Effect of Processing Variables on Compaction and Relaxation Ratio of Water Hyacinth Briquettes

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Abstract. Fuel wood collection has grave consequences 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 water hyacinth and plantain peels were milled into three particle sizes 0.5, 1.6 and 4.0mm, five binder levels 10, 20, 30, 40, 50% and four pressure levels 3, 5, 7 and 9MPa were used. Manually operated hydraulic press was used for the production of briquettes. The experimental design for this study was 5 x 3 x 4 Randomized Complete Block Design. ASABE standard methods were used to determine the moisture contents, compaction ratio and relaxation ratio of the briquettes. The minimum compaction ratio was obtained at pressure $P_1$ (5.19±0.27) and the maximum at pressure $P_4$ (6.80±0.36). The effect of binder on the compaction ratio ranged from 5.87±0.31 ($B_1$) to 6.04±0.25 ($B_4$) for all the five binder proportions utilized. The ANOVA revealed that there was significant difference among all the values obtained for compaction ratio at the various binder levels ($P<0.001$). The values of compaction ratio obtained indicated more void in the compressed materials. This signifies more volume displacement which is good for packaging, storage and transportation and above all, it is an indication of good quality briquettes.

Key word: Bulk density, compaction, plantain peels, particle size, Niger Delta

1. INTRODUCTION

Compression and densification of forest products and by-products, agricultural residues and agro-industrial residues have been long recognized as a viable technology for alternative energy generation (Hamelink and Faaij, 2006). FAO (1990) reported that most biomass in its natural form is difficult to be utilized as fuel because it is bulk, wet and dispersed. 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, increases the volumetric calorific values, reduces transportation, collection, and storage costs and makes it available for a variety of applications (Grover and Mishra, 1996). Due to the advantages of densification, several biomass materials have been experimentally studied to convert to densified fuels, for examples, saw dust, rice husk, peanut shell, coconut fibre and palm fruit fibre (Chin and Siddiqui, 2000); rice straw (Ndiema et al., 2002); water hyacinth (Heinz et al., 1983); pine cone, olive refuse, paper mill waste, cotton refuse (Yaman et al., 2001); palm shell (Husain et al., 2002); wheat straw (Wamukonya and Jenkins, 1995) and wastes paper (Demirbas and Sahin, 1998).

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. Nendel (1998) 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 binder less 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 (Olorunnisola, 2004). The properties of the biomass materials (solids) that are important to densification are: flow ability and cohesiveness (lubricants and binders can impart these characteristics for compaction), particle size (too fine a particle means higher cohesion, causing poor flow), surface forces (important to agglomeration for strength), adhesiveness, hardness (too hard a particle leads to difficulties in agglomeration) and particle size distribution (sufficient fines needed to cement larger particles together for a stronger unit).

The production of briquette is viewed as an advanced fuel because of its clean burning nature and it can be stored for long periods of time without degradation. Therefore, a micro enterprise can be formed. Any entrepreneur can create briquette from agricultural wastes and sell them in a local market for personal income. In this way, more money stays within the community rather than being exported for foreign fuels. By turning something that was previously unused into a means by which to produce income, the wealth of individual entrepreneurs and the country in general is increased. Utilization of water hyacinth as biofuel is an important way of managing the weed problem and contributing to environmental management as well as creating employment and generating income for those who are most affected by it. The main objective of this study therefore was to investigate the effects of process variables on the compaction ratio and relaxation of water hyacinth briquettes.

2. MATERIALS AND METHODS

This study involved collection of samples in Port-Harcourt, Niger Delta and is located between latitudes $4^\circ 2''$ and $6^\circ 2''$ North of the equator and longitudes $5^\circ 1''$ and $7^\circ 2''$ 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 for 5-7 days. 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 (Table 1). 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 14.3 mm height and 4.7 mm 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 30 mm/min of piston movement to compress the sample. Compacted pressure ranged from 3.0 – 9.0 MPa (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 (2003) standard.

2.1. Compression ratio (Equation 1)

Compression ratio is described as the ratio of the density of the in-die briquettes to initial bulk density of residue. The compaction ratio was determined based on ASABE (2003) standard.

2.2. Relaxation ratio (Equation 2)

Relaxation ratio can be described as the ratio of the compressed density and relaxed density of the briquettes (Bamgboye and Bolufawi, 2008).

\[
\text{Compaction ratio} = \frac{\text{Compressed density}}{\text{Initial bulk density}}
\]

\[\text{Equation 1}\]
Relaxation ratio = \frac{\text{Compressed density}}{\text{Relaxed density}} \tag{2}

Table 1: Process variables at different levels of treatment

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

2.3. Statistical analysis

The data was analysis using Analysis of Variance (ANOVA), Duncan Multiply Range Tests (DMRT) and descriptive statistics. All the analyses were carried out with SPSS statistical software (2007).

3. RESULTS AND DISCUSSIONS

3.1. Relaxation ratio of briquettes and binder proportions

The relaxation of the briquettes varied from 1.76±0.12 (B_1) to 1.98±0.07 (B_5) for the five studied binder levels (Fig. 1). The difference in the relaxation ratio of briquette at the different binder proportions was significant (P<0.001). The DMRT also showed significant difference. The obtained values of relaxation ratio signified that briquettes of low relaxation ratio exhibited low elastic property and more stabled while briquettes of high relaxation ratio exhibited high tendency of elastic property and less stable. Similar observation was made by O’Dogherty (1989) for briquettes produced from hay material had relaxation ratio of 1.68 to 1.8. In addition, Olorunnisola (2007) recorded relaxation ratio of 1.8 to 2.5 for briquettes from wastes paper and coconut shell.

