

# An Experimental Investigation of Biomass Fuel Briquettes' Quality as a Product of Waste Conversion InNekede, Owerri, Nigeria

Comment [PRA1]: Title: An Experimental Study on Biomass Fuel Briquettes' Quality as a Product of Waste Conversion In Nekede, Owerri, Nigeria

## Abstract

Comment [PRA2]: Please make a concise abstract with the addition of an objective and a conclusion

This study experimentally investigated the quality of a biomass fuel briquettes; a Refuse Derived Fuel (RDF) made from bio-wastes generated from a local farm produce market in Nekede, Owerri, Nigeria, known as Umuokomoche daily market. The wastes were mainly waste groceries; vegetable stems, leaves, fruits, plantain peels and stems, yam and potatoe peels, corn cob and all sorts of discarded food / agro materials which constitute over 70% of the total Municipal Solid Wastes (MSW) generated by the community. An experimental rig, a piston-type, hydraulic powered pedal operated Biomass Briquetting Machine was successfully produced and deployed for the briquetting process. It has nine cylinders and nine pistons that provided the compression of the biomass through its upward stroke on the cylinders. This machine is equipped with a removable solid rod for production of hollowed cylindrical briquettes. The biomass wastes generated (gathered) were sun dried, carbonized through pyrolysis in a kiln, crushed, mixed with a 20% starch bond and finally fed to the machine, thereby producing briquettes. The products (briquettes) recorded satisfactory combustion outcomes when tested. The preliminary results showed a calorific value of 4900Kcal/Kg which is adequate as a reliable and alternative energy source for domestic and industrial applications. Other parameters tested are; fixed carbon at 32%, Volatile matter at 44%, Moisture at 5% and are Ash content at 5.02%. A bulk density of 580 kg/m<sup>3</sup> and a Compressive ratio of 1:2.5 were also recorded. The both results confirm the handling ability and ease of transportation of the briquettes.

Comment [PRA3]: Please specify the objective of the study with clear and specific statement

**Keywords:** Biomass, briquettes, fuel wood, pyrolysis, calorific value, agro-waste, municipal solid waste

Comment [PRA4]: Please add a conclusion of this study

## 1.0 INTRODUCTION

The current energy poverty in Nigeria, occasioned by increasing energy demand, insufficient grid electricity supply, increasing costs and shortage of fossil fuel resource and the attendant effects on the environment in form of pollutions, greenhouse gas emissions and general environmental imbalance are current topical issues and requires urgent intervention. The concern that fossil fuel resources are tending towards exhaustion require concerted efforts of all stakeholders towards finding new, sustainable and alternative energy sources [1].

Biomass fuel briquettes have received global acceptability as a better replacement to fuel wood (firewood) and charcoals for heating, cooking and other industrial applications in urban and rural communities. The Nigerian Conservation Foundation (NCF) reported that Nigeria had lost almost all of its original forest because of deforestation and this is partly attributed to the use of

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fuel wood and charcoal for energy. In 2020, the country lost 97.8 kilohectares of natural forest which approximated to emission of 59.5 metric ton of greenhouse gas (CO<sub>2</sub>) to the environment [2-3].

**Comment [PRA6]:** Please mention of source of references

In Nigeria, biomass is the most dominant source of energy and is used significantly in the domestic sector for cooking and many other heat applications. Wood fuels, in the form of forest wood, charcoal and wood processing residues are the most dominant biomass forms of energy in use in Nigeria, although crop residue and other non-woody materials also find some usage. Sa'ad and Bugaje [4] have attributed this high demand for wood and woodwaste as occurrence of energy poverty in Nigeria. Most rural dwellers (about 70% of people in Nigeria) and almost all farmers heavily depend on fuel wood for all their domestic and other commercial activities that require heat[5]. The attraction for biomass briquettes has been premised on its ease of production; sustainable supply advantages; and environmental benefits (minimum environmental pollution).

**Comment [PRA7]:** Please add information on the results of research on biomass briquettes that have been carried out for small or medium scale (if any) especially from outside Nigeria

Ngumbi et al [6] described "briquetting as the process which converts these low density biomass into high density and energy concentrated fuel briquettes".

