RESEARCH ARTICLE
ISSN 2279 – 0586

DENSIFICATION OF WATER HYACINTH FOR BIOFUEL

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ABSTRACT

The major source of energy to the rural community is fuelwood because other sources of energy (electricity, gas and kerosene) are either not available or grossly inadequate where available and they are beyond the reach of the masses. Fuelwood collection has grave consequence on environment resulting in greenhouse gas emissions (GHG), forest conservation and sustainable forest resources management. The selection of water hyacinth as alternative source of energy is an important way of managing the weed problem and contributing to environment management. The physical characteristics of the water hyacinth briquettes were evaluated. The results were statistically analysed using Analysis of Variance (ANOVA), Duncan Multiple Range Test (DMRT). The ungrounded sample presented the lowest bulk density (34.69kg/m^3). The obtained values for initial density of uncompressed mixture of water hyacinth at different binder levels varied between 133.14±7.40 (B_1) and 174.28±8.76kg/m^3 (B_5). The analysis of variance (ANOVA) indicated that the mean values of compressed density at different binder proportions showed significant difference at $P<0.001$. The interaction between relaxed density and binder levels varied between 421.39 ±7.91kg/m^3 (B_1) and 497.01 ± 10.37kg/m^3 (B_5). The relaxed density increased with increased binder proportion. The mean shattering index ranged between 0.62±0.02 (B_1) and 0.96 ±0.01 (B_5) and variation of the values was significant ($P<0.001$). It could be concluded that the production of water hyacinth briquettes is feasible and are environmentally friendliness as compared to firewood and charcoal.

KEYWORDS: Bulk density, Compression, Plantain, Particle Size and Niger Delta.

INTRODUCTION

Water hyacinth has attracted the attention of scientists to use it as a potential biomass for production of biofuel because of its high growth yield and availability in large amount throughout the year and all over the world [1]. Rademaker [2] reported the combination of water hyacinth with brakenfern and water lettuce as a means of enhancing the production of biogas, a medium grade fuel. Koser *et al.* [3] reported densification of heat treated water hyacinth using high technology a double roll press, ram extrusion press and pellet mill. Densification of forest products and its by-products, agricultural residues and agro-industrial residues have been long recognized as a viable technology for alternative energy generation [4]. It is reported that most biomass in its natural form is difficult to be utilized as fuel because it is bulk, wet and dispersed [5].

The major limitations in utilizing biomass as an energy source include low bulk densities and irregular size, making transportation, handling and storage cost enormous. Densification of biomass wastes to the briquettes form is an attractive option for upgrading the biomass properties. The briquetting of biomass improves its handling characteristics, produces a uniform, clean, stable fuel, increases the volumetric calorific values, reduces transportation, collection, and storage costs and makes it available for a variety of applications and or an input for further refining processes [6]. Due to the advantages of densification, several biomass materials have been experimentally studied to convert to densified fuels, for example, saw dust, rice husk, peanut shell, coconut fibre, palm fruit fibre[7], rice straw [8],water hyacinth [9], pine cone, olive refuse, paper mill waste, cotton refuse, [10] palm shell [11] wheat straw [12] and [13]. The combustion of dense granulated and uniformly sized biomass can be easily monitored and controlled more than loose, low bulk density biomass and thereby reduce emissions [14].

Densification increases the biomass bulk density 40-200Kgm^{-3} to a final bulk density of 600-800Kgm^{-3}. These limitations can be overcome by compacting and converting the residues into a high density form. Compression bailing can reduce biomass volume to one-fifth of its loose bulk volume. Nende[*et al.* [15] reported that briquetting of biomass can be done by direct compact, piston press and screw press technology without mixing it with some kind of binder, or using roll or char briquetting. To manufacture binderless briquettes from different biomass a piston or screw press must be utilized.

The machines comes in different forms such as mechanical piston press, hydraulic piston press, conical screw extruder, screw extruder without die heating and twin screw extruder. Several factors affect the strength of briquettes. These include the chemical and physical characteristics of the biomass and as well as the variables of the densification processes such as forming pressure, moisture content, temperature, feed constituent, die dimension, feed particle size.

