EFFECTS OF CONSTITUTIVE CONDITIONS ON UNIT DENSITY OF DENSIFIED SORGHUM AND CASTOR STOVERS

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Abstract

Utilization of agricultural residues (wanted and unwanted) as alternative materials for fossil fuel is of interest due to its environmental friendliness. This paper is aimed to study these materials response to load during densification. Sorghum and Castor stovers grounds were obtained using hammer mill. Different particle sizes were obtained by using three (2 mm, 3 mm, 5 mm) screens in the mill. The grounds were densified using 30000 kN Universal Testing Machine (UTM) model SF300-2041 at three levels of moisture contents and three levels of temperature. The results of the investigation revealed that the highest unit density of castor stover was 1.169 kg/m^3 while that of the sorghum was determined to be 1.188 kg/m^3. There were significant decreases in the unit density as days of storage increases.

Key words: Constitutive, densification, biomass, sorghum stover

1 Introductoin

The density of biomass material plays an important role in the determination of it fuel values. Agricultural biomass, due to its low density limitations, must be processed and handled in an efficient manner to enhance its densification, reduced material waste and increase its bulk density to reduce transportation costs. Jamradloedluk (2007) reported that density is an important property of the solid fuel and that high density products are desirable in terms of transportation, storage and handling of products. In the research work of Kaliyan and Morey (2009), the author recorded unit density of 696 to 1164 kg/m^3 and 419 to 1057 kg/m^3 on the densification of corn stover and switch grass stover respectively at compressive strength of 412 to 946 N.

2 Literature Review

Thoreson et al., (2014) reported that maximum compression pressure of 14.0 MPa was shown to maximize particle density and that only moisture contents below 25 % wb should be used to maximize briquette density and quality. The authors equally stated investigation of process variables on the densification of corn stover briquettes at optimized treatment variables. They revealed that dry particle density increased 50% (310 to 460 kg/m3) when compression pressure increases from 7.0 to 14.0 MPa. Tumuluru et al., (2015) finding revealed that briquettes produced, using an hydraulic press have uniform shape and size, typically 40 x 40 mm cylinders, and unit densities of about 700 – 800 kg/ m^3. The authors further claimed that the quality of briquettes or pellets can be managed by proper control of process and feedstock conditions, formulation, and use of additives. Shastri, (2014) said that the bulk density and flowability of the biomass particles are highly influenced by the particle size and shape.

Briquette densities decreased with increasing feedstock moisture content. Briquettes produced at a low feedstock moistur content of < 9 % (w.b) yielded the highest briquette unit densities > 700 kg/m^3 for all straw samples, whereas briquettes at 15 % (w.b) produced the lowest unit densities with more cracks observed on the surface (Tumuluru et al., 2015). Mambo et al., (2016) developed and carried out performance evaluation of manually operated hydraulic Briquetting machine. Their result revealed that an average value of compressed density was 624. 236 kg/m^3, relax density of 350.093 kg/m3, relaxation ratio of 1.783 for compression of maize cobs using 10 % cassava binder

3 Materials and Methods

The stover materials used in the study were (a) Sorghum Stover and Sorghum Stover Grind (b) Castor Stover and Castor Stover Grind. The equipment used were (a) Purpose- designed and fabricated hammer (b) Purpose- designed and fabricated densification rig (c) Universal Testing Machine (d) Bomb Calorimeter (e) Heating Device (f) Weighing Machine (g) Oven Shaker

Sorghum stover consisting sorghum leaves and stem was obtained from the Department of Agricultural Engineering demonstration farm, Kwara State Polytechnic, Ilorin. The grind was obtained by using the hammer mill to reduce the stover to particle size. Figure 1 shows typical sorghum stover.

Figure 1**:** Dry Sorghum Stem and Leaves**.**

Castor Stover comprising castor leaves and stem was obtained from a fallow plot along Stadium Road, Ilorin, Kwara State. The grind was obtained by using the hammer mill to reduce the stover to the required particle size. Figure 2 shows a typical castor stover.

