Petroleum and Coal

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Development and Performance Evaluation of a Manual Briquetting Machine for Biofuel Production

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Received January 12, 2021; Accepted April 16, 2021

Abstract

Using biomass briquettes is one of the effective ways of utilizing established natural resources. Biomass briquettes are cleaner, safer and easier to handle and will help to mitigate the greenhouse effect by replacing wood or fossil fuels for cooking and industrial processes. In this work, a briquetting machine was developed using locally sourced materials to produce stable briquettes from available biomass residue (saw dust briquette (SB), rice husk briquette (RB), paper briquette (PB) and 50% rice husk + 50% paper briquette (50R – 50p –B)). The results indicate that the machine produced stable briquettes, saw-dust briquette, rice husk briquette, paper briquette and 50% rice husk + 50% paper briquette has the density ratios of 0.3, 0.5, 0.42 and 0.49 respectively with relaxation ratios of 3.37, 2.0, 2.36 and 2.03 respectively. The burning rates and specific fuel consumption for 50% rice husk + 50% paper briquette yielded a better result than the rice husk alone while the burning rates and specific fuel consumption for saw dust yielded better results than the waste paper.

Keywords: *Biomass; Briquette; Residue; Energy; Manual.*

1. Introduction

Many of the primary energy sources in the developing countries for activities such as cooking and space heating are through wood burning and other agricultural products. An increasing population using fuel-efficient biomass materials will eventually lead to a shortage of such materials unless steps are taken to reverse the trend [1]. Nigeria's energy availability for utilization remains a daunting problem;

Most importantly the exorbitant price of kerosene, cooking gas and the firewood together with the threats in the environment. There is a need to source alternate sources of energy. This has prompted the need to improve the use of agro-waste as substitutes, and to develop machines such as briquetting machines that will enable the production of these substitutes even in our localities. Studies have shown that the combustion of exhaustible fossil fuels satisfies more than 80 % of the world's energy demand. Global demand for energy is expected to increase by about 50 % by 2025, where the bulk of this increase comes from rapidly emerging countries [2]. Considering the increasing world population, combined with increased demand for energy per capital and global warming, it is more than important to provide a long-term alternative energy supply. There are tons wastes and bio- residues generated in Nigeria, however, poorly utilized, since these wastes are often incinerated and allowed to decay thereby, resulting to environmental degradation and pollution [3-5].

Scientific studies have however found that there is an excess of potential energy in these residues [6]. Annually, surplus number of corncobs, rice husks and other residues are generated in Nigeria, but most of them gets burnt and forgotten. However, these agricultural residues can be used to produce bio-fuels or cottage applications at home and in the industry [7].

Maximum utilization of biomass briquettes is one of the effective ways of using established natural resources. Briquetting is simply a way to turn loose agricultural residues of biomass, into solid blocks of high density for a source of fuel [8-12]. Besides that, biomass briquettes are cleaner and easier to handle, the replacement of wood or fossil fuels for cooking and industrial processes will help mitigate the greenhouse effect. In many developing countries, briquetting technology has yet to gain a strong foothold due to the constraints of technical implications involved in the technological adaptation of this concept to local conditions [13-14]. In determining its commercial success, providing solutions to the operational problems associated with this technology and ensuring the quality of the raw materials used are crucial factors. The importance of this technology also lies in the protection of wood, a product which is commonly used in developing countries and which contributes to widespread destruction of forests [15-18].

The main goal of this work is to develop a briquetting machine and then produce briquettes of different compositions (saw dust briquette, rice husk briquette, paper briquette and 50% rice husk + 50% paper briquette) with it and finally to evaluate the briquettes been produced by the briquetting machine. The results obtained were compared to evaluate their performances.

2. Materials and method

Materials were soured locally for the machine, and were selected based on quality, durability and cost. This is in order to reduce the overall production cost and achieve the main objective of the work. The machine consists majorly the Frame, mould (Cylinder), ram, press frame, cover and handle. The biomass residues for the production of the briquette are sawdust, rice husk, waste paper and a mixture of 50% rice husk and 50% paper.

