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EFFECTS OF CROP RESIDUE-BASED BINDERS ON THE HANDLING CHARACTERISTICS OF WATER LILY BRIQUETTES

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ABSTRACT

Water lilies, commonly found in shallow water bodies, are found in the Niger Delta region because of the presence of rivers and streams. The study investigated the effect of binder type and concentration on the handling characteristics of water lily briquettes, produced using crop residues, namely, Cassava peels (CA), yam peels (YA), and banana peel (BA) as binders. A dwell time of 20 minutes was observed during the production of the sample briquettes, while a pressure level of 5 MPa was applied for the compaction. Based on the results, the durability of CA-bonded fuel briquettes ranged from 78.21% to 94.24%, while CA bonded and BA bonded fuel briquettes recorded durability value ranges of 77.93% – 93.03% and 75.63% – 90.29%, respectively. The relaxed density of the CA bonded fuel briquettes ranged from 0.522g/cm^3 to 0.548 g/cm^3, while YA bonded fuel briquettes and BA bonded fuel briquettes recorded relaxed density range of 0.521 g/cm^3 to 0.533 g/cm^3 and 0.513 g/cm^3 to 0.518 g/cm^3, respectively. A general improvement of handling properties was recorded with increment of binder concentration. Fuel briquettes with less than 90% durability are not recommended for production as they do not meet threshold strength for handling, by standard (DIN 51731:1996-10).

Keywords: Water Lily, Yam Peel, Energy, Shattering Index, Bioenergy

1.0 INTRODUCTION

Energy is fundamental to the sustainable development of any Nation. Due to the hypocritical approach of Nigerian leaders in addressing the energy needs of the country, the country has not recorded meaningful development in any perspective as a Nation; therefore, it's a clarion call on all patriotic citizens, especially of the Engineering community to come up with affordable energy solutions that will alleviate the plight of our people (Tariebi and Davies). This study is done to investigate some handling characteristics of water lily briquettes, with the aim to have a pre-information about the proper handling of this potential solid fuel, which could be used as an alternative to charcoal and fire-wood to meet energy needs. Briquette is compressed biomass that can be used for heating applications. Process variables (dwell time, compaction pressure, binder proportion, etc.) and feedstock variables (moisture content, particle size, etc.) affect its properties (Davies and Davies, 2014). A reasonable amount of agricultural wastes are produced in many developing nations example of which is cassava peels, yam peels and banana peels but they are often used inefficiently, severely polluting the environment (Tariebi and Davies, 2024, Kaliyan and Morey, 2009). Nigeria is endowed with several networks of Rivers and Streams, especially in the Niger Delta region which battles with the menace of aquatic weeds, with the Government spending amounts running into millions of naira on a yearly basis (Tariebi and Davies, 2024).

Aquatic weeds are plants that grow around or in aquatic bodies, and are characterised by rapid growth. They create several challenges such as: Contribution to Flooding by reduction of water holding capacity, Impedance of Recreational and fishing activities, Creation of habitation for Dangerous Reptiles, hampering of normal operation of Dams, canals, and irrigation facilities etc. Plate 1 is Water Lilies infestation along a creek in Amatolo Town, Southern Ijaw Local Government Area, Bayelsa State (Tariebi, 2025).



Plate 1: Water Lily (Nymphaea spp.)

The briquetting of water lily weeds with crop residues as binding agents is a sustainable way of tackling both the aquatic plants' menace on our rivers as well the problem of indiscriminate disposal of crop residues on the environment. Coconut fiber, sawdust, peanut shell, rice husk, etc. as biomass resources have been experimentally investigated by different researchers for their potential densification into fuel briquettes (Tariebi and Davies, 2024). The current work offers important insights into a few handling characteristics of briquettes made from 1.18 mm water lily particles with various Agro-waste binders at various binder concentration levels and compaction pressure level of 5 MPa. Mulu et al., (2024) investigated and characterized briquettes derived from water hyacinth (*Eichhornia crassipes*) and khat (*cathna edulis forsk*) and concluded that briquettes made from 100% of khat expressed the best combustion characteristics, followed by briquettes made from mixture of khat and water hyacinth at 75:25 and 50:50 ratio. They also reported that briquettes made from 100% of water hyacinth residue recorded highest in terms of durability index and water resistance. Davies and Davies, (2014) investigated water lily briquettes from particle size of (0.075), using plantain peel, yam peel, cassava peel and banana peel as respective binders and reported a general improvement of physical properties with binder increment. They also reported that cassava peel bonded briquettes recorded the highest physical and mechanical handling characteristics. Nkemdirim, (2014) investigated briquette of dried leaves using clay, starch and Arabic gum as binders separately. Based on her report, briquettes produced with 20% of starch as binder were outstandingly the best with a high heating value of 30.2189MJ/kg, a durability index of 81.752% and a high relaxation ratio of 1.7427. However, these reports are