**Comment [PRA8]:** Please combine this sentence with the previous Alinea/paragraph

Biomass briquetting is the densification of loose biomass material to produce compact solid composites of different sizes with the application of pressure. Briquetting of residues takes place with the application of pressure, heat and binding agent on the loose materials to produce the briquettes.

### 1.1 Classification of Biomass Briquetting Machines

Briquetting machine could be classified based on the compaction (compression) pressure of the machine [7-8]. Thus, we have;

- i. Low compaction pressure machines (below 5MPa)
- ii. Intermediate Compaction pressure Machines (5 to 100MPa)
- iii. High Compaction pressure machines (100MPa and above)

Also, depending on the types of equipment used, vis-a-vis the mechanism and mode of operation, briquetting technologies could also be grouped as listed[9-16].

- i. Piston press
- ii. Screw press densification
- iii. Roll press densification
- iv. Pelletizing
- v. Low pressure or manual presses

**Comment [PRA9]:** Please do not present the information in the form of pointers, but in a paragraph flow

Orhorhoro et al [17] designed and fabricated an Improved Low Cost Biomass Briquetting Machine based on mechanical hydraulic powered piston compression principle. The biomass (elephant grass) had calorific values of 14011.2KJ/kg before briquetting. The calorific value

increased to 15013.9KJ/Kg after formation of briquette. This increase was partly attributed to the moisture content of the biomass.

Agidi et al [18] reported a hydraulically operated machine for making briquette from agricultural wastes. The results of testing of the equipment revealed that the highest binder concentration ratios of 30% and 40% produced the best briquettes.

**Comment [PRA10]:** Please combine these sentences with the previous sentences

Yirijor et al [19] assessed the physical and mechanical properties of briquettes produced from dry coconut husk tagged “CNH” and cocoa pod tagged “CCP” Ghana. The agro-waste was gathered, carbonised at 450°C carbonizing temperature. The two form of waste were hammer-milled and mixed at various ratios. The mix ratio, that recorded the highest heating value of 25.83 MJ/kg, good moisture and ash content, as well as good density and durability index was CNP : CCP at 20:80 mix ratio.

Akintaro et al [20] as reported in their study used three binders which were cassava starch, corn starch and gelatin and they produced carbonized corncobs briquettes. The maximum values of moisture content, volatile matter, ash content, fixed carbon and calorific value are 7.62 %, 16.48 %, 5.06 %, 81.30 % and 32.36 MJ/kg respectively.

Laukikand Nikhil [21] designed an automatic screw press briquetting machine for processing of agro-wastes to briquettes fuels in rural India. They used a 1Hp motor and a belt drive transmission and reported high performance.

**Comment [PRA11]:** Please state the research objectives specifically and briefly, and if necessary also mention the targets to be achieved

## 2.0 METHODOLOGY

### 2.1 Design Considerations:

The hydraulic pedal operated briquetting machine was designed to be compact and to take less space when installed. Therefore, portrait shape, rather than landscape was chosen.

The machine was designed to produce nine (solid or hollowed) briquettes per batch, at briquettes diameter of 68 mm. The length and shape of the machine was formed by the following ;

- i. The height of the piston (male member) and cylinder (female member) components at full compression (300 mm)
- ii. The full length of the hydraulic jack at full compression (400 mm)
- iii. The piston base plate thickness and jack sittings (10 mm). The choice of the width of the machine was based on the diameter of mould cylinder, vis-à-vis the briquette size.

The choice of the appropriate tonnage of hydraulic jack was made, after calculating all the masses the jack is expected to lift.

The mass of one compression piston = 130g

For 9 compressive pistons we have  $9 \times 500g = 4500g = 4.5kg$

Mass of one Hole making rod (briquette hole creator) =  $390g$

Therefore, for  $9 \times 390g = 3510g = 3.51kg$

The mass base of one plate =  $3.5kg$

Mass of briquette =  $90g$

For 9 briquettes

We have,  $9 \times 90g = 810g = 0.8kg$

Therefore, total mass to be lifted by the jack is the summation of the masses.

$$\begin{aligned} &= \\ & \text{mass of 9 compressive pistons} + \text{mass of 9 hole pattern rod (briquette hole creator)} + \\ & \text{mass of base plate} + \text{mass of 9 briquettes} \\ &= 4.5kg + 3.51kg + 3.5kg + 0.8kg \\ &= 12.31kg \end{aligned}$$

Osarenmwinda and Ihenyen [22] in their work considered acceleration due to gravity,  $g$ .