2.1. Design consideration and specification

The design specifications of the briquetting machine are;

a) The applied pressure: According to health and safety report by [19], the maximum force that can be exerted manually pulling below the elbow level is 287 N. Therefore, considering the maximum Force exerted for the design to be 287 N per a square meter area.

b) The shape of the briquette produced, which is cylindrical and hollow in shape. The size is considered to be 100 mm in diameter and the hollow diameter to be 20 mm.

c) Easy ejection of the briquette after its production

Table 1 shows the design specifications of the briquetting machine.

Table 1. Design specifications

S/N	Parameters	Specification
1	Length of the base rod L (m)	0.3
2	Inner diameter of the mould (cylinder) d_m (m)	0.1
3	Yield strength of the material (mild steel) $\boldsymbol{\sigma}$ (N/m^2)	220×10^6
4	Force applied at the handle W (N)	287
5	Hoop stress for the material of the cylindrical shell σ_{t1}(N/m^2)	140×10^6
6	Tangential stress for the material of the cylinder σ_{t2}(N/m^2)	60×10^6
7	Length of the cover plate b (m)	0.3

2.2. Design analysis

The machine consists of a base rod which passes through two support plate holes holding the piston. This shaft is connected to the press frame at its end which allows the piston's up and down movement. The ram is inside a cylinder that helps to shape a briquette of a cylindrical type. According to [20], that the best briquette is the one with a diameter of less than or equal to 100 mm and also with a center hole, a center rod passes through the center of the cylinders and is connected to the base frame to create a hole in the briquette when briquetting.

2.3. Base rod

As a result of the applied force W exerted at the handle, the base rod will undergo four reactions as shown in Figure 1.

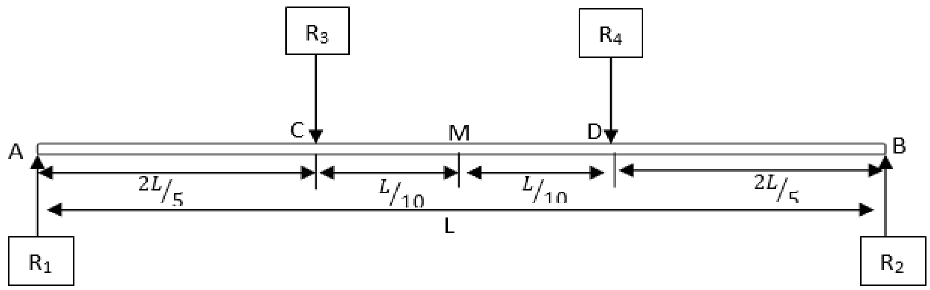

Figure 1. Base rod

Considering the bending equation

$$\frac{\sigma}{Y} = \frac{M}{I} \tag{1}$$

where: M=maximum bending moment; Y=Centroidal height; I=moment of inertia; σ=yield strength

For a symmetrically loaded beam, the maximum bending moment will occur at its mid-point. I.e. L/2. Therefore, applying the Macaulay's equation, the maximum bending moment for the beam is given as;

$$M = R_1 \langle {}^{L}/_{2} \rangle - R_3 \langle {}^{L}/_{2} - {}^{2L}/_{5} \rangle - R_4 \langle {}^{L}/_{2} - {}^{3L}/_{5} \rangle - R_2 \langle {}^{L}/_{2} - L \rangle$$
$$= R_1 \langle {}^{L}/_{2} \rangle - R_3 \langle {}^{L}/_{10} \rangle - R_4 \langle -{}^{L}/_{10} \rangle - R_2 \langle -{}^{L}/_{2} \rangle \tag{2}$$
$$M = R_1 \langle {}^{L}/_{2} \rangle - R_3 \langle {}^{L}/_{10} \rangle$$

Substituting with the parameters, the maximum bending moment, M = 17.22 Nm. The moment of Inertia is given by

$$Y = \frac{d_b}{2} \tag{3}$$

where d_b is the diameter of the base rod.

While, the centroidal height is expressed as Substituting Eq. (3) and (4) into Eq. (1) yields;

$$d_b = \sqrt[3]{\frac{32M}{\sigma\pi}} \tag{4}$$

Therefore, the base rod diameter d_b = 9.27 mm.

