Development and Performance Evaluation of a Low-Cost Hydraulic-Operated Biomass Briquetting Machine

[1*]Olawale U. Dairo, [2]Ademola E. Adeleke, [3]Taofeek Shittu, [4]Nageri A. Ibrahim, [1]Olayemi J. Adeosun and [5]Rita B. Iyerimah

[1] Department of Agricultural & Bio-Resources Engineering, Federal University of Agriculture, Abeokuta, Nigeria
[2] Department of Mechanical Engineering, Federal University Oye-Ekiti, Nigeria
[3]Department of Food Science and Technology, Federal University of Agriculture, Abeokuta, Nigeria
[4]Federal Institute of Industrial Research, Oshodi. Lagos, Nigeria
[5]Department of Nutrition & Dietetics, Federal University of Agriculture, Abeokuta, Nigeria
dairoou@funaab.edu.ng

Abstract— Large quantities of agricultural residues produced in Nigeria can provide an alternative way in meeting her energy demand through briquetting. Biomass briquetting is the process of compacting raw biomass materials (wood, charcoal, crop residues, and animal waste) into standard mini-brick units as solid fuel for improved handling and efficiency. A small scale, 40 bar hydraulic operated piston briquetting machine with a capacity of 120 briquettes per hour was developed. The machine comprised of hydraulic, control, press, power, ejection and frame sections, and adopted the binder-less technology. Sawdust and rice husk were used as sample biomass materials. The compressed biomass obtained from the developed machine in form of briquettes had mean diameter and height of 30 mm ±0.02 and 16 mm ±0.01 respectively. The force, deflection, and Young Modulus at peak were 16.30 N, 3.29 mm and 548.11 N/mm^2 for Sawdust Briquettes (SB) respectively, while 12.50 N, 1.49 mm; and 481 N/mm^2 were obtained for Rice Husk Briquettes (RHB). The yield stress for SB and RHB were 12 and 9 N/mm^2. The heating values obtained for SB and RHB were 51.0 Kcal/g and 39.4 Kcal/g respectively. The output efficiency of the machine was 88% indicating a satisfactory performance of the machine.

Keywords— Biomass, briquette, solid fuel, saw dust, rice husk, renewable energy

1 Introduction

Agricultural and forestry residues offer much potential for renewable energy sources in form of biomass. With advances in the knowledge biotechnology and bioengineering, some resources, which could have been classified as waste, now form the basis for energy production (McKendry, 2002). The briquetting process is the conversion of agricultural wastes into uniformly shaped briquettes that are easy to use, transport and store (Wilaipon, 2008). The idea of briquetting is to use materials that are otherwise not stable due to lack of density, compressing them into a solid fuel of a convenient shape that can be burned like wood or charcoal (Olorunnisola, 2007). Biomass briquetting technology has potential to drastically reduce the rate of deforestation in developing countries, because it provides a means to get more energy from less wood. Wood waste, agricultural straw and grasses are the most prominent biomass energy source (Tumurulu et al, 2010). Cioabla and Ionel, (2011) also projected that by 2030, biomass may be an outstanding solution for individual heating, dominated by wood logs, wood chips and pellets in rural areas. Zhanbin (2003) termed normal temperature briquetting technology for biomass as briquetting done at the material original moisture content (usually between 8- 35% wet basis) with no requirement for electrical heating as in the case of screw briquetting and no temperature control is required.

Several researchers including Oladeji (2011), Adekoya (1998), UNEP(2009), Bogale (2009), Njenga et al. (2009), Davison,(2010), Uzoma *et al.* (2011) have developed some manual or low pressure briquette press based on normal temperature briquetting technology, while Obi *et al.* (2012) reported that constraint in the advancement of biomass briquetting in Africa and Nigeria in particular has been associated with the development of briquetting press for local commercial manufacture. He further stated that existing machines in rural communities address the utilization of waste biomass for briquette production at the household level. Some of the commercial limitations associated with the existing machines is use of human strength in the application of pressure for biomass densification making them gender sensitive, producing poor quality briquettes. Other limitation is low production capacity mostly associated with time spent in the ejection of the compressed biomass from the moulds.

