Performance Evaluation of Briquette Produced from a Designed and Fabricated Piston-Type Briquetting Machine

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Abstract

Briquetting is an effective way of utilizing agricultural residues as an efficient, effective and clean energy for rural and sub-urban communities. Thus, the need for a locally manufactured machine that is accessible and easy to operate. Therefore, a piston-type briquetting machine was designed and fabricated in this study. The performance of the machine was also evaluated by compacting sawdust and rice husks into briquettes in which the efficiency and capacity of the machine were 85.7% and 68.56 kg/h, respectively. Sawdust and rice husk were mixed in the ratios 100:0, 94:6, 92:8, 90:10 by weight and was bonded using an organic binder at constant proportion for all the samples. From the result, the density (820 - 870 kg/m^3), moisture content ($5.76 - 12.09$ %), drop to fracture ($8 - 20$ times) and water resistance ($93.75 - 94.24$ %) increased as the rice husk particles increased in the briquette while porosity decreased with increased rice husk particles in the briquette. More so, volatile matter, ash content, fixed carbon content and heating values decreased as the rice husk particles increased and sawdust particles decreased in the briquettes. It could be concluded that the machine would be useful to compact quality solid fuels that would be able to withstand handling, transportation and storage challenges.

Keywords: Briquette; sawdust; rice husk; proximate analysis; ultimate analysis; piston-type briquetting machine

I. INTRODUCTION

Energy plays an important role in order to have a meaningful economic and social development in any nation [1]. The continuous depletion of various non-renewable energy resources available and the greenhouse gas effects necessitates for increased interests in renewable energy. Agro-wastes (biomass) are vastly and hugely available in many developing countries yet they are left untapped as useful fuel. Biomass is a biological material derived from plant or plant-based materials [2]. Biomass has become an important alternative renewable energy due to its low greenhouse gas, low cost of production and low acidic gas emissions [3]. Hence, biomass energy research has attracted world-wide interest. Biomass is one of the most commonly and readily available renewable energy resources and serves as feedstock for bio-energy and can be used to generate heat, electricity and other forms of energy [2, 4 – 5]. Biomass resources such as wood and wood wastes, agricultural crops and their processing residues, municipal solid wastes, animal wastes, and so on are found to be very abundant [6 – 8].

II. RELATED WORK

Briquetting is a solid fuel production process through which biomass is compacted to become fuel that can be useful for both rural and semi-urban sectors [9]. Through densification, the density of biomass materials could be increased and volume reduced [10 – 13]. Various studies on briquettes have indicated improvement in densified biomass produced [9, 14 – 15]. Agricultural residues both field or process residues [9] which are plant biomass (lignocellulosic materials) are considered to be the most promising, abundant and underutilized biological fuel resources. It has been found to be useful and cost-effective source of renewable energy. Such agricultural wastes that have utilized for briquette fuel include palm oil mill, sawdust, rice husk, rice bran, Areca leaves, rice straw, sugarcane leaves and so on [1, 3, 5, 9, 16 – 18].

Rice husk is the outermost layer of the paddy grain. Aside other lignocellulosic constituents present in it, it is very rich in silica. The abundance nature of rice husk has made it a strong attractive material for production of high-valuable bio-product such as biofuels, electronics, particle-board composites and absorbence [16, 19 – 21]. More so, sawdust is a residue obtained from processed woods and generated yearly in millions of tons [21 – 26]. Nazari *et al.* [27] utilized agro-waste material in producing biomass briquette. Rice husk and banana residue at various percentage compositions and sizes were utilized for briquette production. This study was conducted to assess the combustion performance of the biomass composite briquette which was produced. The composite briquette was densified at constant and controlled temperature as well as pressure by varying the particle size and ratio of the raw materials. From the combustion performance results, it was reported that biomass composite briquette utilized has the tendency to be used as solid fuel. Solid biomass fuel obtained from rice straw and rice bran was prepared and characterized by Chou *et al.* [3]. A rice straw smashing machine was developed. The biomass was compressed and characterization at room temperature was done. It was reported that hot-pressing temperature has significant effect on the air-dry density and the compressive strength of the briquette.

Compaction machine is required to densify biomass for usage as solid fuels. Several studies have been done on developing some manual, low pressure and low-cost briquette making machines [28 – 36]. Muhammad *et al.* [33] designed a briquetting machine to densify grinded biomass materials. The grinded materials passed through hopper and power screw rotating at 300 rpm with a 15 kW electric motor which compressed the material through the tapper die that was heated externally by electric heaters. The machine capacity was 200 kg/h. A ten tonnes capacity briquetting machine was designed and fabricated by Osarenmwinda and Ihenyen [32]. The machine has 20 molding dies with each having transmission rod, piston and ejector. More so, a 100 cylinder mold manually operated hydraulic briquette machine was developed by Mambo *et al.* [34]. The production capacity was obtained to be 122.928 kg/h.

