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Evaluation of some handling and processing parameters for briquetting of guinea corn (*Sorghum bi-color*) residue

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Biomass materials require reduction and densification for the purpose of handling and space requirements. Guinea corn (*Sorghum bi-color*) is a major source of biomass material in the tropic regions. The densification process involves some measurable parameters, namely: pressure, particles size and binder ratio. Guinea corn residue was collected from the Teaching and Research Farm of the Federal Polytechnic at Bida in Nigeria. The moisture content was 9.08% dry basis (db). It was reduced and sieved into three particle sizes D_1 (4.70 mm), D_2 (1.70 mm) and D_3 (0.60 mm). Starch paste of 40, 45, 50 and 55% was added as binder. Briquettes were produced using a hydraulic press and a cylindrical die (56 mmϕ) at the processing pressures of 7.5, 8.5, 9.5 and 10.5 Megapascal (MPa). The bulk density of the unprocessed material was 46.03 kg/m^3. The mean relaxed briquettes bulk density was 208.15 kg/m^3, which reflects a volume reduction of about 450%. The maximum density of the briquettes ranged from 789 to 1372 kg/m^3. For the expansion characteristics, the maximum and minimum axial relaxation occurred in the first 30 min of the extrusion. All the processing parameters were found to be significant at P<0.05 test level for all the measured characteristics. The briquettes were kept for six months under ambient condition without deterioration.

Key words: Guinea corn, briquettes, residue, parameters.

INTRODUCTION

Mechanics of agricultural material as a scientific discipline is presently being developed. For now, there are many process-material interactions that do not have exact methods of representation. Nevertheless, the experimental methods developed so far, can somehow be used successfully to select, design and optimize machines, (Sitkei. 1986). Heinimo (2008) postulated that at present, biomass covers approximately 11% of the global total primary energy consumption of slightly more than 430 EJ/year. Briquetting of forest products, agricultural wastes and rural-agro industrial residues has long been recognized as a viable technology for

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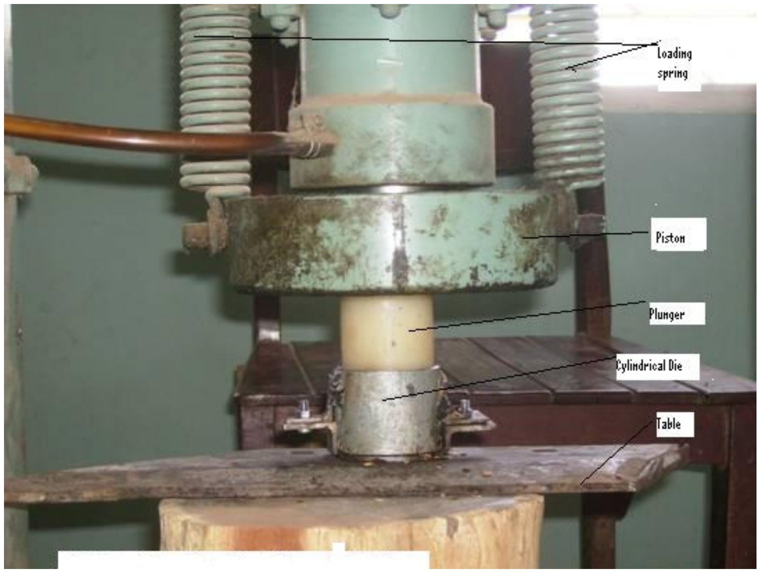

Figure 1. Hydraulic powered press fitted with plunger and cylinder die.

alternative energy generation (Resch, 1982). This statement is also buttressed by Gurkan et al. (2010). Briquetting technology is fast gaining prominence in the world of science today because of its numerous advantages of helping to densify very bulky (low density) materials, particularly those of biomass origin.

The compaction of agricultural residues into briquettes in general terms improves the economics of material handling, transportation and storage, thereby enhancing more versatile application in use. Munoz-Hernandez et al. (2004), identified some methods of achieving densification using commercial machines which include bailing, cubing, pelleting and briquetting; by means of piston, extrusion screws or by roll presses. Furthermore, it was identified that one of the requirements to design, construct and improve densification system is based mainly on the knowledge of suitable levels of process variables such as die geometry, relaxation time, die and material temperature and pressure. Other material variables include moisture content and its distribution, size and shape of the particles, size distribution of the particles, biochemical and mechanical characteristic (Rehkugler and Buchele, 1969). Although the effect of binder is still under intense research, Tabil et al. (1997) concluded that, there exists little scientific information related to the effectiveness of binders. However, a few researchers have postulated that at relatively low pressure application, the effect of binder might enhance densification. Starch has been used as a binding agent for briquetting of Rattan furniture waste and guinea corn (*Sorghum bi-color*) residue (Olorunshola, 2004; Bamgboye and Bolufawi, 2009).

Some researchers have used mechanical elements of commercial machines as experimental prototypes for densification, but the constraints here include, cost of instrumentation and large volumes of materials required for the experiment. Experimental tests by means of presses and laboratory dies for densification have offered easier and less expensive ways to conduct experimental tests under controlled conditions. Under laboratory conditions, technical information needed for economic and technical decisions can be obtained; for instance, in a closed-end die, the temperature and the use of binder can be controlled with high precision such as achieved by Faborode and O'Callaghan (1987) and Mohsenin and Zaske (1976).