The pre-treatment operations on dry water hyacinth sample such as addition of binder (organic and inorganic) and partial pyrolysis is pertinent due to high pressure, temperature and hence energy requirement in existing briquetting presses is considered unattainable as this make the cost of technology prohibitive [16]. This study aims at investigating the effect of binder. Compaction pressure and particle size on the densification of water hyacinth residue and possibility of utilizing water hyacinth as alternative source of energy, as an important way of managing the weed problem and contributing to environment management

MATERIALS AND METHODS

This study involved collection of samples in Port- Harcourt, Niger Delta and is located between latitudes 4^0 2" and 6^0 2" North of the equator and longitudes 5^0 1" and 7^0 2" East of the Greenwich meridian. The water hyacinth was harvested manually. Water hyacinth sample was cleaned to devoid of foreign matters (stone, dust and plant materials) prior drying. The sample was sundried and finally milled to desire particle sizes using hammer mill. The particle size distribution was achieved by using Particle Size Analysis Equipment consisting of sieve shaker and Tylers sieves of various diameter or particles size openings. The percentages of binder used in the mixture were 10, 20, 30, 40 and 50%. The agitating process was done in a mixer to enhance proper blending prior compaction.

The pre-treatment processing of briquette sample for this study comprised of drying, size reduction and compaction operations. The raw materials were sundried for 5-7days. The dried raw materials were ground using hammer mill. The particle size distribution was achieved by using Particle Size Analysis Equipment consisting of sieve shaker and Tylers sieves of various diameter or particles size openings 0.5, 1.6 and 4mm (Table1). The percentages of binder used in the mixture were 10, 20, 30, 40 and 50% (Table 1). The agitating process was done in a mixer to enhance proper blending prior compaction. A steel cylindrical die of dimension 14.3mm height and 4.7mm in diameter was used for this study. The die was freely filled with known amount of weight (charge) of each sample mixture and be positioned in the hydraulic powered press machine for compression into briquettes.

The piston was actuated through hydraulic pump at the speed of 30mm/min of piston movement to compress the sample. Compacted pressure ranged from 3.0 – 9.0MPa (Table 1). A known pressure was applied at a time to the material in the die and allowed to stay for 45 seconds (dwell time) before released and the briquette formed was extruded. Stop watch was used for purpose of timing. Prior the release of applied pressure the maximum depth of piston movement was measured for the purpose of calculating the volume displacement to enable the determination of compressive density of the briquette. Each briquette was replicated three times according to the level of process variables. The moisture content of the ground material before and after compaction was determined using ASABE [17] standard. The bulk density of the loose materials used was measured according to ASABE [17]. The relaxed and

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compressive densities of briquettes were determined according to reported literature [18, 19].

Table 1. Process variable

Process variable	Different levels
Compaction pressure	P_1 (3MPa), P_2(5MPa), P_3(7MPa) and P_4 (9MPa).
Binder proportion	B_1(10%), B_2 (20%), B_3 (30%), B_4 (40%) and B_5 (50%).
Particle size	D_1 (0.5mm), D_2 (1.6mm) and D_3 (4.0mm).

The data was analysis using Analysis of variance, Duncan Multiply Range Tests and descriptive statistics. All the analyses were carried out with SPSS statistical software.

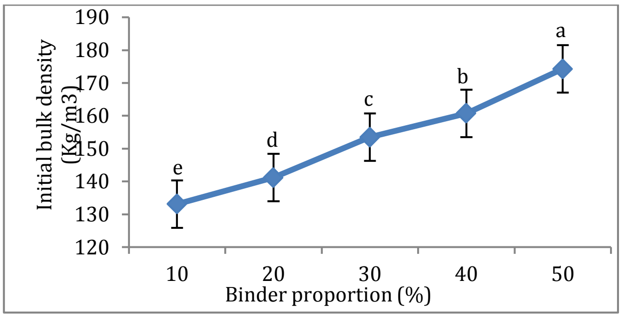

Figure 1. Initial bulk density and binder proportion of briquette (Means of different letter are significantly different (P<0.05))