Furthermore, piston-mold process has been employed for densification of logs of wood residues and sawdust, rice husks, peanut shell, coconut fibers and palm fruit fibers; into biomass briquettes, respectively [37 – 38]. The die for the production of lignocellulosic briquettes from the combination of African Mongoy and Canadian Oak was designed by Granada *et al.* [39]. Screw press extruder briquetting machine was employed by Sengar *et al.* [36] and the briquette characteristics were investigated thereafter. An investigation on the performance of briquette produced from sawdust ad neem powder blend through the usage of manually operated hydraulic pelletizer was performed by Rajaseenivasan *et al.* [40]. Various physical and combustion characteristics were carried out on the briquettes. The strength of the briquette increased with little reduction in burning rate with the addition of neem powder as binding agent.

Owing to the abundance and good properties of rice husk and sawdust as biomass sources, it is important that they be compacted at certain mix proportions to form briquette with increased volumetric and heating values. In order to produce briquette for rural and sub-urban dwellers, densification of biomass is very important for the easy handling and transportation of the briquettes. Therefore, this study has highlighted a newly developed piston-type briquetting machine for briquette production. Furthermore, the briquettes produced were subjected to series of evaluation to ascertain the handling and heating value qualities of the briquette.

III. MATERIALS AND METHOD

The choice of material for the briquetting machine depends on the particular operation of the machine and the mode of operation of the machine component. In this study, the design analyses of the briquetting machine were done. Determination of material for component parts was done as well as describing the operating principle of the machine. The rectangular casing, square mold and frame are made of mild steel.

III.I *Operation of the briquetting machine*

For effective operation of the machine, the operator should be able to identify major parts and understand the working principle. The machine is powered by a gear motor. Biomass has to be mixed with the addition of a binder that serves as an adhesive to the mixture before it is introduced into the machine hopper. When the machine is switched on, the biomass mixture is poured into the hopper for processing into briquette. The prime mover, which is the electric motor, will drive a gear mounted on a shaft. The shaft then rotates and it is facilitated with a pillow bearing. The movement of the shaft enables the rotation of the wheel which in turns gives the link a reciprocating motion. Since the link is attached to the piston, it aids the forward and backward movement of the piston. As the piston moves forward, it presses the biomass against the mold. With the force of the piston, the mixed biomass is rammed into the shape of the mold. As the piston returns to its initial position, the exit is opened for the briquette to be ejected from the casing.

III.II *Design consideration*

The design is an illustration of a gear motor and piston type briquetting machine for the production of briquette from saw-dust. The gear motor gives rotation to the shaft which is connected to a wheel to give rotary motion. The wheel rotates and provides forward and backward movement of the piston through a link attached at its end.

III.II *Design calculation*

Design of the hopper. The volume of the hopper is calculated using Eq. (1)

$$V = \frac{1}{3} \times h \times \left(A_1 + A_z\sqrt{A_1} \times A_2\right) \qquad (1)$$

where V = volume of the hopper in (m³); A_1 = area of the top in (m³); A_2 = area of the hopper base in (m³) and H = height of the hopper in (m).

The volume of the hopper was calculated to be $0.0304 \, m^3$

Computation of the size of the rectangular casing. The volume of the rectangular casing was obtained using Eq. (2).

$$Vhc = L_1 B_1 H_1 \qquad (2)$$

where H_1 = height of the rectangular casing, L_1 = length of the rectangular casing and B_1 = breadth of rectangular casing where compaction of the briquette occurs.

The value was computed to be $0.0074 \, m^3$.

Design of the mould unit. Equation (3) was utilized to determine the volume of the rectangular mold.

$$V = LBH \qquad (3)$$

where V = volume of the mould, L = length of the mould, B = breadth of the mould and H = height of the mould.

The volume for the mould was derived to be $0.001 m^3$.

Determination of the compression force. The force required to compress the briquette was calculated using Eq. (4);

$$F = W \times \frac{a}{A_0} \qquad (4)$$

where W = assumed weight of the biomass to be compressed, F = force applied on the plunger, a = area of the rectangular casing and A_0 = area of the plunger.

Piston design. The following dimensions were used for the design of the piston. These include piston shaft diameter, d (0.034 m), actual length of rectangular casing, L (0.608 m), extension of piston (Link) (0.418 m) and diameter of wheel (0.18 m).

However due to large deflection which can be caused by buckling, the least moment of inertia, it can be expressed as given by Eq. (5).

$$I = AK^2 \tag{5}$$

where A is the cross-sectional area (m²), K is the radius of gyration of the cross-section area and I is the moment of inertia (m⁴).