limited as binder type, particle size, binder concentration, etc., as feedstock variables, and compaction pressure, dwell time, temperature of die etc., as process variables has significant impact on the results.

Significant work has been done on aquatic weeds' briquetting by researchers, but there is a dearth of information on the comparative investigation of handling characteristics of water lily briquettes bonded by crop residues (cassava peels, yam peels, and banana peels, respectively). Thus, this study investigated the handling characteristics of briquettes produced from water Lilies that were bounded with cassava, yam and banana peels.

2.0 METHODOLOGY

2.1 Water Lily Harvest and Pretreatment

Water Lily plant samples were collected for this study from a stream in Amassoma, Southern Ijaw Local Government Area, Bayelsa State, and transported to the Farm Structures Laboratory at the Department of Agricultural and Environmental Engineering, Faculty of Engineering, Niger Delta University, Wilberforce Island, Bayelsa State, Nigeria. The sun-dried water lily plants were chopped into pieces and then comminuted using a disk mill (Plate 3) and Tyler sieves to obtain 1.18mm particle sizes as seen in Plate 2.



Plate 2: Water Lily Grinds



Plate 3: Disk Mill

2.2 Crop Residue Collection and Pretreatment

Samples of crop residue (Yam peels, Banana peels and Cassava peels) were collected from dumping site. After giving them a thorough washing to get rid of foreign bodies, they were sun-dried and ground into smaller pieces to speed up the densification process. Tyler sieves were used to obtain size particles of 1.18mm see (Plate 4-6) which were used for the experiment. In line with procedures followed by (Tariebi and Davies, 2024; Nkemdirim, 2014). The concentration binders were varied from B1 (20%) to B4 (80%) in step increments of 20%, while the weight of water lily plant residue was kept constant across all mixtures. The resulting mixture was hydrated by addition of 200ml of boiled water with consequent stirring until it becomes homogeneous, which then was fed into the die (Plate 7) for densification on a hydraulic compression machine as shown in Plate 8. The briquette was expelled and taken for additional research after a 20minute hold time.



Plate 4: Cassava Peel Powder



Plate 5: Yam Peel Powder



Plate 6: Banana Peel Powder



Plate 7: Die

2.3 Compaction Process

The hydraulic press used for this experiment, which is a product of RANGER, model RP20HD is shown in Plate 8 below. It consist of a frame, actuator hydraulic cylinder with two toggle levers, a central hydraulic cylinder with protruding piston for compaction, hydraulic connection lines, two retracting springs mounted adjacent to the piston from both sides, a dial gauge, a pressure control valve. In order to produce the fuel briquettes, the control valve was closed, a cylindrical mould, filled with the feedstock to the brim, was placed on the anvil of the machine, the piston was actuated by hydraulic cylinder via the manual pumping action of the two toggle levers, which descends into an auxiliary piston, that is part of the mould, consequently compacting the feedstock in the mould, which then was allowed for 20 minutes hold time, before ejection for further experimentation. The piston retracts back to its original position, under the action of retracting springs, when the control valve is opened, which relieves the system of the pressure generated, consequently making the machine ready for another cycle of compaction. Five (5) fuel briquette samples per binder concentration level were produced, 20 fuel briquettes per binder type, and 60 fuel briquettes, in total across the three binder types was produced. The replication of briquette samples per binder concentration level, was done to minimize errors associated with measurements by using the mean of the measurements from five fuel briquette samples. A pressure value of 5MPa was used for this experiment.



Plate 8: Hydraulic Compression Machine

2.4 Physical Properties of Sample Fuel Briquettes

Physical characteristics such as relaxation ratio, compressed density, relaxed density shattering index were investigated under this study (Tariebi and Davies, 2024; Sotande and Alandele, 2010).