Figure 2: Castor Stover

The hammer mill used in this research work was developed following engineering procedures for fabrication. The Photograph of the hammer mill is shown in Figure 3

Figure 3 The hammer mil

The experimental densification rig for the study consisted of five major parts namely: Piston, Seat Cap on UTM, Ejection Unit, Compression Chamber, and Base for the Chamber. **The Exploded view of the densified rig is as shown in Figure 4**

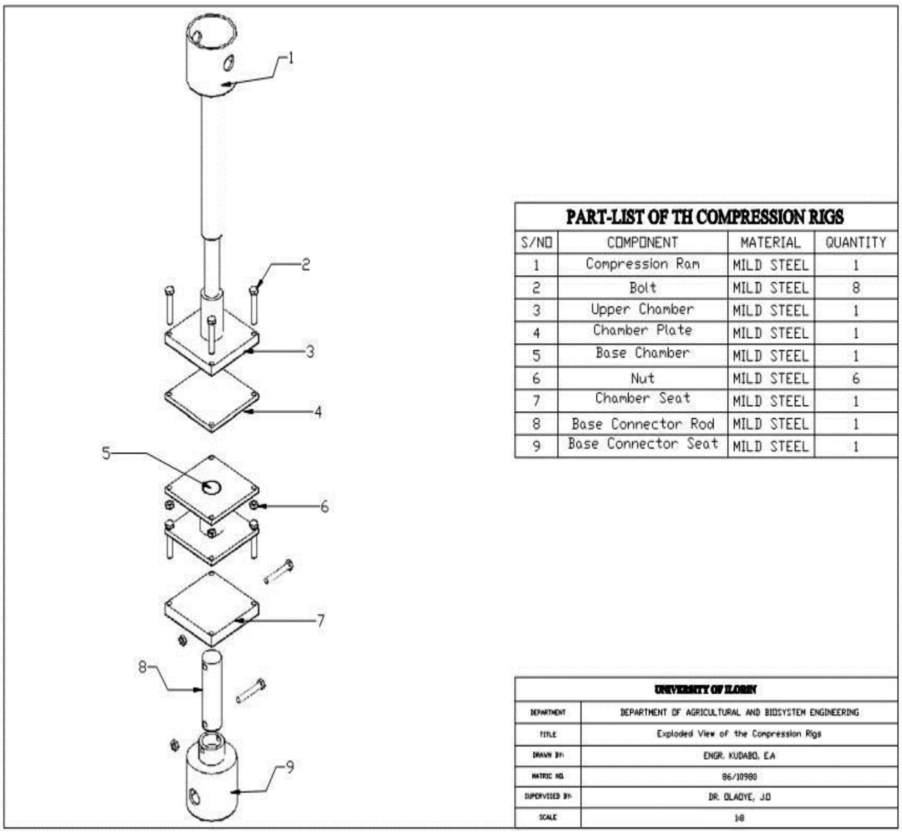


Figure 3: Exploded view of the densification rig

Universal testing machine of model SF 300-2041 at department of Agricultural and Bio-System Engineering, University of Ilorin was used. The Universal Testing Machine is as shown in Figure 5. The universal testing machine has an attached Oven and heating device Siemen TKL-96 (Figure 6).

Figure 4: The Universal Testing Machine

Figure 5: The **heating device Siemen TKL-96**

The sorghum Stover (***Sorghum bicolor***) used in this research was harvested during December, 2014 and stored inside open shed in the Department of Agricultural and Bio-Environmental Engineering Technology, Research farm, Kwara State polytechnic, Ilorin. The hammer mill designed and fabricated in the study was used to grind the sorghum and castor stover. Three screen sizes were used in order to obtain sorghum and castor stover grinds of different particle sizes. The hammer mill grinds with cyclone reduced particle size of solid materials by shear and impact action. Figure 7 and 8 show the photograph of the ground sorghum and castor stover.

Figure 6: Sorghum Stover grind

Figure 7: Castor Stover grind.