Therefore, radius of gyration was obtained using Eq. (6). The values of the moment of inertia and the cross-sectional area of the wheel were obtained using Eqs. (7) and (8), respectively.

$$K = \sqrt{\frac{I}{A}} \tag{6}$$

$$I = \frac{\pi d^4}{64} \tag{7}$$

$$A = \frac{\pi d^2}{4} \tag{8}$$

where d= diameter of piston rod.

By computation, the radius of gyration (K) was obtained to be 1.1×10^{-2} m.

The orthographic views and the isometric drawing of the briquetting machine are shown in Figs. 1 and 2, respectively. Some of the major parts of the briquetting machine are identified in Fig. 2.

III.III Process of briquette preparation

The major biomass materials for the briquette production include rice husk, saw dust and organic binder (UF). Rice husk was obtained from a local rice milling industry in Oro, Kwara State while saw dust was obtained from local saw mill industry in Omu-Aran, Kwara State. The rice husk and saw dust were initially sun-dried for three days to reduce moisture content. After this, the rice husk and saw dust were sieved to < 2 mm. To obtain the briquette of the desired quality, various combinations of major constituents were tried as shown in

Table 1. The mixtures of the saw dust and rice husk were bonded using UF (binder). The mixture of the biomass was fed to briquetting machine for the production of the briquette. Four samples were produced for each of the composition stated in Table 1.

III.IV Performance evaluation of the machine

The briquetting machine was subjected to test based on the sample based proportion mixture. The input mass of the biomass and the output mass of the briquette formed were measured using a weighing balance. The processing time of the biomass to form briquette was recorded for each test using the stop watch. The biomass loss was obtained using Eq. (9). The efficiency as well as the capacity of the machine was obtained using Eqs. (10) and (11a,b), respectively.

$$Biomass\ Loss\ (kg) = Mi - Mo \tag{9}$$

$$Efficiency = \frac{Mo}{Mi} \times 100\% \tag{10}$$

$$MC\ (kg/h) = BFR \times 1\ hour \tag{11a}$$

However,

$$BFR = \frac{Average\ mass\ of\ output\ briquette\ (kg)}{Average\ processing\ time\ (s)} \tag{11b}$$

where Mi, Mo, MC and BFR are the mass of input biomass, mass of output briquette, machine capacity and briquette forming rate, respectively.

Table 1. Percentage weight combinations for briquette production

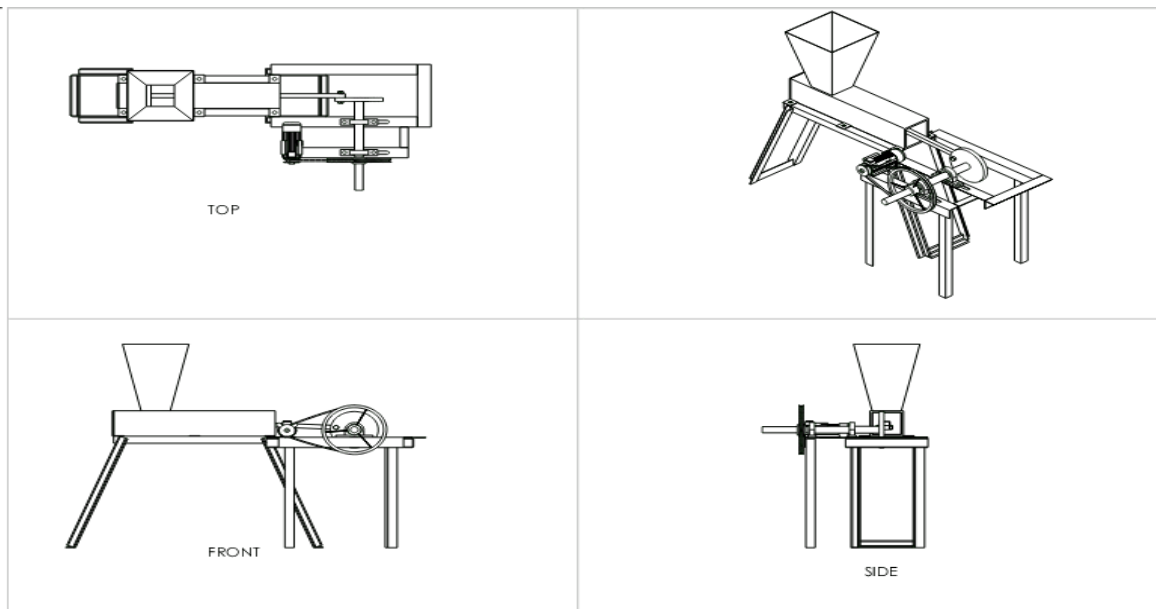| SAMPLE	SAWDUST (%wt.)	RICE HUSK (%wt.)
A	100	0
B	94	6
C	92	8
D	90	10