Thus, taking  $g = 9.81$

$$\therefore \text{the weight to be raised} = 12.31kg \times 9.81 = 120.76kg$$

Therefore, a 10 tonnes Hydraulic Jack was selected for the machine.

## 2.2 Description Of Components of the Pedal Operated Biomass Briquetting Machine

Components of briquette machine are:

1. **Cylinder and piston**: There are nine cylinders, each of 70mm inside diameter placed on a 5mm thick plate, which coincided with a nine pistons each of 68mm external diameter. Placed concentrically under the cylinder as shown in fig 1. The upward movement of the piston in the cylinder brings about the compression or densification of the biomass.

**Comment [PRA12]:** 1. Please do not present the information in the form of pointers, but in a paragraph flow  
2. Calculation information does not need to be explained in detail, but it is enough to explain the technical stages so that important values are mentioned

**Comment [PRA13]:** The main components of the machine used are not stated in the form of pointers, but are sufficiently explained in brief and sequential paragraphs

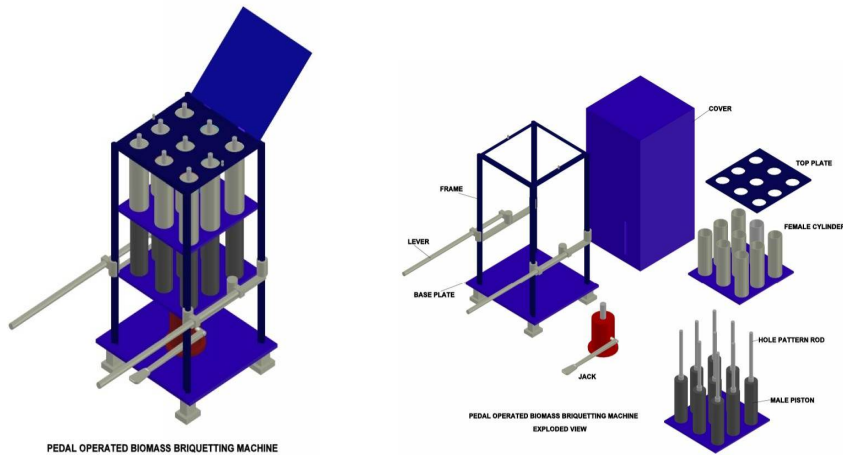


Fig 1: Pedal operated biomass briquetting machine: Isometric and Exploded views

2. **Hydraulic Jack:** Hydraulic jack of 10 ton provides the piston motion of the machine, thereby compressing the carbonised biomass in the cylinder.
3. **Foot operated Pedal:** the foot operated pedal provides an ease of use of the machine. It is almost effortless operating the machine.
4. **Lever:** the lever helps in pushing out the briquettes from the cylinders after compression.
5. **Stopper:** the moveable stopper provides a wedge for the piston plate whenever jacking is stopped or paused.
6. **Hole making rod:** This is a removeable rod which creates a hole on the center of the briquettes thereby making it cylindrically hollowed.
7. **Inlet and outlet door:** it provides a channel for feeding of the machine with the feedstock (biomass) and for the removal of the briquettes.
8. **Hole pattern guide and welded nut:** the nut provides an attachment for the hole making pattern on the piston while the pattern guide helps to retain the vertical alignment of the hole making pattern.

## 2.3 Fabrication

### 2.3.1 Methods of Construction

This machine was fabricated using electric Arc welding . See the fig 3.

Design Parameters of the Pedal operated briquetting Machine is shown on table 1.0

Comment [PRA14]: Please merged in one sentence

S/N	Part List	Quantity	Dimension (mm)
1	Piston (male) member	9	Height=300 mm, Diameter= 68 mm
2	Cylinder (female) member	9	Length = 260 mm, Diameter = 70 mm
3	Jack	1	Height at rest = 200 mm, Height at load = 400 mm
4	Hollowed briquette making rod (removable in case of solid briquettes)	9	Length= 130 mm
5	Lever (removable)	2	820 mm long
6	Base plate	1	435 mm by 420 mm
7	Height of Briquetting Machine		800 mm
8	Width of Briquetting Machine		450mm
9	Compaction Pressure		Low Pressure

Comment [PRA15]: What does it mean by S?N, please mention?