After milling, the grinds had about (10 %) moisture content wet basis content. To increase the moisture content of the grinds, a pre determined amount of distilled water was added to the grinds, thoroughly mixed and stored in zip – lock plastic bags at 5^0c for 48hr for tempering (Kaliyan and Morey 2006). Bulk densities of the grinds, were calculated from the mass of grinds that occupied a 250ml glass container (Kaliyan and Morey 2006). While measuring the bulk density of the grinds, the glass container was manually filled by slowly discharging the samples to the container from a height of about 100mm, and the container with the sample was tapped gently about 4 - 6 times on a laboratory bench to remove large voids inside the sample as well as to reduce the sample filling error.

Particle size and particle size distribution of the grinds were determined based on ASAE standard S319.3 (ASAE Standardization 2011) and using Bolt sieve shaker shown in Figure 9. This was done by placing the samples of grind successfully in a stack of sieves arranged from the largest to the smallest opening and placed on the sieve shaker.

Figure 8: The sieve shaker Apparatus and the sample for the determination of particle Size distribution

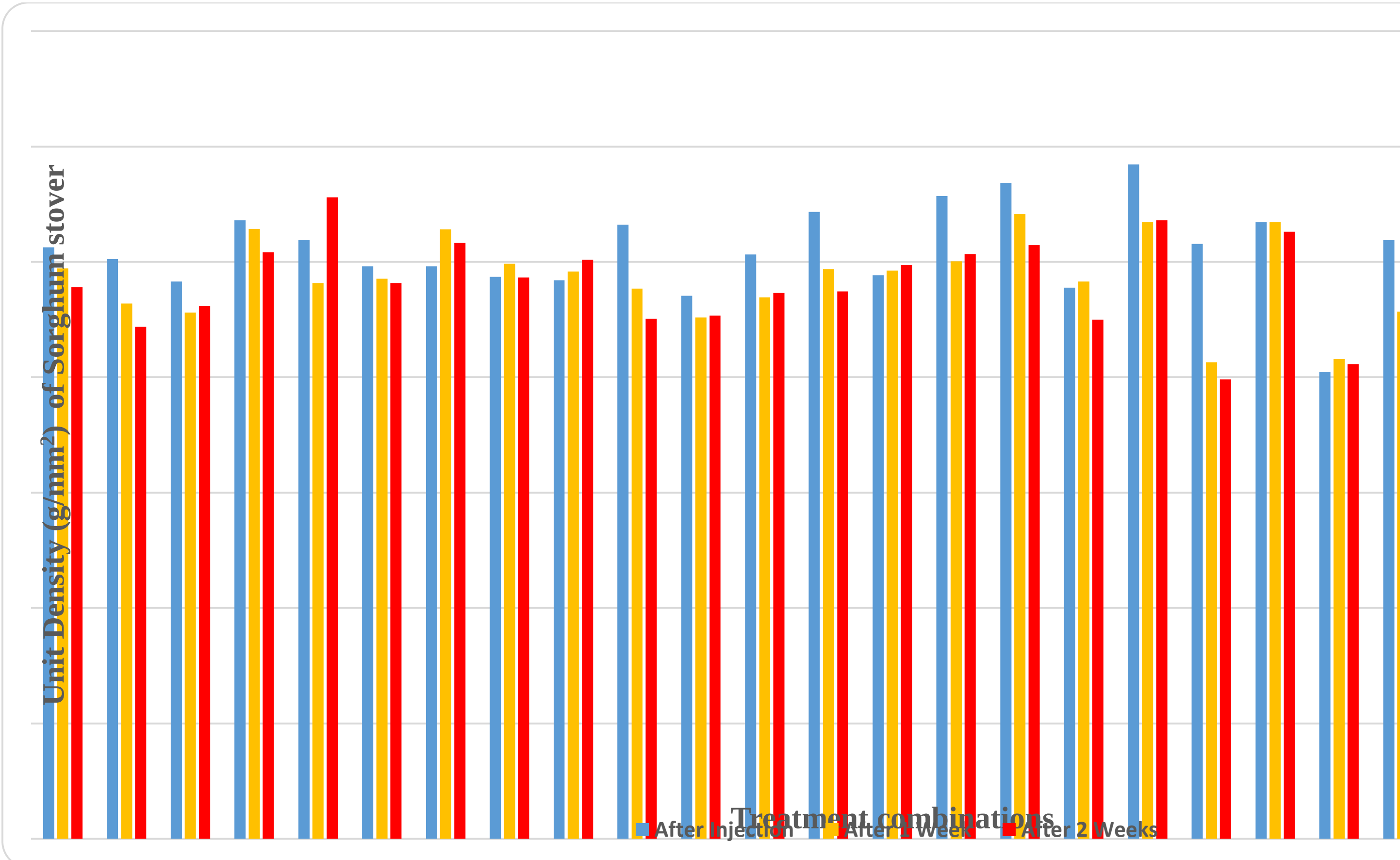
Tests were conducted using universal testing machine FS 300-02041. The machine was controlled by computer installed software. About 10.0g of biomass grind was added to the die with a funnel. A steel rod was used to stir the grind for ease of flow through the funnel. Subsequently the bottom of the piston was inserted into the die, and the top of the piston was connected to the cross head of the testing machine load cell by a pin connection. The control software actuated the crosshead piston to compress the grind from zero pressure to a set maximum pressure at a constant speed of 100 mm min^{-1} (Kaliyan and Morey 2006).