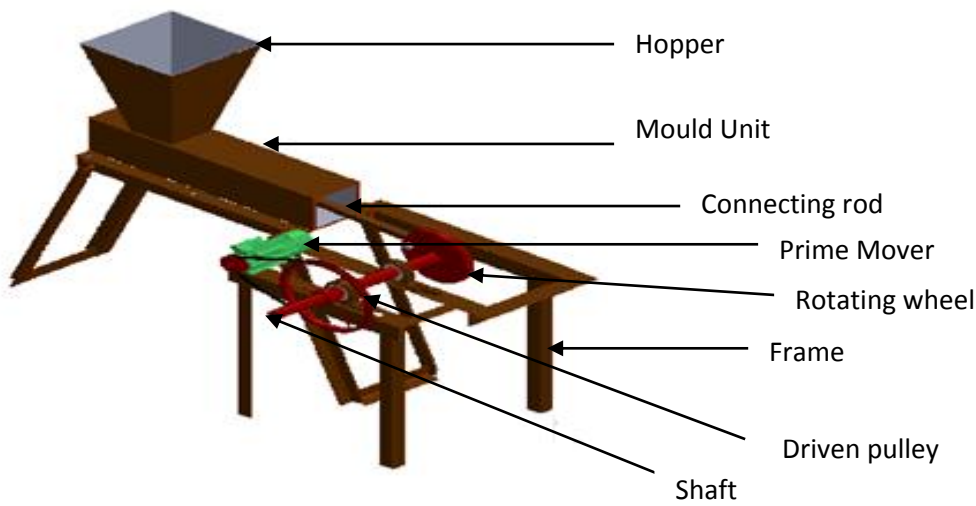**Fig. 1.** Orthographic drawing of the briquetting machine

Fig. 2. Isometric drawing of the briquette machine

Some of the briquette samples produced from the designed and fabricated briquetting machine are shown in Fig. 3.

Fig. 3. Briquettes produced using the briquetting machine

III. V Determination of the physical properties and heating value

Bulk density. In order to determine the density for each sample of the briquettes produced, the weight of each sample using a Camry weighing scale was determined in triplicate and the average was recorded. The density of briquette was determined by dividing the mass of the briquette per its volume as given in Eq. (12).

$$Bulk\ density(kgm^{-3}) = \frac{weight\ of\ briquette,(kg)}{Volume\ of\ briquette,(m^3)} \qquad (12)$$

Drop to fracture. Each briquette sample was repeatedly dropped from a stationary starting point at 2 m height into a concrete floor until it got fractured. The number of drops taken for each briquette to disintegrate into pieces is recorded [41].

Water Resistance. The resistance to water penetration was measured as the percentage of water absorbed by briquette when submerged in water. This is a test to determine the response of the briquettes during rainy seasons or while in contact with water. Each briquette was submerged in 2.5 litres of water at a room temperature of $27°C$ for 30 seconds. The percentage of water gained was calculated using Eqs. (13) and (14) [42].

$$Water\ gained\ by\ briquette(\%) = \frac{w_2-w_1}{w_1} \times 100 \qquad (13)$$
$$\%RWP = 100 - water\ gain\ (\%) \qquad (14)$$

where w_1 = Initial weight of briquette (kg) and w_2 = Final weight of briquette (kg), RWP= Resistance to water penetration

Porosity index test. Porosity index test is a measure of the percentage of water absorbed by a briquette submerged in water. Each briquette was submerged in 2.5 litres of water at $27°C$ for 30 seconds. The percentage water gain was calculated by using Eq. (15).

$$Porosity = \frac{w_2-w_1}{w_1} \times 100 \qquad (15)$$

where w_1= Initial weight of briquette before immersion (kg) and w_2 = Final weight of briquette after immersion (kg).

Shatter index test. It is used for determining the hardness of briquette was dropped on concrete floor from a height of one meter. The weight and size of the disintegrated briquette was recorded. The percentage loss of the material was calculated by using the Eq. (16) [36].

$$Percentage\ of\ weight\ loss = \frac{w_2-w_1}{w_1} \qquad (16)$$

where w_1= Weight of briquette before shattering (g) and w_2= Weight of briquette after shattering (g).

Moisture content. The samples were dried in an oven (Uclear England, Model number: DHG-9053A) at 105ºC until the samples arrived at a constant weight according to BS EN 14774-1 standard [43]. The values taken were measure in triplicates and the average value recorded for each briquette sample. Moisture content was calculated using Eq. (17).

$$Moisture\ Content = \frac{W_b-W_a}{W_b} \times 100 \qquad (17)$$

where W_b is the weight of sample before oven drying and W_a is the weight of sample after oven drying on a dry basis.

Volatile matter content. Two grams of each briquette sample was measured and placed in a crucible of known mass and oven-dried to constant mass. A heating furnace (Vecstar Ltd, Model No/Serial No: LF3/F4244) was used at a temperature of 555°C for 10 minutes according to CEN/TS 15148 standard method [44] also used by Onukak *et al.* [45] and Ogwu *et al.* [46]. The volatile matter (Vm) was then evaluated as the percentage loss in mass of the sample using Eq. (18).

$$Vm = \frac{B-C}{B} \times 100 \qquad (18)$$

where B is the weight of the sample before oven-drying (g) and C is the weight of the sample after oven drying (g).