Table 1.0: Design Parameters of the Pedal operated briquetting Machine

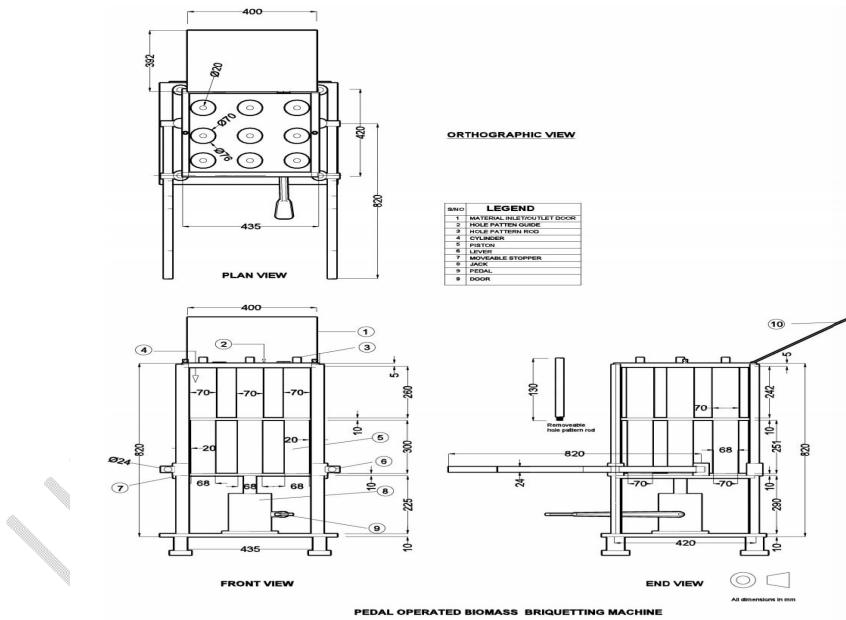


Fig 2: Orthographic views of Mechanisms of the Pedal operated briquetting machine

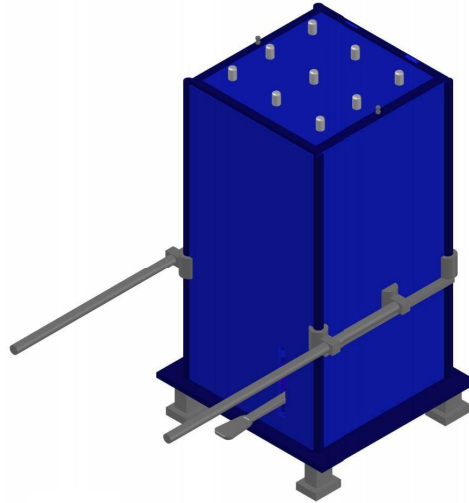
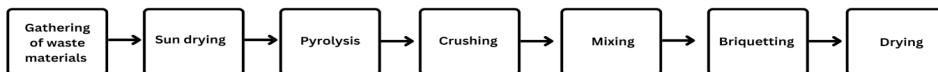


Fig 3: PEDAL OPERATED BIOMASS BRIQUETTING MACHINE

### 3.0 EXPERIMENTATION

#### 3.0 Process Flow For Briquetting



##### 1. Gathering biomass waste material

The raw materials gathered are agro-waste and Municipal Solid Waste (MSW) from a local food/farm produce market in Umuokomoche, Nekede, owerri, Nigeria, a host community to Federal polytechnic Nekede Nigeria. The wastes are mainly vegetable stems, fruits, yam and potatoe peels, coconut peels, plantain bunch and sorts of bio-wastes generated from the market.

##### 2. Sun Drying

After gathering the waste materials, we first cut them into smaller sizes to enable faster drying. They were thereafter sundried for 7 days.

**3. Pyrolysis:** The biomass was pyrolysed in a kiln at temperature of 350 °c - 400°c for 45minutes. The biochar was quenched with water.

##### 4. Crushing of the waste products

In the briquetting process, the material were later crushed into fine granules.