The main objectives of this work was to find the levels of some selected processing parameters that provide optimum responses in terms of some measured post briquetting characteristics in briquetting of guinea corn residue. The parameters selected include pressure, particle size distribution, binder quantity and dwell-time.

MATERIALS AND METHODS

A 3 x 4 x 4 randomized complete block design (RCBD) experiment was used to synchronize the parameters of pressure (P), particle size (D) and binder/residue ratio (B) (Gomez and Gomez, 1983) adopting a dwell-time of 90 s. The operating pressures were 7.5, 8.5, 9.5 and 10.5 Megapascal (MPa). The particle size distribution was obtained by size reduction (milling) and sieve analysis. The particle sizes obtained were distributed into three categories: D_1 = 4.70 mm, D_2 = 1.70 mm and D_3 = 0.60mm. The binder/residue ratio was 40, 45, 50 and 55% by weight of binder/residue. Each sample briquette was produced using a fixed die charge packed in a steel cylinder 56 mm diameter positioned and compressed in a hydraulic press as shown in Figure 1. The briquettes formed are displayed in Figure 2.

Some measured characteristics of the briquettes included the bulk and initial densities, maximum and relaxed densities and the rate of expansion. The compaction energies were also determined.

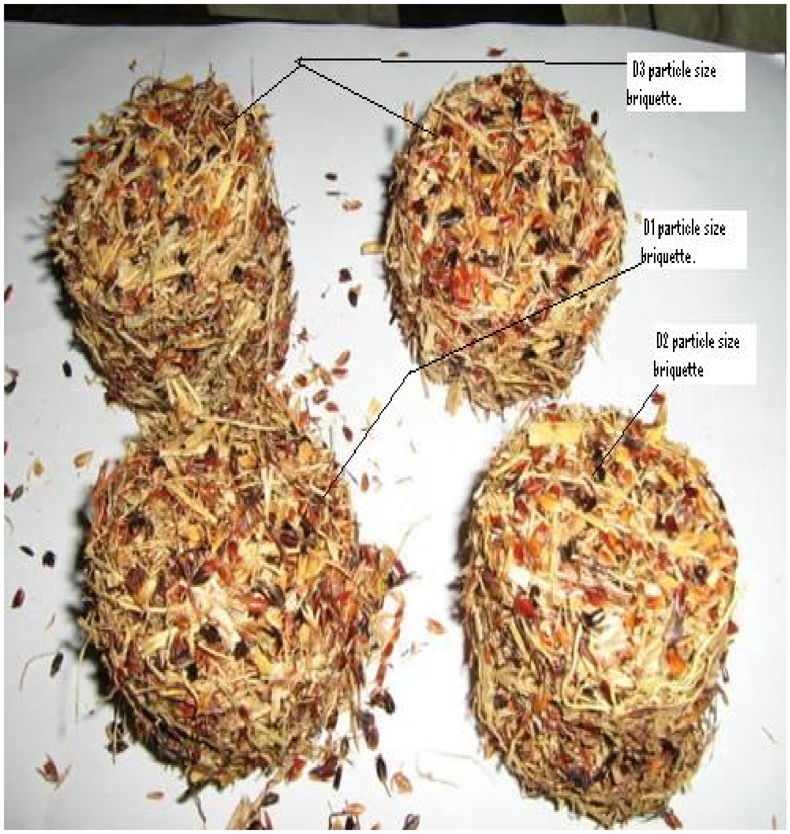

Figure 2. Briquettes produced form the hydraulic press.

Table 1. Initial density (Y_o) Kg/m^3.

Binder ratio (%)	Particle size D_1 (4.7 mm)	Particle size D_2 (1.7 mm)	Particle size D_3 (0.6 mm)
B_1	141	208	175
B_2	149	212	205
B_3	146	216	246
B_4	140	247	250

P, Pressure in Megapascal (MPa); D, particle size in mm; B, binder ratio; Y, density kg/m^3; r, Y_d/Y_o; r_d, Y_r/Y_d; r_r, $1/r_d$.

Other characteristics determined included compaction ratio (r) and relaxation ratio (r_r) which are derivatives of the initial, maximum and relaxed densities. The readings were treated statistically using, means and analysis of variance (ANOVA). Correlation and regression analysis were used to streamline the statistically treated data. The various densities and expansion rates were subjected to ANOVA test to determine the level of significance of the processing parameters (P, D and B) for the measured characteristics. The shelf live was estimated after observing the briquette for the period of six months under ambient condition.

RESULTS AND DISCUSSION

The various densities are in kg/m^3: initial density (Y_o) (zero pressure application), maximum density (Y_d) (in-die density) and relaxed density (Y_r) are displayed in Tables 1, 2 (a, b and c) and 3 (a, b and c).

A careful study of the data in Tables 1 to 3 reveal the following observations: the maximum densities for the particle size D_1, D_2 and D_3 varied from 798 to 1372 kg/m^3 as shown in Tables 2a, b and c. These values are much higher than the initial densities of the uncompressed mixture (141 to 250 kg/m^3) shown in Table 1. Thus, this process has been able to obtain improved density which is a desirable factor in briquetting. The bulk density of the unprocessed material was 46.03 kg/m^3 while the mean bulk density of the relaxed briquette was 208.15 kg/m^{3,} reflecting a volume reduction of about 450%. An increase in the maximum density was observed for all the particle

Table 2a. Maximum density (Y_d) Kg/m^3 (D_1).