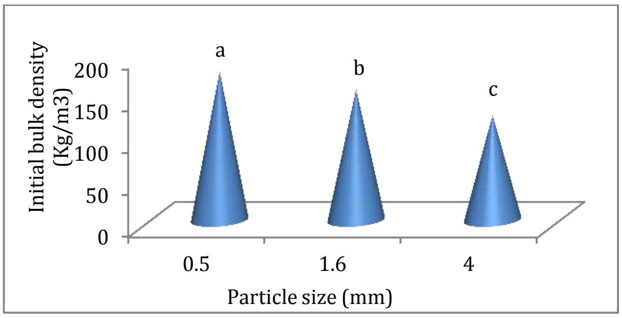

Figure 2. Initial bulk density and particle size of briquette (Means of different letter are significantly different (P<0.05))

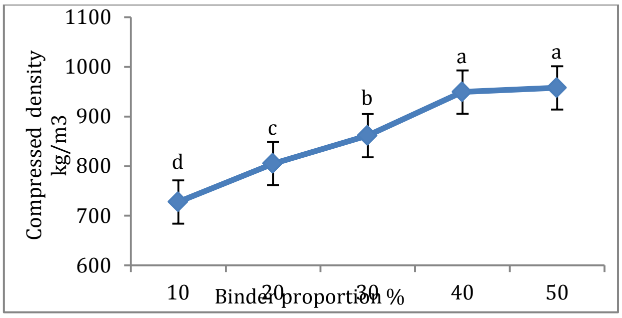

Figure 3. Compressed density and binder proportion of briquette (Means of different letter are significantly different P<0.05))

RESULTS AND DISCUSSION

A summary of the results of bulk density of ungrounded and grounded water hyacinth are shown in Table 2. The obtained results for ungrounded and grounded water hyacinth for bulk and tap densities were investigated at the 7.9% moisture content wet basis. The ungrounded sample presented the lowest bulk density (34.69kg/m^3). Milling water hyacinth, the bulk density increased to 155.56 kg/m^3 with respect to 0.5mm particle size, 101.69kg/m^3 for particle size 1.6mm and 82.55kg/m^3 for particle size 4mm. This implied that milling process had positive influence on the bulk density of biomass thus particle size of biomass is a function of bulk density. The smaller particles fill the void space than the coarser ones that produce a denser bulk density. The recorded variation increase in the percentage bulk density with respect to particle sizes revealed 349.71% for 0.5mm, 193% for 1.6mm and 139% for particle size 4mm with respect to bulk density of ungrounded water hyacinth. The variation in the bulk density might be adduced to particle shape and size, orientation of the particles, specific density of the individual particles and particle size distribution. Due to milling process, the cost of transportation had been drastically reduced. Furthermore, the design of equipment and process operations such as conveyors, storage silo and as well as heat transfer machines will be greatly affected. In the literature it is reported bulk density of 100 kg/m^3 for water hyacinth of particle size ranging from 0.5-2.5mm and moisture content 11.8% wet basis [3]. That study results are in agreement with the present study observations of bulk densities 82%-155% for particle sizes of 0.5-4mm and moisture content of 7.9% wet basis. The bulk density of grounded water hyacinth (processed) in the present study increased with decreased in particle size of the processed sample. This study is in support of literature report [20] that bulk density of the coir path increased with decreased in the particle size. Hoque *et al.*, [21] made similar observation for wood chips that bulk density is inversely proportional to the wood chips of particle size 0.6-4mm. The bulk densities of loose and standard baled straw were 40kg/m^3 and 110 kg/m^3 respectively as compared with bulk density of unprocessed wood residue, which is approximately 250kg/m^3 [23]. Loose bulk densities of switch grass and wheat straw varied from 49.44kg/m^3 and 24.16kg/m^3 to 266.52kg/m^3 and 111.13 kg/m^3 at 8-60% moisture content for 6, 12, 25 and 50mm particle sizes [20]. Importance of these results indicated the actualization of volume reduction of the raw material which provides a technology benefit.