This study developed a small scale, low pressure hydraulic operated briquetting machine with an ejection module and characterized the briquette produced using sawdust and rice husk in terms of compressive strength and heating value.

* Corresponding Author

2 Materials and Methods

2.1 Design Assumptions

In developing the machine the following assumptions were made:

i. Preliminary study showed that for a cylinder stroke length of 0.03m the calculated stroke time was 5 sec at a stroke speed of 0.006 m/s
ii. The pressure used for compression process ranging between 0 – 40 bar and the volumetric efficiency of 0.95 was assumed.

iii. The moisture content of the biomass materials was assumed to be uniform according to Arun *et al.* (1998) and Daniel (2009).

Figure 1 shows the conceptual design of the machine.

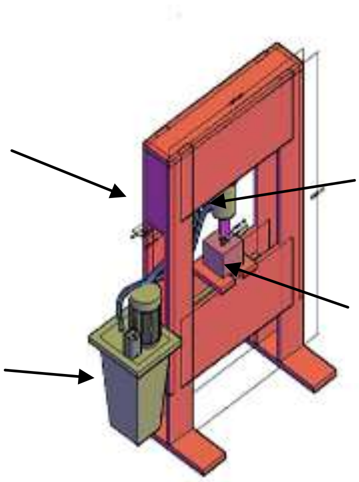

Fig. 1 Conceptual Design of the Biomass Briquetting Machine

2.2 Sample and Sample characterization

Two biomass raw materials (sawdust and rice husk) were sourced from a local wood market and a rice milling unit at Ilorin- East local government area of Kwara state. These materials were spread on flat trays and dried under the sun for three day. The moisture content of the biomass materials after drying was determined using the Standard S358.2 method (ASAE, 1983). Dried samples were sieved using standard mesh sizes of 4.0, 2.5 and 1 µm.

2.3 Characterisation of Raw Biomass Behaviours in Compaction

As a preliminary step for an optimised briquetting – making machine design, experimental tests were carried out for characterising the biomass mechanical behaviours in compaction; in particular, they were aimed at obtaining some parameters such as value biomass material mass, biomass output and input height, and biomass density using a Weber press.

i. Determination of biomass material mass

To determine the biomass material mass a relationship was established by quantified 50, 100, 150, and 200 cm3 volume of raw biomass material fed into empty measuring cylinder then weighed on a digital weighing balance to obtain the corresponding weights.

ii. Sample and Sample characterization

Two biomass raw materials (sawdust and rice husk) were sourced from a local wood market and a rice milling unit at Ilorin- East local government area of Kwara state. These materials were spread on flat trays and dried under the sun for three day. The moisture content of the biomass materials after drying was determined using the Standard S358.2 method (ASAE, 1983). Dried samples were sieved using standard mesh sizes of 4.0, 2.5 and 1 µm.

iii. Characterisation of raw biomass behaviours in compaction

As a preliminary step for an optimised briquetting – making machine design, experimental tests were carried out for characterising the biomass mechanical behaviours in compaction; in particular, they were aimed at obtaining some parameters such as value biomass material mass, biomass output and input height, and biomass density using a Weber press.

iv. Determination of biomass material mass

To determine the biomass material mass a relationship was established by quantified 50, 100, 150, and 200 cm3 volume of raw biomass material fed into empty measuring cylinder then weighed on a digital weighing balance to obtain the corresponding weights.

v. Biomass bulk density

The bulk density of sample materials were determined by obtaining the weights of biomass in a known volume using Equation 1.

$$\rho = M/V \qquad (1)$$

where, ρ is density, M is the mass and V is volume of the mould.

vi. Determination of biomass output height or thickness

Raw biomass material of 50, 100, 150, and 200cm3 respectively were fed into improvised mould and plungers, compressed with Weber hydraulic press of 16 tons capacity to determine the difference in height and the consequent thickness of the compressed biomass at different volume. The averages of five replicates of all experimental parameters were in the design analyses.

vii. Compressive test

Compressive strength test for the produced briquettes were carried out using Testomeric Universal Testing Machine (M500 – 25 kN) at Federal Institute of Industrial Research, Oshodi.