Ash content. Two grams of each briquette sample was measured then placed in a crucible of known mass and oven dried to constant mass. These samples were later heated in the furnace (Vecstar Ltd, Model No/Serial No: LF3/F4244) of $555°C$ for 4 hours according to ASTM E-1755-01 standard [47] and weighed after cooling. The ash content was then estimated from the percentage loss in mass of the sample using Eq. (19).

$$Ash\ content = \frac{D}{B} \times 100 \qquad (19)$$

where D is weight of ash (Furnace dried) (g) and B is the weight of the oven dried sample (g).

Fixed carbon content. To determine the percentage fixed carbon of each sample of briquettes, Eq. (20) was utilized as stated by Sengar *et al.* [36] and Adeleke *et al.* [23].

$$Fc(wt\%) = 100 - (Vm + Mc + Ac) \qquad (20)$$

where Vm is volatile matter, Mc is moisture content, Ac is ash content and Fc is fixed carbon of the briquette sample.

Heating Value. The heating value of each briquette sample was determined using the Aruofor model [48] given in Eq. (21).

$$Hv = 2.326(147.6Fc + 144Vm) \qquad (21)$$

where Fc is fixed carbon, Vm is the percentage volatile matter and Hv is heating value in kJ/kg

III.VI Elemental composition

The results of the proximate analysis such as fixed carbon (F_c) and volatile matter (V_m) were used to compute the elemental composition of common organic elements which include carbon (C), hydrogen (H), and oxygen (O) for the briquettes produced. Equations (22), (23) and (24), respectively, were

employed to determine the values for C, H and O of each briquette at an estimated confidence level of 95% [49]:

$$C = 0.637F_c + 0.455V_m \tag{22}$$

$$H = 0.052F_c + 0.062V_m \tag{23}$$

$$O = 0.304F_c + 0.476V_m \tag{24}$$

IV. RESULTS AND DISCUSSION

The results obtained from various tests performed on the briquettes produced from the developed briquetting machine have been analyzed.

IV.I Performance evaluation of the machine

The efficiency of the machine and the capacity of the machine were determined through the experimental tests as shown in Table 2.

Table 2. Performance evaluation of the briquetting machine

Test	Pt (s)	Mi (kg)	Mo (kg)	Loss (kg)
1	45	1	0.82	0.18
2	46	1	0.83	0.17
3	49	1	0.84	0.16
4	48	1	0.86	0.14
5	43	1	0.85	0.15
6	45	1	0.87	0.13
7	44	1	0.87	0.13
8	45	1	0.88	0.12
9	46	1	0.86	0.14
10	44	1	0.85	0.15
11	42	1	0.86	0.14
12	43	1	0.89	0.11
Average	**45**	**1**	**0.857**	**0.143**

*Pt-Processing time; Mi-Mass of biomass input; Mo- Mass of briquette output

From Table 2, the average mass of the briquette formed was 0.857 kg while the loss was 0.143 kg. Also, the average processing time for the machine to transform from biomass to solid fuel (briquette) was 45 s. The efficiency of the machine was calculated to be 85.7% and the capacity of the machine was 68.56kg/h.

IV.II Physical properties of briquette

Bulk density. Density is an important parameter that determines physical quality of briquettes. According to Davies and Davies [42], the higher the density, the better and higher is the energy/volume ratio. The bulk density of each briquette based on the proportion of mixture of saw dust and rice husk is displayed in Fig. 4. It was observed that the maximum density was obtained in samples C and D (870 kg/m³), followed by