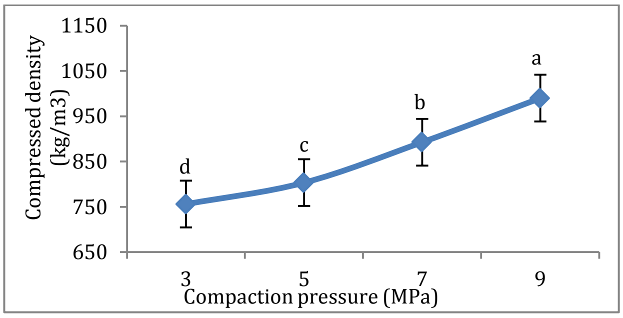

Figure 4. Compressed density and compaction pressure of briquette (Means of different letter are significantly different (P<0.05))

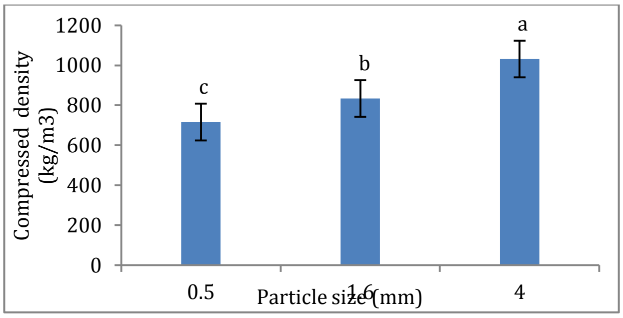

Figure 5. Compressed density and particle size of briquette (Means of different letter are significantly different (P < 0.05))

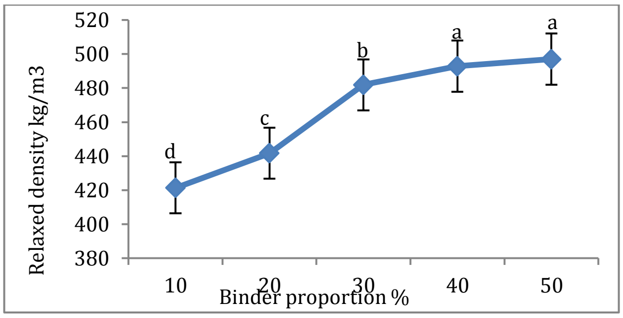

Figure 6. Relaxed density and binder proportion of briquette (Means of different letter are significantly different (P <0.05))

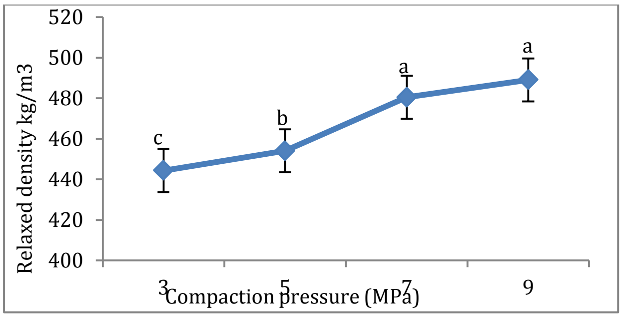

Figure 7. Relaxed density and compaction pressure briquette (Means of different letter are significantly different (P<0.05))

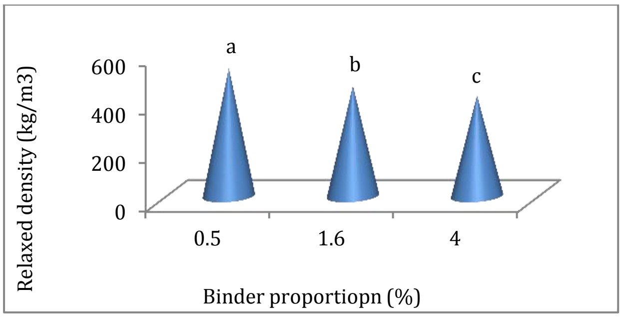

Figure 8. Relaxed density and particle size of briquette (Means of different letter are significant different (P<0.05))

Table 2. Physical properties of the experimental water hyacinth

Whole water hyacinth	Particle size (mm)	Geometric mean diameter (mm)	Bulk density (kg/m^3)	Increment wrt bulk density (%)
Ungrounded	-	-	34.69	-
Grounded	0.5mm	0.25	155.56	349.71
Grounded	1.6mm	0.47	106.69	193.54
Grounded	4.0mm	0.96	82.55	139.63

Note: wrt- with respect to.