viii. Heating value

Heating value was determined by adopting the sensible heat method of Jorelyn *et al.* (2008). The biomass briquettes was used to boil 150g of water and data obtained from initial and final mass of briquette, briquettes consumed, temperature of water from initial to final and the time to boil was used in Equation 2 (Jorelyn *et. al.*, 2008) in calculating the sensible heat.

$$Q = C_p * W * \Delta T \qquad (2)$$

where, Q is sensible heat (Cal), C_p is specific heat of water (Cal/g^{0}C), ΔT is change in temperature (^{0}C) and W is weight of water (g)

The heating value was obtained using Equation 3 as obtained from Jorelyn *et al.* (2008)

$$q = Q/W_b \quad (3)$$

where q is the Heat value, Q is sensible heat (Cal) and W_b is the weight of briquette used.

ix. Briquettes durability index

Briquettes shattering index (durability index) was determined using the drop shatter for coal method of ASTMD440-86 (ASTM, 1998) according to Equation 4

$$\emptyset = W_i/W_f \quad (4)$$

where, Ø is the shattering index, W_i is weight of briquettes before dropping and W_f is weight of briquettes retained on the screen after dropping.

x. Machine Efficiency

The output efficiency of the developed hydraulic press was obtained using Equation 5

$$\eta = N_0/N_d \quad (5)$$

2.4 Design

When designing the biomass briquette machine, consideration was given to the behaviour of the machine and its structural members, under the action of external loads (Archies *et al*; 1983). An existing 30 ton hydraulic press frame was modified to produce the hydraulic forces required for densification, consequently, the required force, capacity, hydraulic pressure selection, piston area, piston diameter, hydraulic cylinder speed, material flow required hydraulic pump selection and electric motor were calculated and compared to the specification of the hydraulic press.

i. Force required for densification

From preliminary experiment, it was found that 80 ton force would compress biomass material of the volume 80cm3 as obtained from the Weber press using force relationship of Equation 6 as F = 78. 48 kN.

$$F = mg \quad (6)$$

.

ii. Machine Capacity

The capacity of press was calculated using Equation 7 according to Oumarou et al. (2010) and was obtained as 120 briquettes per hour.

$$C = N * 60/t \quad (7)$$

where N is number of briquettes per operation and t is the time taken to complete one operation cycle.

iii. Press Piston area, diameter and hydraulic cylinder speed

The piston area for the design was calculated using Equation 8 as A = 31. 39 m^2

$$A = F/P \quad (8)$$

where, A is piston area in (cm^2), F is force required to densify (kN), P is pressure (N/m^2)

The piston diameter was also calculated using Equation 9 as d = 6. 32 cm

$$d = \sqrt{4 * A/\pi} \quad (9)$$

The speed of hydraulic cylinder was obtained from stroke speed relationship given by Equation 10

$$V = L/T \quad (10)$$

where, V is stroke speed (m/s) , *L* is cylinder stroke length (m) and *T* is time allow to stroke (s)

From preliminary experiment for a stroke length *L* of 0.03 m, T was found as 5 sec, hence V = 0.006 m/s

iv. Material flow rate for densification

The material flow rate was obtained using Equation 11

$$Q = (6 * A * V)/(\%V) \quad (11)$$

where, Q is material flow rate required (L/h) , A is Piston area (cm2) and V is Stroke speed (m/s), %V is Volume efficiency (usually 0. 95) with Q = 1. 19 L/h.

v. Hydraulic pump and motor selection

The capacity of hydraulic pump was calculated using Equation 12 (Oumarou *et al.*, 2010) as P = 0. 40 kW

$$P = (Q \times \text{Pressure})/600 \quad (12)$$

Electric motor selection, Power = 0.42 kW

$$P = P_o/V_T \quad (13)$$

where P is power (kW), P_0 is the Power Output (kW) and V_T is percentage total Volume

The calculated pump and motor capacities were below the specification of 0.5 kW and 1.0 hp (0.746kW) of the existing hydraulic press selected.

3 RESULTS

The developed small scale biomass briquetting machine comprising the six components of hydraulic, press, frame, ejection, control, and power unit is shown in Plate 1 while the components are as described

3.1 The frame

This component carried the total load of the machine. It was made with a 100 mm by 50 mm hollow pipe with length and breadth of 600 mm and 1300 mm respectively. The height at the right end was 300 mm with a hole of 100 mm drilled to anchor the hydraulic cylinder at the centre position of the frame level. To stabilize the frame a flat bar of 200 mm by 50mm was used to support the base.