sample B with a density of 860 kg/m³. Sample A has the least density of 820 kg/m³. According to Rajaseenivasan *et al.* [40], increase in the density of briquettes lead to size reduction and often improve the rate of combustion. Briquettes with high density have been reported to sufficiently withstand failure and shocks during transportation and storage [5]. The density of sawdust-charcoal briquette in the study of Akowuah *et al.* [5] was found to be higher when compared to densities obtained for each sample in this study. This might be due to more compaction between the particles of sawdust- charcoal briquettes as compared to the particles of sawdust-rice husk briquettes as charcoal particles is smaller than rice particle thereby reducing pores in the sawdust-charcoal briquette. It is suggested that for more compaction of the sawdust and rice husk, lesser particle sizes could be utilized.
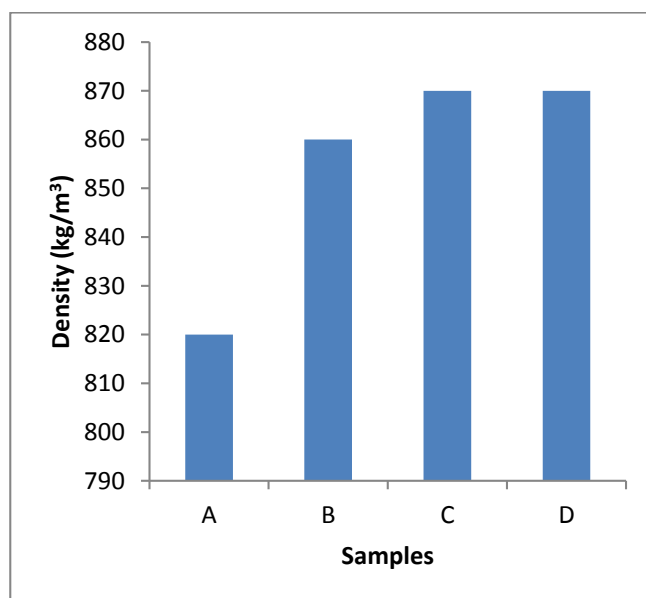

Fig. 4. Density of different briquette samples

Drop to fracture. Figure 5 shows the number of drops form 2 m that the briquettes are capable of withstanding before fracture. The drop to fracture value for samples A, B, C and D are 8, 10, 16 and 20 times, respectively. It was observed that the drop to fracture of briquetted fuel from sample D was maximum, since the number of drops recorded before it became fractured was the highest i.e. 20 times. This means a high quantity of rice husk mixed with sawdust to produce bricks has a better strength compared to the ones with a lower quantity of rice husk, that is, the higher the percentage of rice husk the better the quality of the briquette. Furthermore, during transportation, utilization and storage, sample D will be able to resist damage more than other samples.

Water resistance. Water resistance index (WRI) is useful to identify the behavior of briquette when exposed to rain or conditions of high humidity during transportation or storage. The WRI of the produced briquettes are shown in Fig. 5. The water resistance percentage for the samples increased from samples A to D with the values ranging from 93.75 - 95.24%. Based on the analysis, it was observed that the briquette fuel

from sample D has the minimum value of water gained hence has the highest resistance to water penetration. This makes sample D the most desirable in terms of water resistance property compared to other samples [42].

Porosity index. The porosity of briquette samples varied from 4.76 to 6.25% as shown in Fig. 6. Sample A has the highest porosity index with 6.25% while sample D has the least with 4.76%. This shows that sample A has a higher absorption of water compared to the other three samples which makes it more porous. As the rice husk content increases per sample, the porosity decreases as displayed in Fig. 6. The sample with the least porosity index values showed that the particles of the biomass briquette adhered more to each other [17]. Sawdust could be said to have more coarse and loose particles than rice husk. Hence, the briquettes from the mixture of sawdust and rice husk require pores that will assist oxygen passage during combustion. The highest porosity value indicated that the sample will be able to combust faster when compared to other samples.

Shatter index. The measure of the briquette strength is the shatter index. To avoid damages during handling, the shatter index as well as the impact resistance is required [40]. The shatter index values obtained for samples A, B, C and D are 74.12, 76.19, 75.6 and 81.9%, respectively as shown in Fig. 6. It was observed from Fig. 8 that the briquettes from sample D have good shatter indices with retention of 81.9% of its weight on concrete floor whereas the percentage retention of sample A was about 74.12 percent which was the least among all the samples. This shows that sample D will be more resistant to damages during handling and transportation when compared to other samples. For shatter index to be high, the density, drop to fracture and water resistance should correspondingly be high.

Generally, it was observed that the higher the porosity, the lower the water resistance ability. Sample D has the highest water resistance thus lowest porosity. Although sample D has the lowest porosity, it has enough pores to allow oxygen in for combustion process though lower than that of sample A. The more the rice husk constituents in the biomass briquettes, the more the density. The density of each sample has effect on the water resistance. As the density increased, the water resistance increased. More so, shatter index increased with increment in density but porosity index decreased as density increased.

IV.III Proximate analysis

The results of the proximate analysis for the briquettes samples are shown in Table 3. Moisture content is a parameter that helps to determine the quality of briquette in terms of its burning properties [1, 50]. Low moisture content of biomass is an indication of ease of combustion. Drying is important for briquettes to reduce high moisture content that could induce high energy consumption for its initial drying rather than releasing immediate energy. Low moisture content also

disallows disintegration and decomposition of the briquette during handling, transportation and storage [1, 25, 51]. The moisture content values obtained from briquetted fuel of sawdust-rice husk mixture produced using the briquetting machine is as shown in Table 2. The values of moisture content (5.76 – 12.09%) of the sawdust rice husk briquettes was within the range (not more than 15%) as recommended by Wilaipon [13] and Grover and Mishra [52] which was reported by Akowuah *et al.* [5] for agro-waste briquettes.