2.4. The mould

The mould is made up of two cylindrical shape pipes open at both ends. Due to the applied force during compaction, it causes an exertion of pressure inside the cylinder in the directions as shown in Figure 2. The pressure exerted in the cylinder is given by

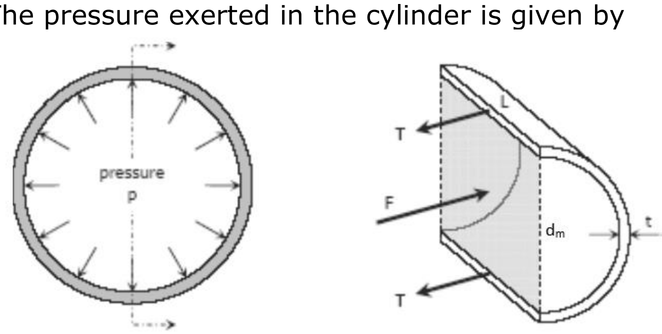

Figure 2. Sections of the cylinder

$P = \frac{Force}{Area} \qquad P = \frac{F}{\pi \frac{d_m{}^2}{4}}$ (5)

where F=W/2 (the force acting in each cylinder). Therefore, P becomes,

$P = \frac{2W}{\pi d_m{}^2}$ (6)

Hence, P = 18.27KN/m^2.

2.5. The cover plate

In this case, the cover plate bending occurs in the x – direction only as shown in Figure 3.

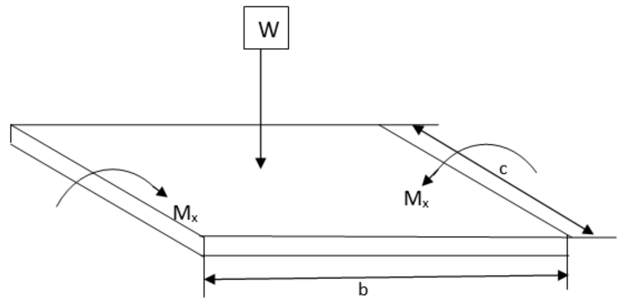

Figure 3. The cover plate with the load and bending moments

The minimum thickness of the appropriate cover plate can be obtained from the deflection equation. The maximum bending moment is given as,

$M_{max} = \frac{5Wb^2}{12}$ (7)

The maximum yield strength is,

$\sigma_{max} = \frac{M_{max}{}^{t_b}/_2}{\left(\frac{1}{12}\right)t_b{}^2}$ (8)

Therefore, the thickness of the cover plate is expressed as

$t_b = \sqrt{\frac{5Wb^2}{2\sigma_{max}}}$ (9)

2.6. Fabrication process

The manual briquetting machine was designed using the required equipment, such as the drilling machine, measuring tape, tri-square, hack saw, vice, Electric hand grinder, turning / facing parts lathe and electrode welding. Figure 4 shows the first angle projection of the machine, 3-D projection of the machine and the manual briquetting machine at its finished stage.

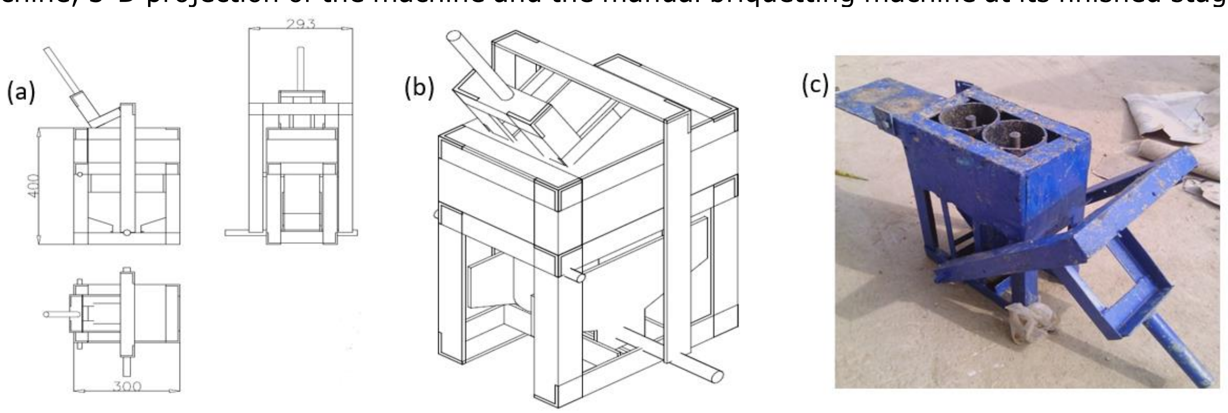

Figure 4. (a) First angle projection of the manual briquetting machine (All dimensions in mm), (b) 3-D projection of the manual Briquetting machine, (c) The Manual Briquetting Machine

2.7. Choice and preparation of binders

Cassava starch was the binder used in the briquette preparation. Cassava starch was chosen because it was evaluated as one of the best combustible binders [21] and is readily available at a relatively affordable rates in the market.