3.2 The press

The mould is where raw materials are fed. It consisted of two hollow cylinder, 30 mm diameter, 5 mm thickness, and 110 mm long embedded in a box shaped die made of mild steel 70 mm × 110 mm in dimension. The plungers (Plate 2) were made up of two solid shaft mild steel of 28 mm diameter and 170 mm long. The plungers were attached to the machine piston head by welding.

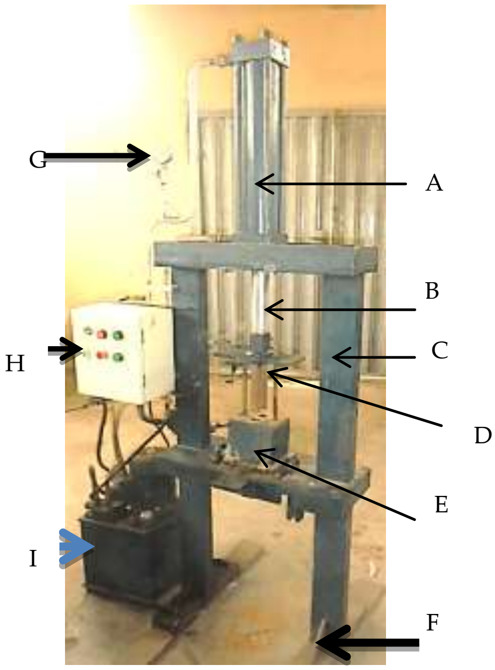

Plate 1: Biomass briquetting machine developed
Legend: A, Hydraulic cylinder; B, Piston; C, Frame; D, Plunger; E, Mould die; F, Support base; G, Electrical control panel; I, Storage tank

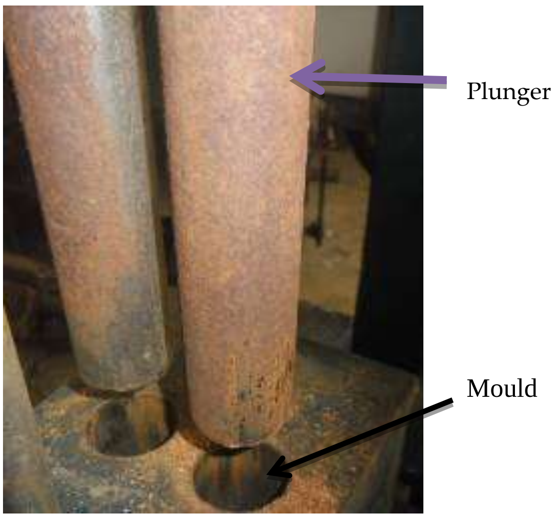

Plate 2: Biomass briquetting machine mould and plunger

3.3 Hydraulic unit

The hydraulic cylinder houses the piston and convey hydraulic fluid into and from the hydraulic storage reservoir. The hydraulic pipe conveying the fluid has an external diameter of 100 mm. The piston moves in a vertical oscillatory motion resulting into compression and ejection stages of the briquette. The internal diameter of the solid steel piston was 75 mm**.** The hydraulic fluid storage tank served as a reservoir for hydraulic oil and houses a pump of 0. 5kw rating. The storage was made of galvanized iron sheet of 300 mm × 270 mm × 270 mm with a capacity of 35 litre. It was supported at the base with two pieces of angle iron and raise above the ground at about 50 mm.

