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## Research Paper

# Design and fabrication of hydraulically operated machine for making briquette from agricultural waste

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A hydraulically operated machine for making briquette from agricultural wastes was designed, fabricated and tested. The equipment is capable of converting agricultural waste materials like rice husk, saw dust and sugar cane bagasse to briquettes that are capable of producing heat energy useful for domestic and industrial applications. Its major component parts include hydraulic jack, frame, pistons and compression cylinders. The results of testing of the equipment revealed that the highest binder concentration ratios of 30% and 40% produced the best briquettes. The compression ratios of the machine for the different materials are of appreciable levels ranging from 1: 2.5 to 1: 3.2 with rice husk having the least and saw dust the highest. Also the bulk densities of the briquettes produced also varied widely with rice husk recording lowest value of 2.5 kg/m<sup>3</sup> and saw dust the highest value of 5.2 kg/m<sup>3</sup>. In addition the compressive strength of the bagasse produced with saw dust was higher with value of 1.8 KN/m<sup>2</sup> and that of rice husk was lower with value 0.26 KN/m<sup>2</sup>.

**Key word:** Hydraulically, agricultural, wastes and briquettes

## INTRODUCTION

Briquettes are compressed mass of biomass which are utilized as sources of heat energy. The biomass is usually subjected to a process of densification before attaining a usable form. Densification is a method of pre-treating loose, bulky biomass materials and compressing them into a compact form suitable for use in combustion equipment. This technology makes it easier for the materials to be handled, transported and stored (Ehab, 2004). Since briquettes are formed by application of pressure on biomass mixed with binding agents, it has been established that the binding force and density of the product depends mainly on the intensity of the pressure (Lindley and Vossoughi, 1989). The biomass materials

used are usually waste products that cost little or no money to obtain. Some of such materials from which briquettes are made include old papers, partially decomposed plant waste, wood residues, rice husks which are utilized as alternative fuel to charcoal, firewood or coal (Adegoke and Mohammed, 2002). Enormous benefits can be derivable from the use of briquettes; some of these include low cost of the raw materials, emission of cleaner smoke and contribution towards conservation of soil and forest (Ogunrinede 2007). Briquette production also exemplifies the potential of appropriate technology. It saves trees and prevents problems like soil erosion and desertification by providing

an alternative to wood for heating and cooking. In addition it converts agricultural waste like hulls, husks, corn stocks, grass, leaves, food and animal garbage to valuable resources. It is also a source of cleaner burning fuel. The use of agricultural waste products for the production alternative fuel has been identified as one of several options for replacing or extending the economic life of the country's limited fossil products (Jorelyn et al., 2008). In addition to providing the above benefits, briquetting engenders many micro enterprise opportunities of making the presses from locally available materials, supplying materials and making the briquettes, selling and delivering the briquettes. (Sustainable Energy, 2003). Briquetting was first proposed in Russia in the 1830's by a Russian inventor, F.P Veshniakov, who developed a method of producing hard briquettes from waste wood, charcoal and hard coal (Ogunrinede, 2007). However, an understanding of the structure of the material and their action under pressure is very necessary for the design of the equipment. Presently, several equipments have been developed. Depending on the operating range of pressure, these equipments are classified under high, medium and low pressure machines. High pressure machines operate at high pressures of over 100 MPa thereby generating temperatures of 200-250°C.

The medium pressure machines work at 5-100 MPa and generate lower temperatures while the low pressure equipment operate at lower pressures and generating correspondingly lower temperatures. The technology of briquette production satisfies the requirement of appropriate technology. This is because it saves trees and prevents problems like soil erosion and desertification by providing an alternative to burning wood for heating and cooking. It converts agricultural waste like hulls, husks, corn stocks, grass, leaves, and animal garbage to valuable resources.

In addition to providing the above benefits, briquetting engenders the emergence of many micro enterprise opportunities by making the presses from locally available materials or making the briquettes and selling the briquettes (Sustainable Energy, 2003). Using briquette will help to conserve forests and fossil fuel reserves, reduce the amount of waste going to landfill and lower the heating costs, making it a worthwhile investment. Finally, turning "throw-away" materials into a fuel source is attractive because it is a sustainable process. Many different methods and technologies exist for pressing briquettes.

## **MATERIALS AND METHODS**

### **Machine description**

The briquette making machine consists of the following components as shown in (Figures 1 to 3 and Plate 1).

### **Hydraulic jack**

The machine is hydraulically operated. The hydraulic jack provides the mechanical force that moves the piston up, thereby compressing the material in the compression chamber. The hydraulic jack is connected to a base frame at the bottom and a plate carrying the piston at the top.

### **Frame**

The frame is made from mild steel plates of low carbon steel. Steel plates are very useful in the fabrication of briquetting machines. They were also used in the fabrication of other component of the briquetting machine, such as, the cylinder head cover, the pressure plate and the base plates.