Binder ratio (%)	P_1	P_2	P_3	P_4
B_1	1161	1204	1292	1372
B_2	1018	1074	1192	1307
B_3	899	924	987	1050
B_4	789	888	917	1015

P, Pressure in Megapascal (MPa); D, particle size in mm; B, binder ratio; Y, density kg/m^3; r, Y_d/Y_o; r_d, Y_r/Y_d; r_r, $1/r_d$.

Table 2b. Maximum density (Y_d) Kg/m^3 (D_2).

Binder ratio (%)	P_1	P_2	P_3	P_4
B_1	917	980	1030	1110
B_2	899	960	996	1093
B_3	892	932	994	1053
B_4	872	911	932	938

P, Pressure in Megapascal (MPa); D, particle size in mm; B, binder ratio; Y, density kg/m^3; r, Y_d/Y_o; r_d, Y_r/Y_d; r_r, $1/r_d$.

Table 2c. Maximum density (Y_d) Kg/m^3 (D_3).

Binder ratio (%)	P_1	P_2	P_3	P_4
B_1	821	960	1015	1093
B_2	789	928	960	980
B_3	789	861	917	960

P, Pressure in Megapascal (MPa); D, particle size in mm; B, binder ratio; Y, density kg/m^3; r, Y_d/Y_o; r_d, Y_r/Y_d; r_r, $1/r_d$.

Table 3a. Relaxed density (Y_r) Kg/m^3 (D_1).

Binder ratio (%)	P_1	P_2	P_3	P_4
B_1	235	242	244	248
B_2	238	240	244	235
B_3	239	240	240	238
B_4	281	304	289	292

P, Pressure in Megapascal (MPa); D, particle size in mm; B, binder ratio; Y, density kg/m^3; r, Y_d/Y_o; r_d, Y_r/Y_d; r_r, $1/r_d$.

Table 3b. Relaxed density (Y_r) Kg/m^3 (D_2).

Binder ratio (%)	P_1	P_2	P_3	P_4
B_1	347	357	352	248
B_2	334	334	328	245
B_3	329	330	325	243
B_4	324	323	323	292

P, Pressure in Megapascal (MPa); D, particle size in mm; B, binder ratio; Y, density kg/m^3; r, Y_d/Y_o; r_d, Y_r/Y_d; r_r, $1/r_d$.

Table 3c. Relaxed density Kg/m^3 (D_3).

Binder ratio (%)	P_1	P_2	P_3	P_4
B_1	389	405	415	436
B_2	427	435	424	433
B_3	388	400	397	406

P, Pressure in Megapascal (MPa); D, particle size in mm; B, binder ratio; Y, density kg/m^3; r, Y_d/Y_o; r_d, Y_r/Y_d; r_r, $1/r_d$.