Density is an important parameter, which characterizes the briquetting process. If the density is higher, the energy/volume ratio is higher too. Hence, high density products are desirable in terms of transportation, storage and handling or transportation, storage, better material handling and it is cost effective than its natural state.

The influence of binder proportions and particle sizes on the initial bulk density of water hyacinth mixed with binder was investigated. The obtained values for initial density of uncompressed mixture of water hyacinth at different binder level varied from 133.14±7.40 (B_1) to 174.28±8.76kg/m^3 (B_5) (**Figure 1**). The initial bulk density increased with increased in binder proportion. ANOVA and DMRT showed that the difference in the initial bulk density values at the different binder proportions was significant (P<0.001). This signified a desirable development for densification process.

The effect of particle size on bulk density of uncompressed mixture of water hyacinth was investigated. The particle size 0.5mm recorded the highest value of initial bulk density (177.08±4.63kg/m^3), followed by particle size 1.6mm (155.64±3.68kg/m^3) and the lowest particle size was 4mm (124.99±3.61kg/m^3) (**Figure 2**). ANOVA and DMRT indicated significant difference in these values. The bulk densities of water hyacinth with binder were higher (177.08 kg/m^3, 155.64 kg/m^3 and 124.99 kg/m^3) (**Figure 2**) than those of unmilled (34.69kg/m^3) and milled (155.56 kg/m^3, 106.69 kg/m^3 and 82.55 kg/m^3) 100% water hyacinth.

The effect of binder proportions on compressive density of briquettes was studied compressive density of briquettes at the different binder proportions are presented in **Figure 3**. The recorded values showed increased in binder (10-50%) with increased compressed density [727.80 ±44.61 (B_1) to 957.89 ± 19.02kg/m^3 (B_5)]. The analysis of variance (ANOVA) indicated that the mean values of compressed density at different binder proportion showed significant difference at P<0.001 but Duncan Multiple Range Test (DMRT) showed that there was no significant difference between the values of compressed density at B_4 (949.45±25.43 kg/m^3) and B_5 (957.89±19.02 kg/m^3). The data presented showed that briquettes consisting water hyacinth and 10-30% binder recorded lower resistance to compression than briquettes with higher binder levels. The upsurge observed in compressed density with increased binder inclusion could be attributed to relative increase in the initial bulk density of the biomass. The recorded values of compressed density were higher than the initial bulk density (133.14±7.40kg/m^3) of the uncompressed mixture of water hyacinth and binder. It is clearly shown that compressed density is directly proportional to binder proportions. This trend was in agreement with the values reported by Olorunnisola [18] for production of fuel briquettes from waste paper and coconut hush admixture ranged from 8.1 to 11.2kg/m^3 at different binder levels. The effect of binder proportion on compressed density was studied by Sotannde *et al.,* [19] and that study reported that the difference in binder type and blending ratio had significant effect on the compressed density of the briquettes (P<0.05).

The effect of compressed pressure was equally determined on compressive density and the obtained values ranged between 755.81 ±25.14kg/m^3 (P_1) and 989.82 ± 30.94kg/m^3 (P_4) as shown in **Figure 4**. This signified that the higher the pressure the higher the compressive density hence, high density is desirable to reduce the cost of transportation, handling and storage. Furthermore, the densified products could easily be handled using standard handling and storage equipment [13, 23, 24, 25}. ANOVA and DMRT indicated that the differences among the compressed density values of the briquettes at the different compaction pressure levels were statistically different (P<0.001).

The effect of particle sizes as a function of compressed density of briquettes was presented in **Figure 5**. The briquettes processed with 0.5mm particle size had the lowest compressed density (715.75 ± 18.76kg/m^3) while particle size 4mm recorded the highest compressive density (1031.36 ± 15.28kg/m^3). ANOVA and DMRT indicated that the values of compressed density of the briquettes at particle sizes 0.5mm, 1.6mm and 4mm were significantly important (P<0.001). The observed reduction in the compressive density related to particle size 0.5mm could be attributed inter particle bonding with virtually no inter-particle pores. The porosity index of fine particle is lower than medium and large particle size Olorunnisola [18]. The importance of briquettes density cannot be over emphasized since it has direct relationship with bulk thermal properties of the briquettes. The density of fuel briquette is a function of thermal conductivity, burning rate, thermal decomposition and as well as ignition time.