The starch colloid of 0.05 by weight was combined with boiling water in preparation of the binder just enough to create a gel that can promote the particles' proper agglomeration [22-23]. The weights of cassava starch, cold and boiling water were determined by the weight of the biomass feedstock to form the appropriate percentage binder ratio.

2.8. Production of the briquette from residue

The residues used in briquette processing include saw-dust, rice husk [24], and waste paper from various sources. In their case, the waste paper was pounded into a mortar with a pestle to reduce the sizes into smaller units. In addition, the mixture of 50% rice husk and 50% paper by volume was also used for briquette production.

The residue samples were mixed thoroughly with the prepared cassava starch gel in separate containers using b until the mixture became consistent. The mixed residue was poured into the fabricated briquetting machine's mould cavities. Figure 5 shows the rice husk briquette, paper briquette, 50% rice husk and 50% paper briquette and saw dust briquette respectively.

Figure 5. (a) Rice Husk Briquette (b) Paper Briquette (c) Saw dust Briquette (d) 50% Rice husk + 50% Paper Briquette

2.9. Properties of the generated briquettes

The briquettes density was determined after the ejection from the mould for each residue from the mass volume ratio of the briquette. A digital weighing scale was used to obtain the mass of the briquette. While the volume was measured using a Vernier caliper to measure the length, width, and thickness of the briquette.

After three days, the relaxed density of the briquettes was determined from the measured density in drying condition. It was measured as the weight ratio and new volume of the briquette. Relaxed density is the density of the briquette after stability. Therefore,

$$\text{Density ratio} = \frac{\text{Relaxed density}}{\text{maximum density}} \quad (10) \text{ and}$$

$$\text{Relaxation ratio} = \frac{\text{maximum density}}{\text{relaxed density}} \quad (11)$$

Also, boiling water test was evaluated to compare the produced briquettes with each other in terms of their efficiencies.

This test revealed the time taken by each briquette to boil under the same conditions. The method utilized by [24] was adopted when carrying out the testing. Using small cooking pot and domestic charcoal stove, known mass of each briquette sample was used for boiling 100cm^3 of water. Other fuel properties of the briquettes such as burning rate and particular fuel consumption were also determined during this test. The extent of evolution of smoke was detected, too.

Burning rate is the ratio of the mass of the fuel burnt (in grams) to the total time taken (in minute). It is calculated by the expression in Eq. (12)

$$\text{Burning rate} = \frac{\text{mass of fuel consumed (g)}}{\text{Total time taken (min.)}} \tag{12}$$

While the specific fuel consumption (SFC) which is the ratio of the mass of fuel consumed (in grams) to the quantity of boiling water (in Liters) is expressed as in Eq. (13)

$$\text{SFC} = \frac{\text{mass of fuel consumed (g)}}{\text{Total volume of boiling water (Liters)}} \tag{13}$$

3. Results and discussion

3.1. Density

Figure 5 shows the maximum and relaxed densities of the samples. Figure 5 reveals that SB has the maximum density while its relaxed density is the lowest of all the samples produced. This is because SB is a lignocellulose material. On the one hand, the density of PB is the lowest while on the other hand the RB has the highest relaxed density. Also, the relaxation ratios 3.37, 2.0, 2.36, and 2.03 respectively as shown in Figure 6. Comparing their relaxation ratio with the values obtained for coconut husk by [26-27] ranging from 1.70 to 2.86 and [22] ranging from 1.80 to 2.25. Our standards for a stable briquette compare favorably well, and also nice enough. The lower relaxation ratio indicates a more stable briquette [28-29], while the higher value indicates a high relaxation tendency, i.e. a less stable briquette. The relaxation ratio values obtained in this study indicated that the briquettes developed using the Briquetting machine are stable and are sufficiently good for packaging, storage, and transport.