2.5 Compressed Density of Fuel Briquettes

Compressed densities of the briquettes were evaluated as the ratio of mass of freshly demolded briquettes in grams to their respective volumes in cubic centimeters. The mass was measured with digital weighing balance shown in Plate 9, while the volume was calculated after the linear dimensions of the briquette sample were obtained using vernier calipers. It was then calculated using equation (1) below (Tariebi and Davies, 2024; Olorunnisola, 2007)



Plate 9: Digital Balance with 0.01g Precision

$$\text{Compressed Density} = \frac{MEASURED\ MASS\ (g)}{CALCULATED\ VOLUME\ (cm^3)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ 1$$

2.6 Relaxed Density of Fuel Briquettes

Relaxed density was determined after ensuring that the fuel briquettes produced has been dried to a stable state, as the ratio of the dried briquette's mass in grams to the volume of dried briquette in cubic centimeter, derived from its new stable linear dimensions, in line with the procedure adopted by (Tariebi and Davies, 2024; Olorunnisola, 2007) expressed in equation (2).

$$\text{Relaxed Density} = \frac{MASS\ OF\ DRIED\ BRIQUETTE\ (g)}{NEW\ VOLUME\ \ OF\ DRIED\ BRIQUETTE\ (cm^3)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ 2$$

2.7 Relaxation Ratio of Fuel Briquettes

This was determined as the ratio of compressed density to relaxed density in accordance with (Tariebi and Davies, 2024; Bolufawi and Bamgboye, 2014) as expressed in equation (3).

$$\text{Relaxation Ratio} = \frac{COMPRESSED\ DENSITY}{RELAXED\ DENSITY} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ 3$$

2.8 Shattering Index of Fuel Briquettes

Durability or shattering index, gives a picture of the briquette's interaction with material handling equipment and was evaluated based on ASTM D440-86 (ASTM 2002) Standard. The relaxed briquette was pre-weighed and then released to drop gravitationally from a height of 1.5meter onto a concrete base. After that, a sieve with a 2.36 mm aperture was used to filter the material, taking record of the mass that was retained on the sieve. This was done in triplicate and the mean recorded using equation (4) (Kpalo et al., 2020; Suprin, 2008).

$$D = \frac{M_a}{M_b} \text{x } 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ 4$$

Where, M_a – Mass of briquette after dropping and that was retained on sieve,

M_b – Mass of briquette before dropping and

D – Durability in percentage.

3.0 RESULTS AND DISCUSSION

3.1 Water Lily Briquettes

Plate 10, show samples of crop residues bonded water lily fuel briquettes using cassava peels (CA), yam peels (YA), and banana peels (BA) as binders separately, while corresponding sections illustrate the effect on the handling characteristics.



Plate 10: Water Lily fuel briquette samples

3.1 Effect of Binder Level on Relaxed Density of Water Lily Fuel Briquettes (WL-B)

Relaxed density of water lily fuel briquettes, has a positive correlation with binder concentration level across all binder types, as illustrated (Fig. 1). Based on the outcome of study, cassava peel bonded briquettes recorded relaxed density ranged from 0.522 g/cm^3 to 0.548 g/cm^3, while of yam peel bonded briquettes and banana peel bonded fuel briquettes were recorded relaxed density range of 0.521 g/cm^3 to 0.533 g/cm^3 and 0.513 g/cm^3 to 0.518 g/cm^3, respectively. The improvement in relaxed density could be as a result of better agglomeration of particles, encouraged by the presence of the binders, which also agrees with the reports of (Thabuot et al., 2015) concerning holey bio-briquettes. The concentration of the binder in the feedstock indicated statistical significance on relaxed density of the fuel briquettes, at ($p<0.05$).