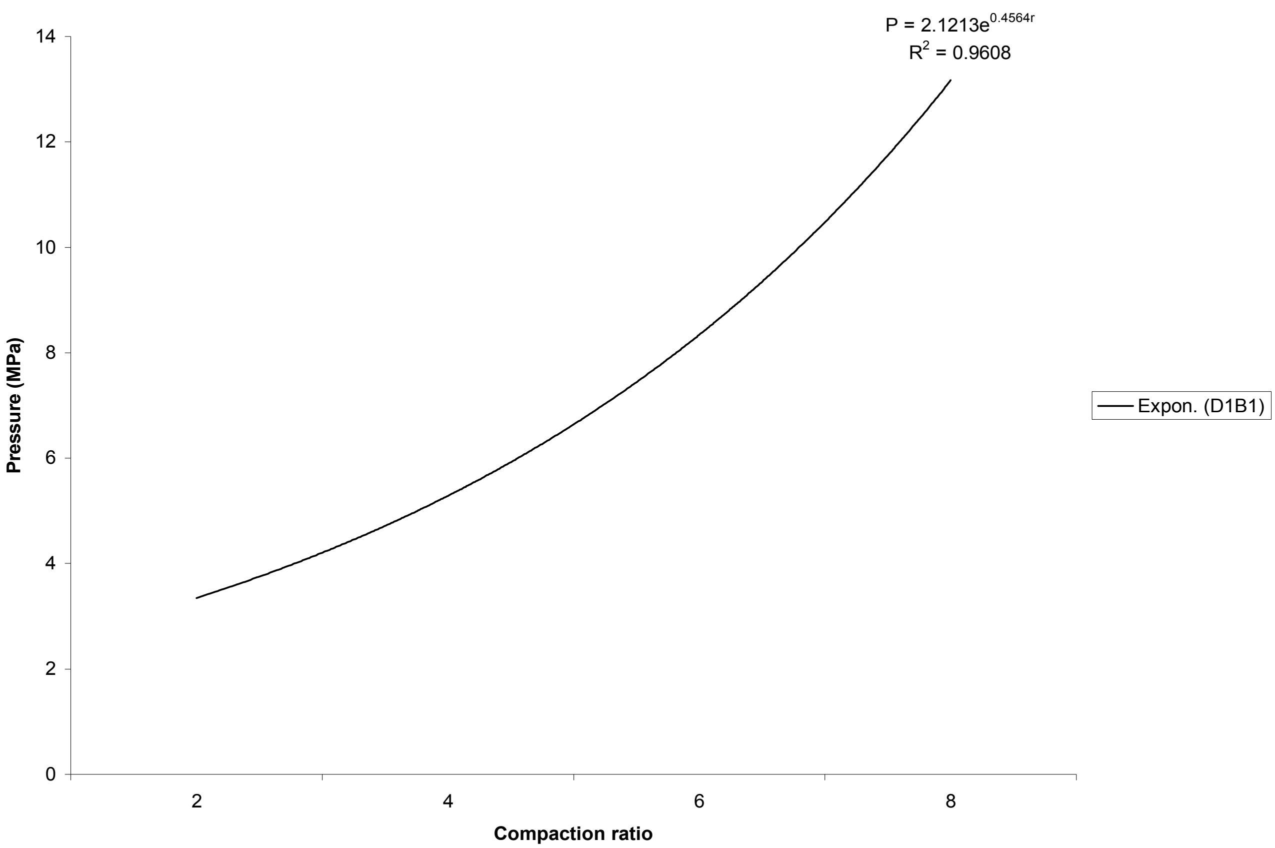

Figure 3. Relationship between pressure and compression ratio for D_1B_1.

sizes with increasing pressure. A decrease in density was also observed with increasing binder ratio. The relaxed briquette densities shown in Tables 3a, b and c were smaller than the recorded maximum densities because of the expansion of the briquette after extrusion.

The ANOVA showed that the effect of the processing parameters, pressure, binder ratio and particle size were significant at $P < 0.05$. The relationship between the selected parameters and some measured characteristics are as shown in Figures 3 to 10. The effects of pressure and compaction ratio on the particle sizes of the material are graphically shown in Figures 3 to 5. The graphs are exponential in nature. The area under each curve in Figures 3 to 5 are estimates of the compaction energy. The energies of compaction are found to reduce with reducing particle size dimension. The rates of expansion of the briquettes considering the binder ratio at the background are illustrated by Figures 6 and 7. It was observed that the most rapid rate of expansion took place in the first 100 min after extrusion. Figures 8 to 10 showed the effect of binder on maximum and relaxed density for briquettes with D_1, D_2 and D_3 particle size. For the expansion characteristic (axial relaxation), the maximum and minimum axial relaxation occurred in the first 30 min of the extrusion with values 138.64 and 28.0% in the longitudinal axis while the maximum and minimum radial relaxation were 11.50 and 4.0%, respectively. For briquettes with D_1 particle size, the maximum density decreases with increasing binder ratio indicating that more of the spaces have been filled with binder materials which to some extent is not compressible. The relaxed density does not exhibit the phenomenon

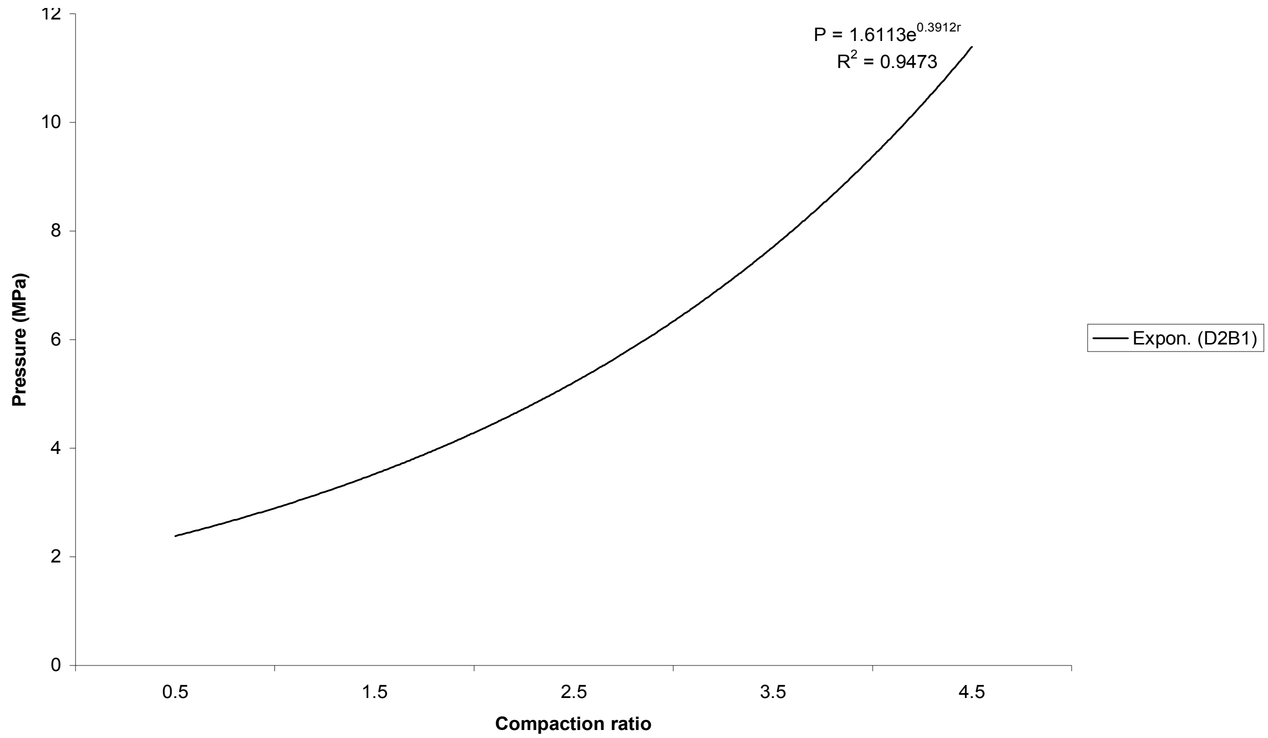

Figure 4. Relationship between pressure and compression ratio for D_2B_1.