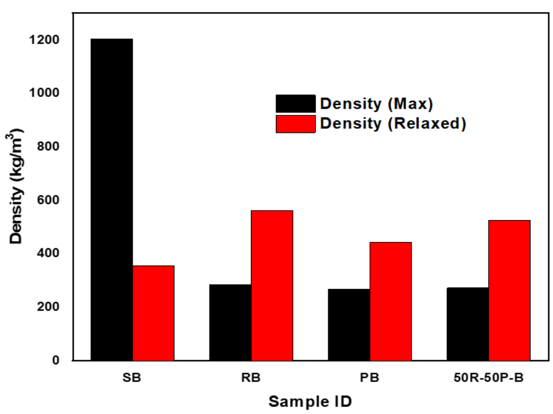

Figure 6. Maximum and relaxed densities for the samples

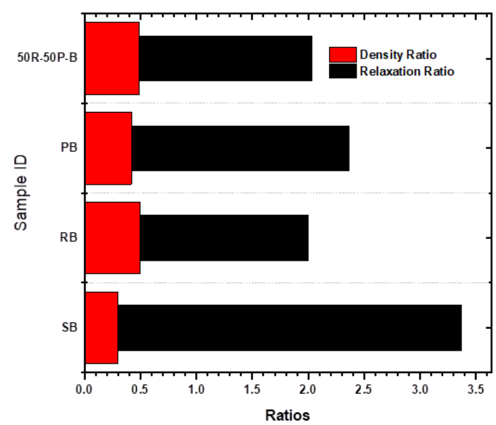

Figure 7. Density and relaxation ratio of the sample

3.2. Boiling test

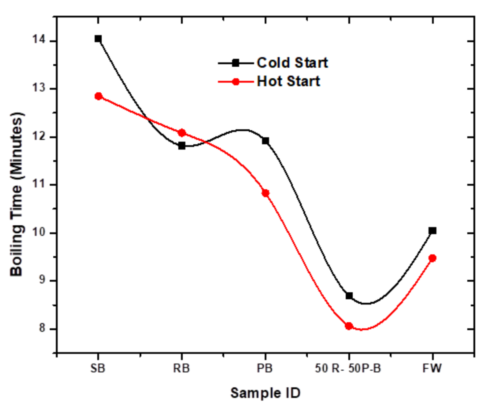

Figure 7. Time taken to boil water for the samples

Figure 7 displays the water boiling test of the samples as compared to the fire wood FW. Figure 7 reveals that SB has the highest boiling time in the cold and hot start. However, 50R–50p–B out performed all other briquettes tested as it has the lowest boiling time during the cold and hot start. This performance encourages the mixture of two or more biomass for the production briquettes for biofuel generation. The addition of 50% paper to the rice husk briquette mixture, the resultant briquette became more stable after production. In the coming days, compression tests will be carried on different briquettes [30] to evaluate more properties on the briquettes and make some predictions and forecasting on future trends in briquettes [31-34].

3.3. Specific fuel consumption

Table 2 shows the specific fuel consumption of the briquettes used. During the combustion test it was observed that all the briquettes ignited easily with a few drops of kerosene and they burnt well without smoky flames.

Table 2. Specific fuel consumption and burning rate

Sample ID	Mf	Ttt	Tvb	Sfp	Br
SB	155.52	27.57	2	77.76	5.64
RB	204.78	23.92	2	102.39	8.56
PB	142.60	23.83	2	71.30	5.98
50R-50P-B	164.59	21.38	2	82.30	7.69

From Table 2, it is shown that the RB has the highest fuel consumption, which depicts the poorest in terms of efficiency. The best briquette performance in this work is the SB, however, comparing the performance of RB with 50R – 50p –B, it is shown that the 50R – 50p –B out performs the rice husk briquette, which indicates that better results can be obtained from mixture of biomass residues.

4. Conclusion

The work successfully developed a manual briquetting machine from locally sourced materials. The machine was then used to produce four different briquettes which were tested in order to compare their performance amongst themselves and with existing literature. The 50R-50P-B performed better than the RB and PB in the combustion test while the SB remained the best in terms of performance. This is an indicator that optimal mixing of biomass for the production of briquettes in biofuel generation will be the new norm. Finally, this briquetting machine will be very useful for those in the rural areas and other underdeveloped parts of the world especially as it is relatively cheap and will serve the desired purpose.

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