##### 5. mixing

After crushing the charred biomass, a cassava processed starch solution was prepared on a bowl and mixed with the fine granulated biochar as a bonding material. The starch was 20% of the total mass of biochar.

#### 6. Briquetting

The mixture was fed to the briquetting machine to produce cylindrical shaped briquettes. See fig 4 and fig 5.

#### 7. Drying of Briquettes

Briquettes were sundried to expel more moisture added during mixing.

Comment [PRA16]: Please merge in one sequent paragraph

### 3.2 Composition Of Briquettes

Briquettes comprised of the following;

#### (i). Charred biomass

This is the lightweight black residue, made of carbon and ashes, remaining after the pyrolysis of biomass.

#### (ii). Briquette binder

Due to the lack of plasticity, the binder needs to be added in the process of charcoal briquettes. The proportion of binder (starch) in the biochar briquettes is within the range of 15% - 20%.



Fig 4: Briquetting Process Fig 5: Biomass briquettes

### 3.3 Summarized Instructional Guide for the Pedal Operated Biomass Briquetting Machine

1. Attach the hole making rod
2. Filled to the brim the nine cylinder of the machine
3. Connect the pattern guide
4. Close the inlet or outlet door
5. Lock the doors with the help of bolt and nut attached to the door

6. Jacking: foot-pedal the hydraulic jack until the jack become very stiff
7. Introduce the moveable stopper directly under the piston plate and release the jack
8. Open the inlet/outlet door and press the lever to release the briquettes.

**Comment [PRA17]:** Please summarize the information and doesn't present it in pointer form

### 3.4 Briquettes Testing

#### Compression Ratio:

Agidi et al calculated the height of the briquette samples as a ratio of the cylinder height.

$$C_{ratio} = \frac{H_{cylinder}}{H_{cylinder} - H_{briquettes}}$$

Where;  $H_{cylinder}$  = Height or length of cylinder (mm)

$$H_{Briquettes} = \text{Briquettes height (mm)}$$

#### Bulk Density:

The mass of briquettes were measured on a measuring balance in the laboratory. Also measured are the height thickness and diameter of the briquettes in order to calculate the volume.

$$\therefore \tau_{bulk} = \frac{M}{V}$$

Where;  $\tau_{bulk}$  = bulk density ( $\frac{kg}{m^3}$ )

$M$  = mass (kg)

$V$  = volume ( $m^3$ )

### Combustion Properties

#### Percentage Volatile Matter (PVM)

Thee briquettes sample was heated in a kiln at between 350 - 400<sup>0</sup> for 20 mins. The PVM was then presented as percentage of weight loss at the sun dried weight of the original sample (Gbabo et al, 2015[23], Agidi et al [18])

$$PVM = \frac{\text{Weight of sundried sample} - \text{Weight of sample in kiln for 15 mins}}{\text{Weight of Sundried sample}}$$

#### The Heating Value:

The heating value (calorific value) was calculated using a bomb calorimeter in line with the ASTM standard for determining calorific value. The test was done in compliance with ASTM D5865 -03 (ATM 2003b) standards for refuse derived fuels Yirijor et al (2022 [19].

**Calculation of Ash Content:**

Ash is the left-over residue after biomass undergoes combustion. 1g of briquette sample was introduced on the crucible and the crucible was placed in the furnace. The furnace was heated to 600°C at a gradual rate and was left for 1 hour, 30 minutes before cooling in a controlled space. The measurement was done in compliance with ASTM E 830-87 (2004 reapproved) standard for refuse derived fuels (RDF);

$$Ashcontent(\%) = \frac{(M_{cucible} + M_{residue}) - M_{crucible}}{M_{briquettesample}}$$

All masses are in grams

**Percentage Fixed Carbon (PFC):**

The percentage fixed carbon was calculated according to Babajide et al (2018)[24].