The compression step involved loading (i.e application of pressure) and unloading (i.e removal of pressure) processes. During loading, the piston went down and compressed the grind. During unloading the piston went up and the briquette formed inside the die relaxed. After the completion of the compression stage, the piston was taken out of the die and the die was removed from the base of the machine and the ejection apparatus was then placed on the Universal Testing machine and the die placed on top of the ejection apparatus. A different software setting was used to operate the crosshead – piston to push (i.e eject) the briquette out of the die. A constant crosshead speed of 100 mm min^{-1} was used to eject the briquette. Figure 10 shows the briquettes produced from the test rig system at different conditions.

Figure 109: Sorghum Stover Briquettes

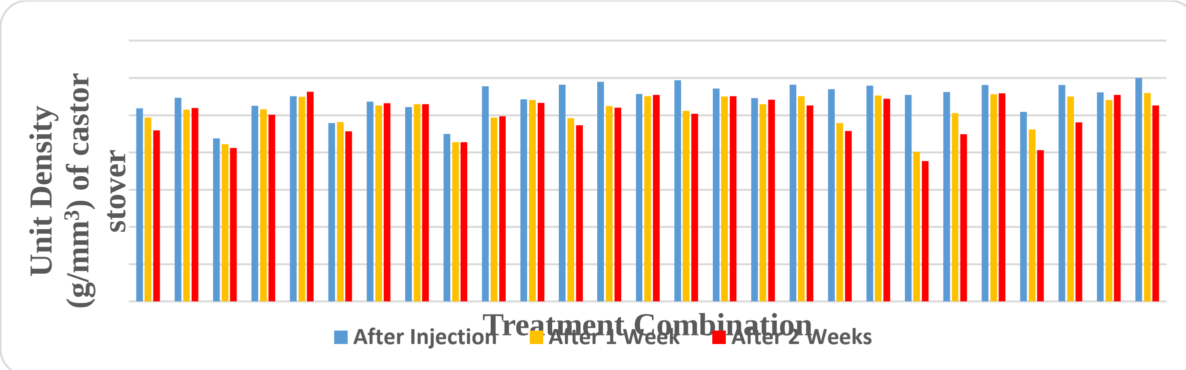
4 Discussions of Findings

Unit density of briquettes was calculated from the mass, diameter and height of the briquettes (ASABE Standards, 2011). The mass was obtained using a sensitive weighing machine while the diameter and height were obtained using venire calliper. These values were obtained immediately after ejection of the briquette from the die and after one and two weeks from the days of ejection from the die. The results obtained are plotted in Figures 11 and 12 for sorghum and castor oil briquettes respectively. Table1 shows the treatment combinations and number as a foot note to the above graphs.



