestic use (Raju *et al.,* 2014; Abdu-zubairu and Gana, 2014). This slightly falls short of the requirement for industrial applications with a recommended fixed carbon of 86.7 % (Pallavi *et al.,* 2013; Raju *et al.,* 2014). FAO (1995) reported that the higher the fixed carbon content the better the briquette produced because the corresponding energy would be

Table 5: The mean percentage fixed carbon of the briquette produced from bark of wood species.

Wood samples	Mean (%)
Daniellia oliveri	81.33 ± 0.80a
Detarium senegalense	78.32 ± 0.78b
Acacia nilotica	83.05 ± 0.58ab

Mean with same alphabet are not significantly different from each other at p<0.05.

Table 6: Analysis of variance for percentage fixed carbon.

SV	DF	SS	MS	F-cal	F-tab
Treatment	2	24.111	12.056	6.792*	3.682
Error	15	26.625	1.775		
Total	17	50.736			

*Significant at p <0.05.

released is usually higher. However, increase in the fixed carbon of briquettes has been demonstrated to be enhanced with increase in binder concentration (Abdu-zubairu and Gana, 2014), thus, this information could be used to improve the fixed carbon of briquettes produces from any selected wood specie.

Heat value

The heat value is the term used to describe the energy content of a fuel and thus it is the most important solid fuel property that determines its use for domestic or industrial purpose (Tables 7 and 8). Table 7 presents the mean heat value of the briquettes produced from bark of the wood sample species. The result shows that briquette produced from *Detarium senegalense* bark residue had the highest mean value of 32.82 MJ/kg which is significantly higher ($p < 0.05$) than the others, while briquette produced from *Daniellia oliveri* had the lowest mean value of 30.02 MJ/kg. The values obtained for the three barks is comparable with those reported by (Emerhi, 2011; Ogwu *et al.,* 2014) for briquettes produced from sawdust of varying wood species). The results also agree with the findings of (Abdu-zubairu and Gana, 2014) who carried out study on briquette produced from agro waste but lower than those reported by Tembe *et al.,* (2014) on rice husk, groundnut shells. The implication is that briquettes produced from the bark of wood generally has higher heating values than briquettes made from wood charcoal and sugarcane bagasse and hence, have good potential as solid fuel materials.

Table 7: The mean heat value (MJ/kg) for the briquettes produced from bark of wood species.

Wood samples	Mean
Daniellia oliveri	30.02 ± 0.09c
Detarium senegalense	32.82 ± 0.13a
Acacia nilotica	30.89 ± 0.14b

Mean with same alphabet are not significantly different from each other at p<0.05.

Table 8: Analysis of variance for heat value.

SV	DF	SS	MS	F-cal	F-tab
Treatment	2	2.667	1.333	81.576*	3.682
Error	15	0.245	0.016		
Total	17	2.912			

*Significant at p <0.05.

Conclusion and Recommendation

The measurement of ash content, volatile matter, fixed carbon and heat value are key parameters to be determined in estimating the quality of solid fuel material such as briquettes, the briquettes produced in this study have good handling property which implied that it could be transported over a long distance without disintegration. The following trend was observed in the briquettes produced: Ash Content (*Detarium senegalense* > Daniellia *oliveri* > *Acacia nilotica*), Volatile matter (*Detarium senegalense* > *Daniellia oliveri* > *Acacia nilotica*, Fixed Carbon (*Detarium senegalense* > *Daniellia oliveri* > *Acacia nilotica*) Heat value (*Detarium senegalense* > *Daniellia oliveri* > *Acacia nilotica*). In a nutshell, the efficiency of the briquette produced based on the general proximate analysis follows the trend: (*Detarium senegalense* > *Daniellia oliveri* > *Acacia nilotica*). The production of briquettes for domestic use using bark granules from the three studied wood species is recommended. However, the use of *Detarium senegalense* bark is a more efficient way of briquette production due to the better performance obtained in all the parameters assessed thus a cheaper way of solid fuel utilization in rural areas and also ensuring cleaner environment by reducing the environmental pollution caused by bark burning. Based on this, government and non- governmental organizations should encourage individuals and finance small scale industries in the production of briquette. This bio-energy technology would also provide employment, reduce deforestation, ensure cleaner environment and also reduce quantity of bark waste.

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