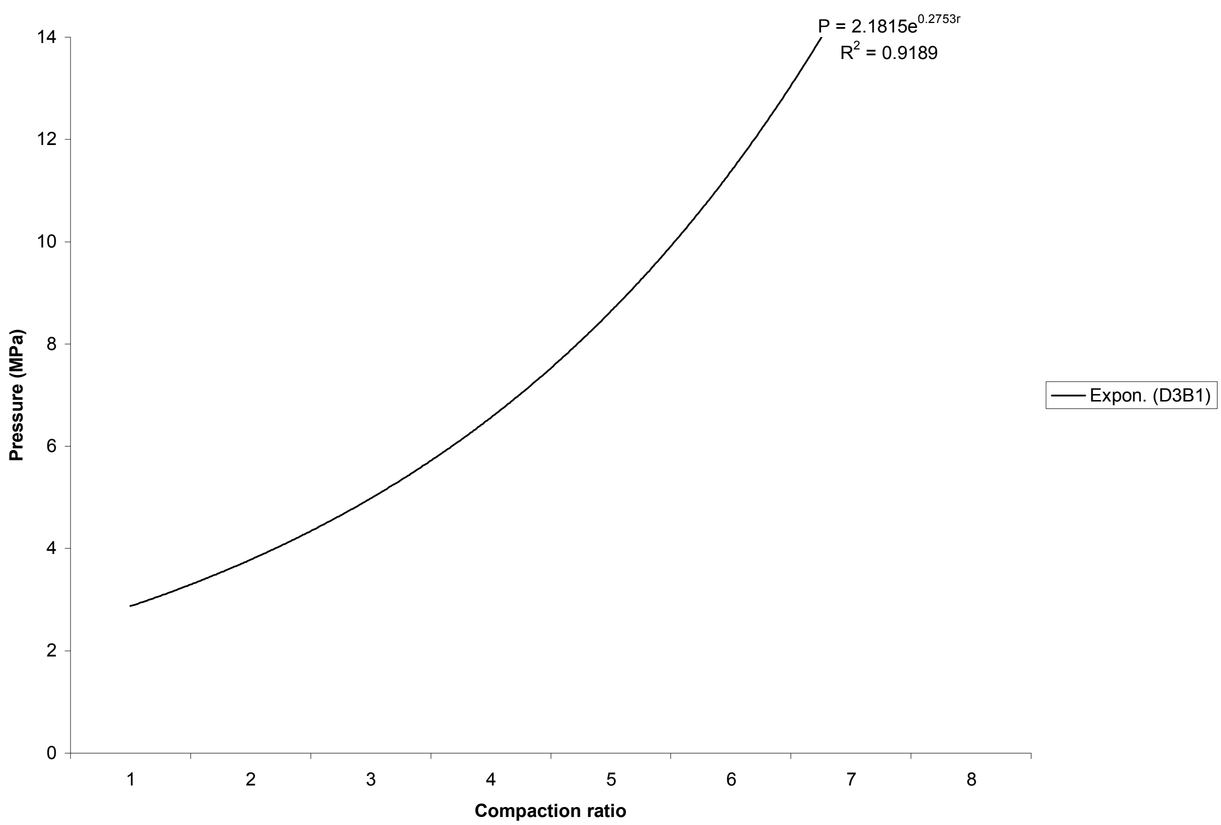

Figure 5. Relationship between pressure and compression ratio for D_3B_1.