3.2. Relaxation ratio of briquettes and compaction pressure

The effect of pressure on the relaxation ratio was determined as shown in Fig. 2. The relaxation ratio ranged from 1.74±0.08 (P_1) to 2.07±0.09 (P_4). The obtained range of relaxation ratio in this study is still within the reported range of 1.8 to 2.5 and 1.65 to 1.8 as reported by O’Dogherty (1989) and Olorunnisola(2007), Sotanne et al.(2010) reported relaxation ratio values 1.11 and 1.32 for briquettes produced from charcoal and Arabic gum respectively but briquettes made from charcoal and cassava starch had relaxation ratio values of 1.17 and 1.34. The DMRT and ANOVA showed that there was significant difference in the relaxation ratio at the different compaction pressure levels (P<0.001).

3.3. Relaxation ratio of briquettes and particle sizes

A cursory view at the Fig. 3 revealed the relationship between particle size and relaxation ratio. The particle size 0.5mm (D_1) had the lowest relaxation (1.35±0.02), followed by particle size 1.6mm (D_2) (1.80±0.05) and the highest (2.51±0.04) was recorded for particle size 4mm (D_3). This is an indication that particle size is directly proportional to relaxation ratio. DMRT and ANOVA showed that variation in the relaxation ratio values at the different particle sizes was significant. These values showed that briquettes produced from D_1 were more stable than those from 1.6mm and 4mm particle sizes. Post compression recovery of the briquettes has been shown to be wasteful energy input due to poor briquettes production (Faborode and O’Callaghan, 1987).

It could be inferred that the more the permanent deformation the better the densification process. Briquettes made from coarser rice husks tend to expand more significantly shortly after released from the briquetting machine (Bamigboye and Bolufawi, 2008). Other studies on the effect of binder types, binder levels, compaction pressure and particle sizes on relaxation ratio of biomass briquettes are Ajayi and Lawal (1995), Ivanov et al. (2003); Jindaporn et al. (2005) and Sotanne et al. (2010).
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Fig. 1: Relaxation ratio and binder proportion of briquettes
Means of different letter are significantly different (P<0.05)

Fig. 2: Relaxation ratio and compaction pressure of briquette
Means of different letter are significantly different (P<0.05)
3.4. Compaction ratio of water hyacinth and binder proportions

The effect of binder on the compaction ratio ranged from 5.87±0.31 (B₁) to 6.04±0.25 (B₄) for all the five binder proportions utilized (Fig. 4). The ANOVA revealed that there was significant difference among all the values obtained for compaction ratio at the various binder levels (P<0.001). The DMRT showed that there was no significant difference between compaction ratio at B₁ (5.91±0.51) and B₂ (5.99±0.40). The values of compaction ratio obtained in this study compare and compete favorably with notable biomass residues. Contrary to the findings of Oladeji (2012) that the higher the binder inclusion, the lesser the compaction ratio. This is an indication that there is more resistance to compression as the binder ratio increased. Compaction ratio of 3.80 was obtained during briquetting of rice husk (Oladeji, 2010), while compaction ratios of 4.2 and 3.5 were obtained during briquetting of groundnut and melon shells respectively (Oladeji et al., 2009).

3.5. Compaction ratio of water hyacinth and compaction pressure

The influence of compaction pressure on the compaction ratio of briquettes was tested. The minimum compaction ratio was obtained at pressure P₁ (5.19±0.27) and the maximum at pressure P₄ (6.80±0.36) (Fig. 5). The ANOVA and DMRT showed significant difference for the compaction ratio values of the water hyacinth briquette at the different compaction pressure (P<0.001). Compaction pressure and compaction ratio were directly correlated. This is an indication that void space could be expelled at higher compaction pressure.

3.6. Compaction ratio of water hyacinth and particle size

Compaction ratio was directly proportional to particle size. The values of compaction ratio ranged from 4.02±0.08 (D₁) to 8.35±0.19 (D₃) (Fig. 6). DMRT and ANOVA indicated significant difference for the compaction ratio at the different particle sizes (P<0.001). Faborede and O’Callaghan (1987) reported that the percentage of voids in an unconsolidated mass of materials is considered important to its mechanical behavior as it affects such processes concerned with air flow, heat flow and compressibility. The recorded significant maximum compaction ratio at binder B₄, pressure P₄ and particle size D₃ indicated that briquettes produced from B₄P₄D₃ was the best among other briquettes. This briquette produced from this densification process might be of measurable high quality, stable, durable and reliable fuel briquettes.Bamgboye and Bolufawi (2008) reported compaction ratio that varied from 3.194 to 9.730 for briquettes from Guinea corn (sorghum bi-color) residue. It was observed that compaction ratio increased with increasing pressure and decreased with increased binder ratio. This showed that void spaces are expelled at higher pressures while less void spaces are present in the residue with higher binder quantity. There was more resistance to compression as the binder ratio increased.
Fig. 4: Compaction ratio and binder proportion of briquettes
Means of different letter are significantly different (P<0.05)

Fig. 5: Compaction ratio and compaction pressure of briquettes
Means of different letter are significantly different (P<0.05)
4. CONCLUSION

A general trend of increased relaxed density was observed with increased binder proportion and 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. It could be inferred that the optimum pressure required for densification is P₃ and above this level it could be regarded as waste of energy. 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 relaxation ratio of the briquettes improved with binder. The particle size is directly proportional to relaxation ratio. These values showed that briquettes produced from D₁ were more stable than those from 1.6mm and 4mm particle sizes. Post compression recovery of the briquettes has been shown to be wasteful energy input due to poor briquettes production.

REFERENCES


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