Thus,

$$\%FixedCarbon = 100\% \text{ briquettesample} - (\% \text{ volatilematter} + \%AshContent)$$

**4.0 RESULTS AND DISCUSSION**

The result of the investigation is presented on average values. Refer to table 2.0;

**Comment [PRA18]:** The narrative in the results and discussion, as well as the discussion about volatile matter until bulk density should be rewrite, in accordance with international journal presentation standards

Parameters Tested	Results
Compression ratio	
Bulk density	2.2 :1
Ash Content	5.02%
Volatile Matter	44%
Calorific Value	4900 Kcal/kg (19600 KJ/Kg)
Fixed Carbon	32%
Moisture Content	5.0%
Bulk Density	502kg/m <sup>3</sup>
Compressive Ratio	1:2.5

Table 2.0: Summary of results ( average values) of Preliminary investigations

**Volatile Matter:** Heating of briquettes liberated volatile matter which is a flammable gas and smoke. It burned as a visible flame under sufficient air, time, temperature and turbulence [25]. The volatile matter of this composite biomass briquette made from non-woody biomass recorded a volatile matter of 44% average value. This value is in line with 40% to 79% recorded by Beena and Bharat [25] for non-woody biomass. In terms of quality considerations, high volatile matter content in briquettes makes it to ignite easily. High volatile matter indicates that the briquette will readily ignite with appropriate flame [26-27]

**Ash Content:**

Ash is the non-combustible fraction of the briquette obtained after combustion. The ash content for the briquette was 5.02% average value. This value is within the acceptable limit of 5-4 wt% for solid biomass [27-28]. It is also in line with 3.4% - 4.9% from non-woody biomass by Babajide et al (2018), and lower than the value from Jirijor et al [19] which recorded 4.53% - 10.12% for non-woody biomass. High ash content is detrimental to combustion and leads to fire management problems, such as regularly removing ash from the stove. Therefore, the briquettes met the acceptable quality in terms of ash concentration.

At higher temperature, the excess ash fuses (soften), thereby forming clinker that entraps combustible matter thereby blocking air distribution.

**Calorific Value:**

The briquettes generated a heating value of 4900 Kcal/Kg (19600 KJ/Kg) which exceeded the minimum heating value for commercial briquette production [19].

**Moisture Content:**

From table 2.0, the moisture content (average value) for the briquette is 5.0%. Note that, the binder concentration was 20% throughout the production. The result compares very well with 4.43 – 7.62% recorded by Akintaro et al [20], 10.3% - 12.2% by Ilochi[29], Beena and Bharat [25]. The result recorded in this work agrees with Pellavi et al [30] which placed moisture content for good quality briquettes at 5 – 10%

Moisture content in briquettes fuels affects combustion and should therefore be as low as possible. It will require excessive energy for drying off moisture.

**Fixed Carbon:**

Percentage fixed carbon determines the heating value of the fuel briquette. The higher the fixed carbon content, the higher the heating value. For the fuel briquette produced, a fixed carbon of 32% was recorded. The results is in agreement with Babajide [24] ,Akogun&Waheed[31] which recorded 17.85% - 39.50% for same agro-waste.

The fixed carbon of the biomass was increased through Pyrolysis at 400°C in the Pyrolysis Kiln before briquetting process.

### **Bulk Density and Compressive Strength:**

The bulk density of the briquettes produced recorded an average value of 502kg/m<sup>3</sup> which is a great improvement from 80 to 100 kg/m<sup>3</sup> range of bulk density for loose biomass. The result is in line with Babajide et al [24] and Lubwama et al [32], which reported 430 to 580 kg/m<sup>3</sup>. A Compressive ratio of 1:2.5 was also recorded. The both results confirm the handling ability and ease of transportation of the briquettes.

### **5.0 CONCLUSION**

An experimental investigation of biomass fuel briquettes' quality as a product of waste conversion in Nekede, Owerri, Nigeria has been presented. An experimental rig, was designed, fabricated and was found useful and efficient in converting agro/food wastes materials (Municipal Solid Wastes) to a refuse derived fuels (RDF) known as biomass briquettes. Investigation of the briquettes fuel quality and usefulness showed that the fuels are capable of generating heat energy for domestic and industrial applications. The results of testing of the briquettes showed a calorific value of 4900Kcal/Kg and a bulk density of 502kg/m<sup>3</sup>. Other parameters tested are; fixed carbon at 32%, Volatile matter at 44%, Moisture at 5% and Ash content at 5.02%. Therefore the briquettes are of good quality and reliable as an alternative energy source for domestic and industrial applications.

**Comment [PRA19]:** It needs to be completed with acknowledgment

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**Comment [PRA20]:** It is necessary to add some of the latest references about briquettes, especially from the results of research from other countries

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