**Treatment combinations 1 to 27 are as defined in table 1*

Figure 1: Effect of treatment combination on the unit density of compressed sorghum stover after injection from the die, immediately, after one week and after two weeks.



**Treatment combinations 1 to 27 are as defined in table 1*

Figure 2: Effect of treatment combination on the unit density of compressed castor stover after injection from the die, immediately, after one week and after two weeks.

Table 1: Treatment combinations for the experiment

S/N	Treatment combination
1	S1M1T1
2	S2M1T1
3	S3M1T1
4	S1M1T2
5	S2M1T2
6	S3M1T2
7	S1M1T3
8	S2M1T3
9	S3M1T3
10	S1M2T1
11	S2M2T1
12	S3M2T1
13	S1M2T2
14	S2M2T2
15	S3M2T2
16	S1M2T3
17	S2M2T3
18	S3M2T3
19	S1M3T1
20	S2M3T1
21	S3M3T1
22	S1M3T2
23	S2M3T2
24	S3M3T2

25	S1M3T3
26	S2M3T3
27	S3M3T3

M1 = First level Moisture Content; 6.3±0.8% w.b;
M2 = Second level Moisture Content; 10.65±0.32% w.b
M3 = Third level Moisture Content; 14.46±0.15% w.b;
S1 = First level Stover Size, 2.00 mm ;
S2 = Second level Stover Size, 3.00 mm
S3 = Third level Stover Size, 5.00 mm
T1 = First level Temperature, 25^{o}C
T2 = Second level Temperature, 50^{o}C;
T3 = Third level Temperature, 80^{o}C

Increasing the nominal moisture content of the grind decreased the unit density of both sorghum and Castor oil stover. It was equally observed from Figure 11 that the unit density decreases as the size increases for briquette produced at temperature of 25 ^{o}C and moisture content of 6.32 ± 0.82 %.

The highest unit density observed in the experiment occurred at the briquette produced of size 5 mm, Moisture content of 10.65 ± 0.32 % and temperature of 80 ^{o}C (S3M2T3) with value 1.169 kg/m^3 for sorghum stover while that of Castor stover occurred at size 5 mm, Moisture content of 10.65 ± 0.32 % w.b and temperature of 50 ^{o}C (S3M2T2) with value 1.188 kg/m^3. Forero-Nunez *et al.* (2015), Kaliyan and Morey (2007) found the same trend in the research on densification of corn stover obtained from hammer mill screen size 3.00 mm and 4.6 mm. This decrease may be ascribed to the relaxation of the intermolecular bonds increasing the volume occupied by the particle (Forero-Nunez *et al.*2015).

Figure 11 and figure 12 present the Histograph of the unit density of the briquette against the storage days under different treatment combination. This is to enable us study what happened to the briquettes as the numbers of day increases for all the treatment combinations. The figures show there were significant drop in the unit density for majority of the treatment combinations. This may be due to the change in briquette mass or volume (possibly due to the drying and elastic – spring back expansion and contraction of the briquettes) during the one- week and two weeks storage. This trend was similar to that of Kaliyan and Morey (2007) that studied the unit density of corn stover and switch grass. It was observed that there exists a decrease in unit density as the storage day increases at room temperature for nearly all the treatment combination. The results are consistent with past finding in Dewangan *et al.* (2016). The significant of this is that the spring back is very low hence durable briquette emerged.

One very important parameter in briquette production is the density. The density of biomass briquettes depends on the density of the original biomass, the pressure, temperature and time of densification. The higher the density, the higher is the energy/volume ratio (Idah and Mopah 2013). The unity density of the sorghum stover decreases on the average of 4.5 % after one week of storage and 6.4 % after two weeks of storage. The implication of this observation is that the stability of the briquette formed is of high quality.

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