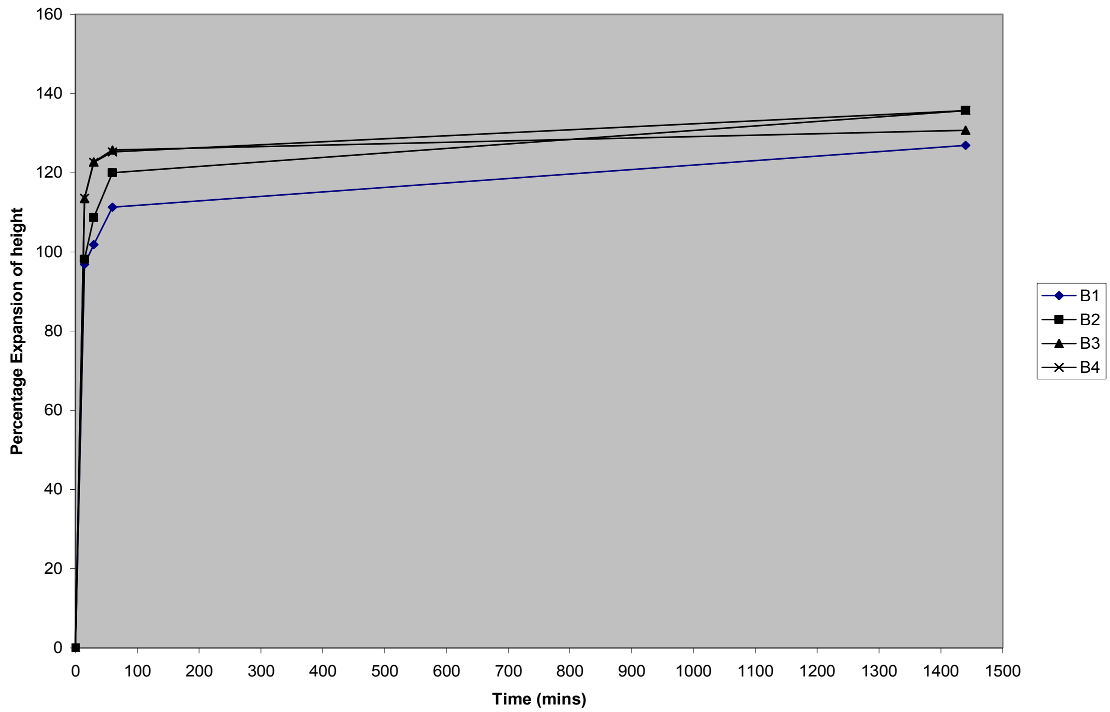

Figure 6. Percentage rate of expansion of briquettes with binder ratio (D_2P_1).

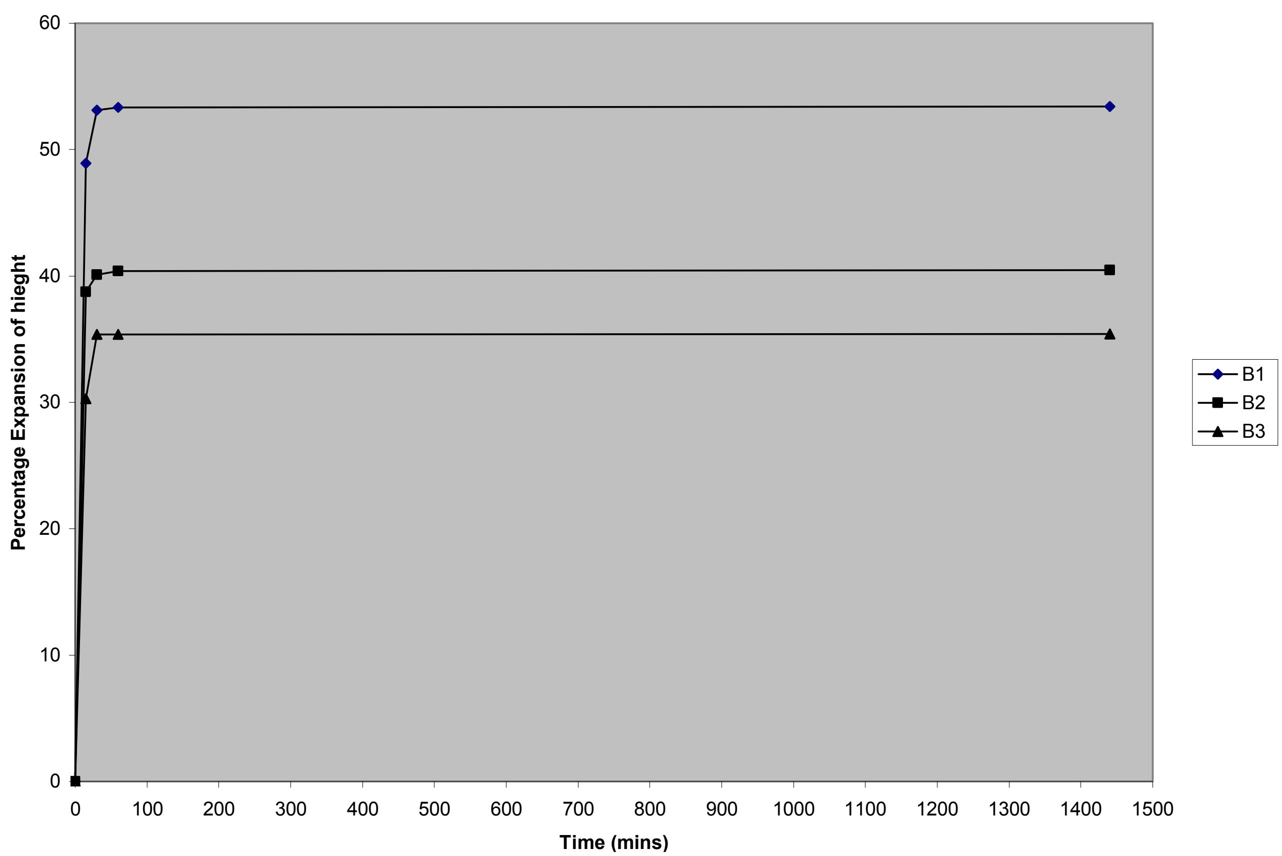

Figure 7. Percentage rate of expansion of briquettes with binder ratio (D_3P_1).