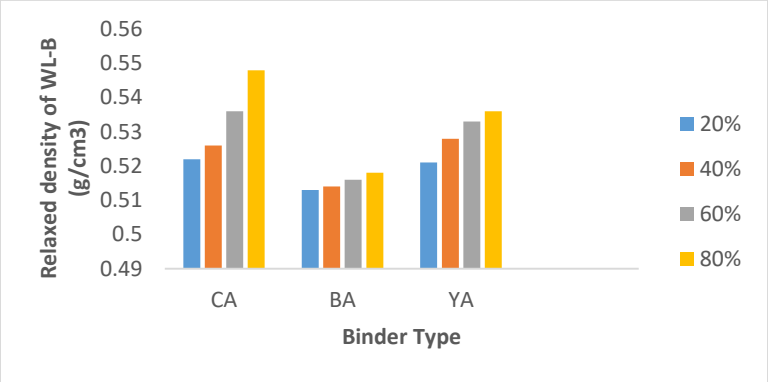


Figure 1: The Effect of Binder Level on Relaxed Density

3.2 Effect of Binder Level on Compressed Density of Water Lily Fuel Briquettes (WLB)

Compressed density of cassava peel bonded fuel briquettes, range from 0.619 g/cm^3 to 0.641 g/cm^3, while yam peel bonded fuel briquettes and banana peel bonded fuel briquettes recorded value ranges of 0.616 g/cm^3 to 0.638 g/cm^3 and 0.608 g/cm^3 to 0.617 g/cm^3. Fig. 2 below, shows that an increase in the binder ratio led to an increase in the compressed density of the fuel briquettes, which is consistent with report on briquettes made from municipal waste (Rajaseenivasan et al., 2016; Thabuot et al., 2015). Cassava peel as binder recorded the highest density range, which could be attributed to higher starch content, which gelatinizes in the presence of water and heat (Ai and Jane, 2024), leading to significant bonding strength, better agglomeration among feedstock particle with a consequent improvement in overall density of the briquettes, which idea is also supported by the report of (Davies and Davies, 2014) concerning water lily briquettes. Application of two-way ANOVA on the results of compressed density of the fuel briquettes, showed statistical significance across binder types and concentration, at ($p<0.05$).

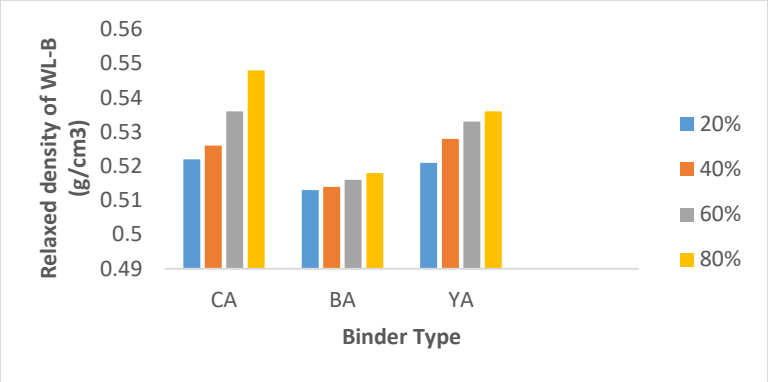


Figure 2: The effect of binder level on compressed density

3.3 The Effect of Binder Level on the Relaxation Ratios of Water Lily Fuel Briquettes

From Figure 3, the relaxation ratio for cassava peel (CA) bonded briquettes varied from 1.204 to 1.233 depending on the binder level, with a mean value of 1.218, while banana peel bonded briquettes and yam peel bonded briquettes recorded relaxation value range of 1.186 – 1.190 with a mean of 1.189 and 1.183 – 1.190 with 1.185 as mean respectively, for binder levels of B1 (20%) to B2 (80%) of the residue weight of water lily. Figure 3 demonstrates a positive correlation between Relaxation ratio and the binder level across all the three binder types used, i.e., an increasing trend of Relaxation ratio with increment in the binder level, this is in conformity with a researched reports on coconut husk briquettes and groundnut and melon shell briquettes (Bolufawi, 2011; Oladeji et al., 2009). Given that lower relaxation ratio values indicated a lower tendency of elastic property and more stability and higher relaxation ratio values indicated a higher tendency of elastic property and less stability, the observed relaxation ratio values obtained for this study across all binder levels suggest that the fuel briquettes have good packaging, storage, and transportation qualities with yam peel bonded briquettes leading as testified by their lower values of relaxation ratios (Oladeji & Enkweremadu, 2012). Application of analysis of variance on experimental results, indicated that the concentration of the binder has no statistical significance on the relaxation ratio of the fuel briquettes at ($p<0.05$).