The volatile matter was found to be 65, 64.7, 64.3, and 62% for samples A to D, respectively. According to Akowuah *et al.* [5] and Loo and Koppejan [53], thermal behaviour of briquettes could be influenced by volatile matter. It was observed that out of all samples, sample A has the highest percentage of volatile matter with a value of 65%. This means the higher the quantity of sawdust the higher the volatile matter content and vice versa. The volatile matter content of Areca leaves briquette investigated by Deepak and Jnanesh [1] was 75.51 % which was more than the highest in this study. This implied that the Areca leaves briquette will easy be ignited when compared with the briquette from this study. It was reported that volatile matter content increased as binder level increases in the study of Obi [9] which made the briquette to fall within the 70 and 86% high volatile matter content and low char content as noted by Akowuah *et al.* [5] and Loo and Koppejan [53].

The non-combustible component of biomass is the ash. According to Kim *et al.* [54], ash has a noteworthy influence on the heat transfer to the fuel surface as well as oxygen diffusion to the fuel surface during combustion. The ash content was found to be 14.92, 12.72, 12.28 and 11.9%. This showed a decrease in ash content value as rice husk particle increased in the briquette mixture from samples A to D. It is important to note that biomass fuels that have low ash content are better suitable for thermal usage when compared to the ones with high ash content [5]. The ash content obtainable in the study of Obi and Okongwu [16] which was decreasing from 19.39 to 15.13% as the briquette blend ratio increased from 1:10 to 1:1 was significantly higher than the ash content of the briquette samples in this study. Higher dust emission is the result of higher ash content in fuel and therefore affects the combustion volume and efficiency [5].

The rough estimate of the heating value of a fuel is termed the fixed carbon content. It is the carbon available for combustion of char. However, it is not the same nor equal to the total amount of carbon in the fuel because some appreciable amount is liberated as hydrocarbons in the volatiles [5]. During burning, it serves as the main heat generator [1].

The fixed carbon percentage considerable increased from samples D to A. This indicates that for increasing energy content of the briquettes, the utilization of sawdust is required and important.
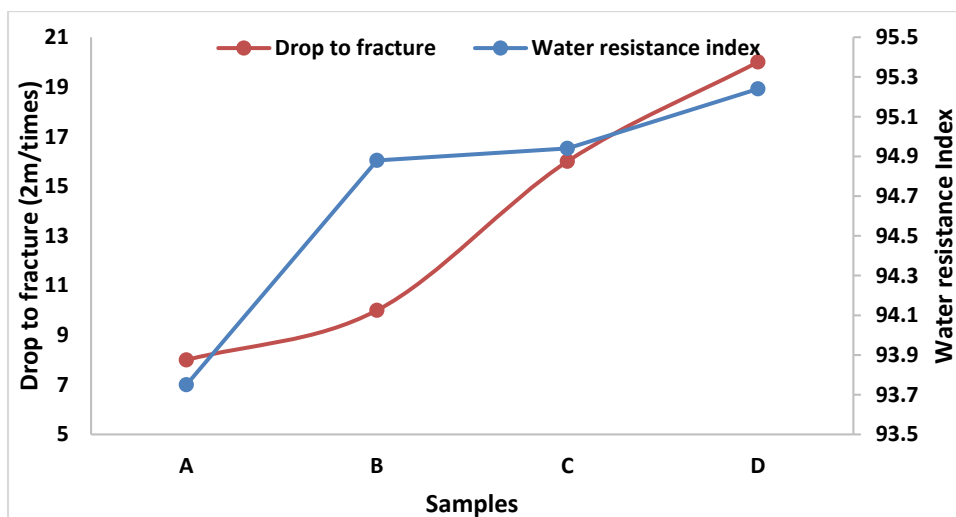
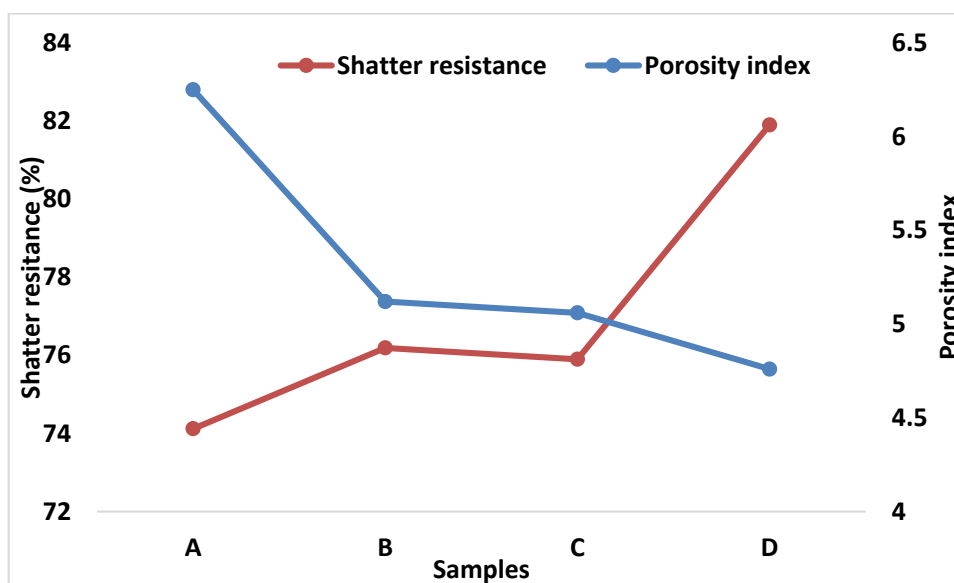**Fig. 5.** Drop to fracture and water resistance index of briquetted fuel