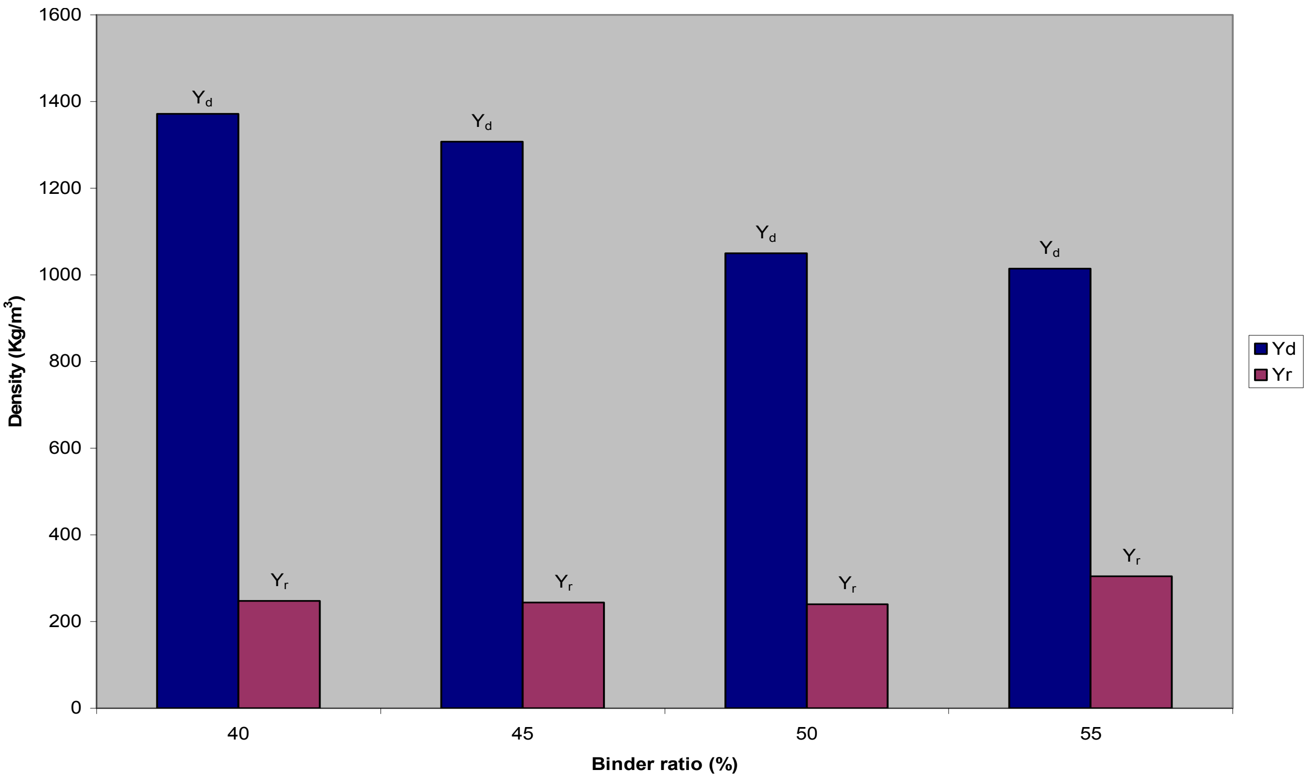

Figure 8. Effect of binder ratio on maximum and relaxed density for D_1 particle size briquettes.