One of the major parameters in densification is relaxed density. Densification of biomass is a process of reducing the bulk volume of the material by mechanical means for easy handling, transportation and storage. Relaxed density is dependent on these factors: the initial density of the biomass, compaction pressure, binder types and levels and particle size of the biomass. The variations of relaxed density of the briquettes under five binder levels, four compaction pressure levels and three different particle sizes after 10-14 days of densification process were recorded.

The effect of binder proportions on relaxed density of briquettes was investigated. The interaction between relaxed density and binder levels varied from 421.39 ±7.91kg/m^3 (B1) to 497.01 ± 10.37kg/m^3 (B5) (**Figure 6**). The relaxed density increased with increased binder proportion. The ANOVA showed significant difference (P<0.001) for the relaxed density of briquettes at the different binder proportions. DMRT indicated significant difference for all the binder proportions except for B_4 and B_5. It could be inferred that the optimum amount of binder required for densification was 40% (B_4) above this level depicted economic loss. At this level of binder, the produced briquettes have the required strength to withstand handling, transportation and storage. Conversely, the corresponding report by Sotannde *et al.,* [19] revealed that the binder types and blending ratio had no significant influence (P>0.05). The binder (plantain peels) used in this research work competed favourably with more than 50 organic and inorganic binders that have been reported for densification. Similar trend was reported by [26, 27] on the relationship between relaxed density and binder proportions. Those studies reported increased in relaxed density with increased in binder proportion for the production of sawdust and palm oil sludge briquettes. Increased in relaxed density with increased binder proportion was equally observed by Chin and Siddiqui [7] for production of some briquettes from sawdust, rice husk, peanut shell, coconut fibre and palm fibre.

The effect of compaction pressure levels on relaxed density of briquettes determined. The interaction between compaction pressure and relaxed density of briquettes was studied. The values ranged between 444.37±10.01 kg/m^3 (P_1) and 489.04±9.69 kg/m^3 (P_4) (**Figure 7**). ANOVA showed that there was significant difference among the values of relaxed density at the different compaction pressure levels but DMRT indicated significant difference except for P_3 and P_4. It could be inferred that the optimum pressure required for densification is P_3 and above this level it could be regarded as waste of energy. A general trend of increased relaxed density was observed with increased compaction pressure. This could be attributed to the possible compactness of the material as pressure increases and the reduction in elastic recovery during relaxation of the formed briquette.

The effect of particle size on relaxed density of briquettes was studied. From **Figure 8**, the relaxed density varied from 529.85±7.45kg/m^3 (D_1) to 415.40±4.61kg/m^3 (D_3). DMRT and ANOVA showed that the relaxed density values at the different particle sizes were significantly different ($P<0.001$). Relaxed density is one of the most important properties that influence handling characteristics, hygroscopic characteristics, and combustion characteristics such as ignition and burning rate behaviour of briquettes. The reduction in the values of relaxed density compared to compressive density could be attributed to considerable elastic recovery and stress relaxation processes that occurred after the briquette was removed from the die to attain its final and stable state. The observed values of relaxed density indicated that briquette of particle size 0.5mm possessed lowest elastic property while briquettes of particle sizes 1.6mm and 4.0mm were of higher elastic property. The particle size reduction increased the total surface area, pores size of the material and the number of contact points for inter-particle bonding in the compaction process. The present study revealed that the smaller the particle size, the lesser the porosity, and on the contrary, the higher the relaxed density of the briquettes according to Saptoadi [28].

CONCLUSION

It was revealed from the study that process variables (particle size, binder proportion and compaction pressure) significantly affect the densification of water hyacinth briquettes. The effect of particle size on bulk density of uncompressed mixture of water hyacinth showed inverse relationship.
Milling process had positive influence on the bulk density of water hyacinth residue. Relaxed density increased with increased binder proportion and compaction pressure. Particle size had inverse relationship with relaxed density. Compressive density increased with increased binder proportion and compaction pressure. Particle size had positive relationship with compressive density.

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