3.4 Control panel

The electrical control panel comprised four current contactors rated at 0.55kw each and four control buttons and one light indicator. The main function of contractors was to use a small control current to energize or to de-energize the load. Two limit switches (Plate 3) were used to disengage the motion transfer from the machine piston. It was fixed at a distance of 400 mm, with rod and cone diameters of 10 and 12 mm respectively. Two cone bushing were welded at the coupler side of plunger and top side of the die

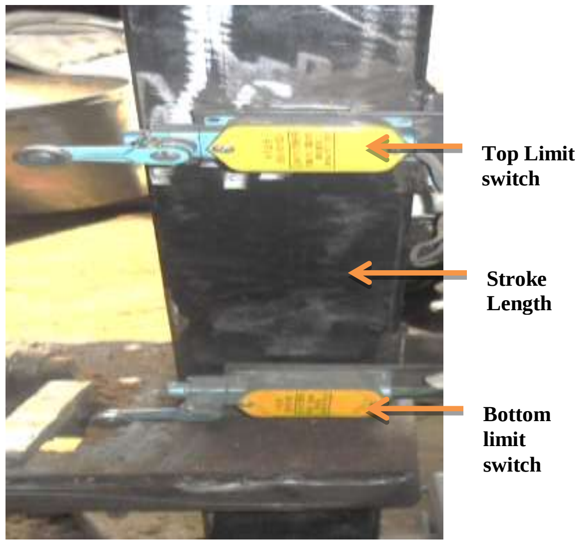

Plate 3: Limit Switches for actuation of system

3.5 The Ejection module

The ejection unit is rectangular in shape with dimension 70 mm × 100 mm is the discharge chamber where the formed briquettes are ejected from the machine. It works in synchronization with the limit switches where a top plate made up of mild steel (80 mm by 110 mm by 40 mm dimension) was provided to covered up the area and that can be move in and out in the discharge chamber.

3.6 Characterization of briquette produced

Plate 4 depicts the briquettes made from the developed machine using sawdust (SB) and rice husk (RHB) as test materials. The average output from the machine is presented in Table 1, where the quantity of briquettes ranged from 100 to 110 for both materials used with sample mean values of 106 ± 3 and 107 ± 2 for sawdust and rice husk briquettes respectively. A t-test showed no significant ($p = 0.288$, $t = -1.08$) differences between the two materials tested in terms of quantity produced. The calculated output efficiencies was found to be between 83 and 92% with an average of 88 ± 2 % for the pooled data.

The result of compressive strength showed the force, deflection and Young Modulus at peak were 16.30 and 12.50N; 3.29 and 1.49mm; 548.11 and 481 N/mm² for sawdust and rice husk briquette respectively. The yield stress values were obtained as 12 and 9 N/mm² for sawdust and rice husk respectively.

Plate 4: Rice Husk Briquette (RHB) and Saw-dust briquette (SB) produced from the developed machine

Table 1. Quantity of briquettes produced by the developed machine per hour

			Output Efficiency	
Test No	Sawdust	Rice husk	Sawdust	Rice husk
1	106	106	0.88	0.88
2	108	108	0.90	0.90
3	102	106	0.85	0.88
4	104	106	0.87	0.88
5	100	102	0.83	0.85
6	104	108	0.87	0.90
7	102	104	0.85	0.87
8	106	106	0.88	0.88
9	104	106	0.87	0.88
10	106	104	0.88	0.87
11	108	106	0.90	0.88
12	108	104	0.90	0.87
13	110	108	0.92	0.90
14	108	110	0.90	0.92
15	106	106	0.88	0.88
16	108	106	0.90	0.88
17	104	106	0.87	0.88
18	106	108	0.88	0.90
19	106	110	0.88	0.92
20	108	110	0.90	0.92
Mean	106	107	0.88	0.89

3.7 Sensible Heat and Heat Value

The average sensible heat and heat values were 10464.80 Kcal and 51.0 Kcal/g; and 9803.80 Kcal and 39.4 Kcal/g for saw dust and rice husk briquettes respectively. The utilized heat value which was equal to the sensible heat per weight of the briquettes consumed, showed that sawdust had the greater heat value of 51.8 kcal/g compared to rice husk 39.4 kcal/g. Heating values obtained from the developed machine were found to be the range of values from by Jorelyn *et al* (2008).

4 Conclusion

The following conclusion can be made from this study

i. A low cost and small scale hydraulic operated briquetting machine with an ejection module was developed.
ii. The machine operate without extrusion and pre heating chambers with moisture content of biomass materials between 10 – 15%
iii. Ejection problem usually associated with manual press are eliminated
iv. The designed machine was simple, easy to operate and with 88% operating efficiency.
v. The result shows that sawdust had greater compressive strength and heat value compare to rice husk

References

Adekoya, L. O (1998). Briquetting of Agricultural wastes: A preliminary study, Proceedings of CIGR International symposium – centre for Agricultural Mechanization Ilorin, Nigeria. Pp 218 - 225

American Society for Testing and Materials (ASTM. D440-86), "Standard test method of drop shatter test for coal," in *Annual Book of ASTM Standards*, vol. 05, pp. 188–191, West Conshohocken, Pa, USA, 1998.