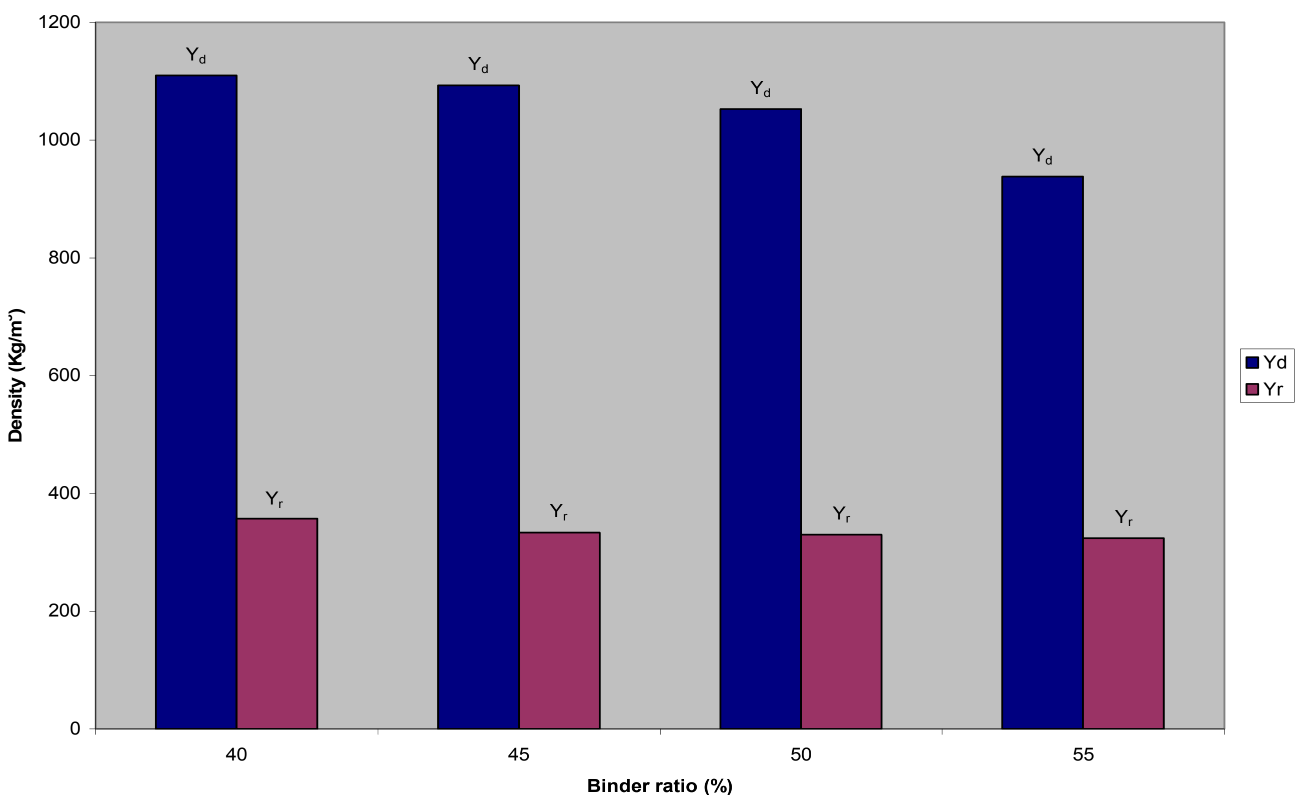

Figure 9. Effect of binder ratio on maximum and relaxed density for D_2 particle size briquettes.

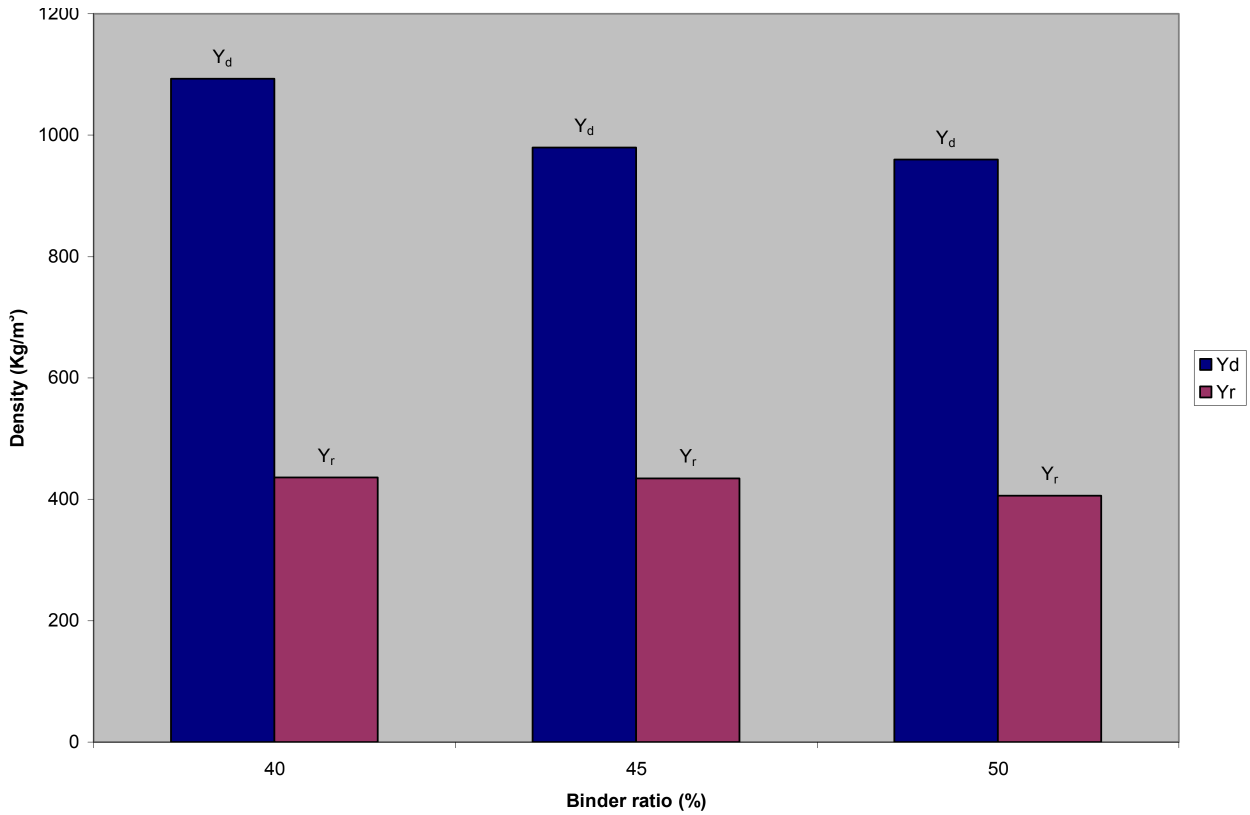

Figure 10. Effect of binder ratio on maximum and relaxed density for D_3 particle size briquettes.

raised above. For D_2 particle size briquettes, there is very little variation in the maximum and relaxed densities.

This phenomenon is traceable to the lustre surface nature of the particle size. For the briquettes with D_3 particle size, the trend was similar to what was observed for D_2 particle size briquettes even though the particles were finer. The briquettes that were kept for shelf life examination did not disintegrate appreciably over a period of about six months, when visually inspected and physically handled.

Conclusion

The measured characteristics indicated that each and every one of the processing parameters of pressure, particle size and binder ratio have singularly or corporately affected the values of the measured characteristics. The compaction energy was directly related to the particle size more than the other processing parameters of pressure and binder ratio. Less compaction energy was recorded for smaller particle size compression process. A large volume reduction (450%) of the material was achievable by these processes. All the processing parameters were found to be significant at $p < 0.05$ for all the measured characteristics. If the right combination of the handling and processing parameters are applied to the materials, the briquettes can be sustained for a long period. For further work, energy balance for size reduction and compression process could be determined by investigation.

Conflict of Interests

The author(s) have not declared any conflict of interests.

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