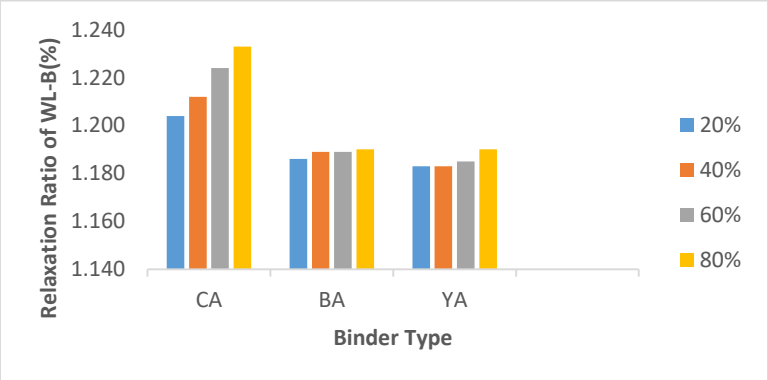


Figure 3: Effect of binder level on Relaxation Ratio

3.3 The Effect of Binder Level on the Shattering Index of Water Lily Fuel Briquettes

As illustrated in Figure 5 below, the fuel briquettes' shattering index exhibits an increasing trend as the binder is added. A possible explanation for the increase in the shattering index with higher binder concentration could be the amalgamation of the constituent components, leading to a strong bonding of particles with more binding agent present. The shattering index or durability of the banana peel bonded water lily fuel briquettes ranged from 75.63% to 90.29% with a mean value of 85.85%, while cassava peel bonded fuel briquettes and yam peel bonded fuel briquettes recorded durability value ranges of 78.21% – 94.24% with 88.63% as mean and 77.93% – 93.03% with 87.87% as mean respectively, for binder levels of 20% to 80% of the residue weight of water lily grinds. In line with standards for solid fuels (DIN 51731-1996-10), fuel briquettes below 90% durability are not recommended for production as they demonstrated higher level of fragility when subjected to an impact force. Similar trend of results was reported by these researchers (Borowski, 2007; Borowski and Hycnar 2013; Gwenzi et al., 2020) on sawdust briquette mixed with neem powder, (Rajaseenivasan et al., 2016 and Kpalo et al., 2020) on a maize cob and oil palm trunk bark briquette and (Yaman et al., 2001) on briquettes made by mixing lignite with leftover paper. Statistical analysis of experimental results showed that the concentration of the binders has statistical significance on the shattering index of crop residue bonded water lily fuel briquettes at ($p<0.05$).

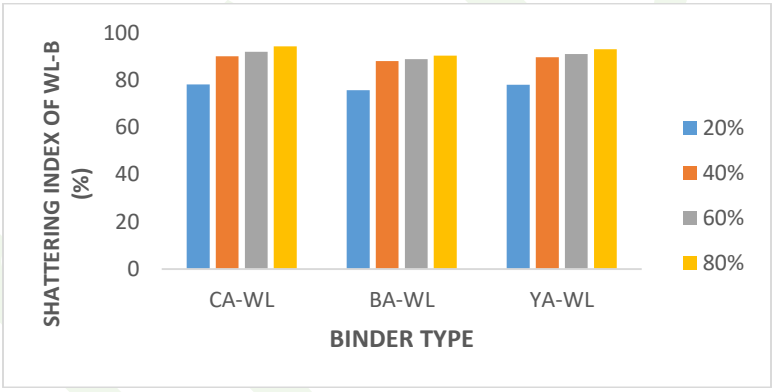


Figure 4: Effect of binder level on the Shattering Index of water lily fuel briquettes

4.0 CONCLUSION

The crop residue bonded water lily fuel briquettes are ecofriendly and has the potential of contributing to environmental sustainability, waste management and local economies, when produced. The percentage of binder added to the feedstock had a substantial impact on the handling properties of the water lily fuel briquettes. Cassava peel bonded water lily fuel briquettes exhibited the highest, in respect to mechanical handling characteristics, followed by yam peel bonded fuel briquettes and banana peel bonded fuel briquettes. Based on findings, every physical property examined showed improvement as the binder level increased; however, because briquettes below 90% durability level do not satisfy requirements for handling by solid fuel standard (DIN 51731-1996-10), hence are not recommended for production. Thermal characteristics of crop residue bonded water lily fuel briquettes, should also be studied to know their suitability for household

and small-scale industrial heating applications. The information gotten from this research will serve as a guide to producer about the right binder ratio for production of stable crop residue bonded water lily fuel briquettes.

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