Arun, K., P. V. R. Tyer., Tara, C. R (1998). A techno-economic evaluation Biomass briquetting in India. Biomass and Bioenergy. Volume 14, Issues 5–6, May–June 1998, Pages 479–488

ASAE (1983). American Society of Agricultural Engineers (ASAE) Standard S 358.2. Moisture Measurement of Grain and Seeds. 37th Ed. St. Joseph, Michigan. USA

Bogale, W (2009). Preparation of charcoal using agricultural wastes. Ethiopian Journal of education and science. Vol. 5 No 1, pp 77 - 91

Cioabla, A. E and Lonel, I (2011). Biomass waste as a renewable source of Biogas production – experiments in: alternative fuel, M. Maximino Editor published by in tech

Daniel, N. , Sven, B. , Per- Anders, H (2009). Pellet production from agricultural Raw materials. Department of energy and technology, Swedish University of Agricultural science, P.O.Box 7032, SE – 75007 uppsala Sweden. Pp 681 – 682

Davison, S. C (2010). Non transport biofuels. A presentation of Pipal ltd. World Biofuels market

Jorelyn, F. M. , Razel, M. P., Johnyver, A. M.(2008). Design and development of Charcoal briquetting machine. Unpublished Thesis, Department of Agricultural Engineering, College of Engineering and Computing, University of Southern Mindanao, Kabacan, Cotabato. Pp 86 – 89

MC Kendry, P. (2002). Energy production from biomass (part 1): Overview of Biomass. Bioresource technology. (83): 37 - 46

Njenga, M., Karanja, N., Prain, G., Malii, J., Munyao, P., Gathuru K. and B. Mwasi. 2009. Community-Based energy briquette production from urban organic waste at Kahawa Soweto informal settlement, Nairobi. Urban Harvest Working Paper Series, no.5 International Potato Center, Lima, Peru. Pp 26.

Obi O F, Adeboye B S and Aneke N N. 2014. Biomass Briquetting and Rural Development in Nigeria. International Journal of Science, Environment ISSN 2278-3687 (O) and Technology, Vol. 3, No 3, 2014, 1043 – 1052

Oladeji, J.T. 2012. A Comparative Study of Effects of Some Processing Parameters on Densification Characteristics of Briquettes Produced from Two Species of Corncob. Pacific Journal of Science and Technology. 13(1):182- 192.

Olorunnisola, A. O. (2007). Production of fuel briquettes from waste paper & Coconut husk admixture agricultural engineering international: the CIGR E-journal, vol. xi

Oumarou, M. B and Oluwole, F. A.(2010). Design of a pedal operated briquettes Press. Continental J. Engineering Sciences 5:61 - 67,

Tumuluru, J. S. , Wright, C. T. , Kenny, K. L. , Hess, J. R. (2010). A review of Biomass densification technology for energy application. A report Prepared for the U. S department of energy by the Idaho National Laboratory, Biofuels & Renewable Energy Technologies, U. S

UNEP (2009). Converting waste agricultural biomass into a source compendium Of technologies. United Nations Environmental Programme, Division of technology, industry & economic, International Environmental Technology Centres Osaka/ Shiga, Japan.

Uzoma, C. C. , Okafor, I. F. , Okpara, C. G (2011). Fuel briquettes technology can save Nigeria’s trees. Continental Journal Environmental Sciences. 5(1): 20 - 20

Wilaipon, P (2008). The effect of briquetting pressure on banana-peel Briquette & the banana waste in Northern Thailand, American Journal of applied science. (1): 167 - 171

Zhanbin, C. (2003). Normal Temperature Briquetting Technology for Biomass with Original Moisture Content, International Conference on Bioenergy Utilization and Evironmental Protection, 6th LAMNET Workshop-Dalian, China, 1-6.