Fig. 6. Shatter resistance and porosity index of briquette

From the work of Deepak and Jnanesh [1] and Akowuah *et al.* [5], Areca leaves briquette and sawdust-charcoal briquette fixed carbon contents were 14.44 and 20.7%, respectively. The fixed content value for the Areca leaves briquette was with the range obtained for the sawdust-rice husk briquette and the sawdust-charcoal briquette was higher.

More so, the fixed carbon content obtained from the study of Obi [9] decreased from 18.61 to 10.81% as the binder level increased from 10 to 100 when palm oil mill sludge was used as binder in rice husk briquette. From Table 3, the decrease in fixed carbon content from samples A to D could be attributed to the decrease in the ash content of the briquette from samples A to D.

The energy content of a fuel could be determined from the heating value. Hence, it is an important parameter which depends on chemical composition and moisture content [5, 9, 16, 25]. The highest heating value was obtained from sample A (27113.38 kJ/kg) while the lowest heating value was obtained from sample D (24501.82 kJ/kg). When compared with the heat value calculated for sawdust-charcoal briquette which was 20,175.81 kJ/kg [5], corncob briquette - 20890 kJ/kg [55], Areca leaves briquette – 3113.15 kCal/kg [1] and so on, the heat values obtained for sawdust-rice husk briquette in this study could be sufficient enough to generate heat that would be required for household cooking and other applications.

Table 3: Proximate analysis of samples

Sample	VM (%)	AC (%)	MC (%)	FC (%)	HHV(kJ/kg)
A	65.0	14.92	5.76	15.56	27113.38
B	64.7	12.72	6.67	14.82	26587.18
C	64.3	12.28	10.11	13.17	26058.39
D	62.0	11.90	12.09	10.88	24501.82

*VM-Volatile matter, AC-Ash content, MC-Moisture content, FC- Fixed carbon content, HHV-High heating value

IV.IV Elemental composition

In the elemental composition for each of the samples as shown in Table 4, it was observed that Sample A has a higher percentage of carbon, hydrogen and oxygen of 39.50, 4.84 and 35.67%, respectively than all the other samples. The carbon, hydrogen and oxygen compositions for the samples ranged from 35.14 to 39.50%; 4.41 to 4.84% and 32.82 to 35.67%, respectively. According to Chaney [56] as reported by Akowauh et al. [5], the biomass analysis of using the gas-analysis procedures revealed the principal constituent of carbon to be between 30 and 60 % of the dry matter; for oxygen to be between 30 and 40 % oxygen; while for hydrogen which is the third main constituent to range from about 5 - 6%. However, other constituents such as nitrogen and sulphur (and chlorine) normally make up less than 1% of dry biomass. Therefore, the carbon, oxygen and hydrogen content values obtained in this study were very satisfactory as they make great contribution to the combustibility of any substance in which they were found [57]. From Table 4, it was observed that the elemental composition of the briquette samples decreased as the amount of rice husk particles increased in the composite briquettes.

Table 4. Elemental composition of briquette samples

Sample	C (%)	H (%)	O (%)
A	39.50	4.84	35.67
B	38.90	4.78	35.31
C	37.60	4.67	34.61
D	35.14	4.41	32.82

V. CONCLUSION

In this study, a piston-type briquetting was designed, fabricated and tested to produce briquette (solid fuels) from composition of sawdust and rice husk at different mix ratios. The efficiency and capacity of the machine were 85.7 % and 68.56 kg/h, respectively. The findings of this study have shown that, composite briquette of sawdust and rice husk would produce good biomass solid fuel. From the physical and combustion characteristics of the produced briquette in this study, the briquettes possessed good physical qualities and also there is high calorific value that will sufficiently generate heat for domestic usage such as cooking. There is great tendency that the briquettes are environmental friendly based on the elemental compositional values of the briquette. There is great future and market potential for this briquetting machine designed and for biomass briquettes in the developing countries hence rural and sub-urban dwellers are encouraged to embrace the usage of biomass briquettes.

ACKNOWLEDGEMENT

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