### **Pistons**

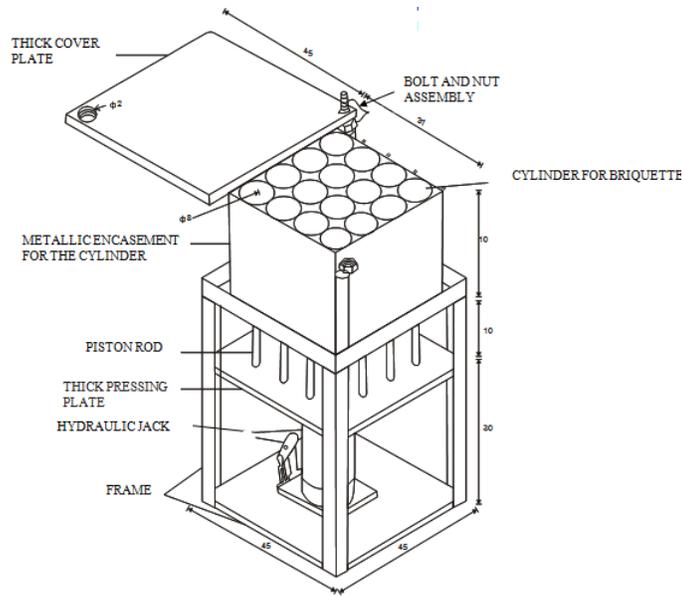
The pistons are used to transfer energy from the hydraulic jack to the compression chamber. The pistons tops were of lesser diameter when compared to the internal diameter of the cylinders; this is to allow free movement of the piston and also to create room for fluid to escape during compression.

### **Compression cylinders**

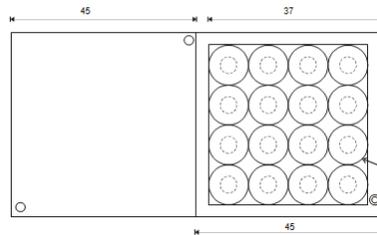
This is the enclosure where compression takes place. It consists of sixteen cylinders held together in an enclosure. Each cylinder has its own piston which transfers the compressive pressure at the bottom through the pistons to the briquette materials inside the cylinders. It also serves as a mould since the briquettes are forced to shape of the cylinders.

### **Mode of operation of the machine**

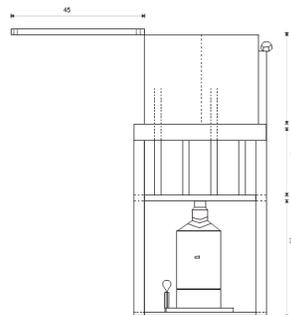
The agricultural waste (rice husk, sawdust and sugarcane (bagasse) is mixed thoroughly with the binding material (starch). The hydraulic jack is lowered with the aid of a relief valve. The screw holding the top cover is unscrewed and the top cover is opened for the agricultural waste already mixed with the binder to be fed into the cylinder. The cover is then put back in place and screwed. The valve is then closed and the handle is inserted into the pump lever and actuated until the maximum. It is then allowed for 3 to 5 min for the water to drain in order to enable the briquette to become well compacted. The top cover is opened and the pump is further actuated to push the briquettes up for easy removal. The wet briquettes are gently removed and placed on a tray and dried under the sun. The whole process is repeated for a new batch of briquettes to be produced.



**Figure 1.** Isometric view of the hydraulically operated briquetting machine.



**Figure 2.** Plan view of the hydraulically operated briquetting machine.



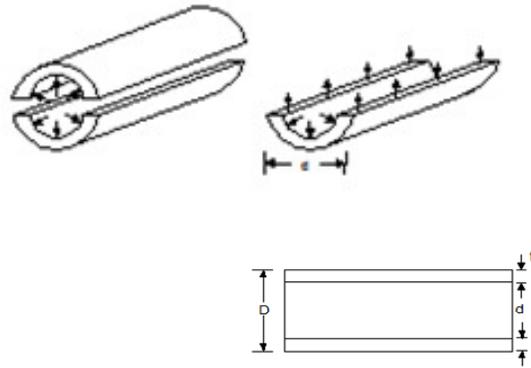
**Figure 3.** Side view of the hydraulically operated briquetting machine.

**Design analysis**

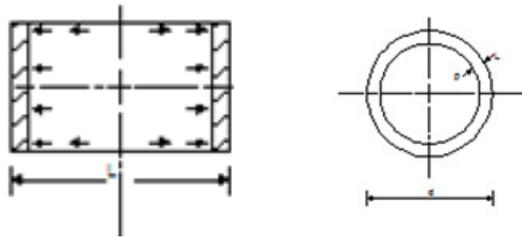
**Determination of maximum shear stress in the cylinder**

The internal walls of the cylinders would be subjected to

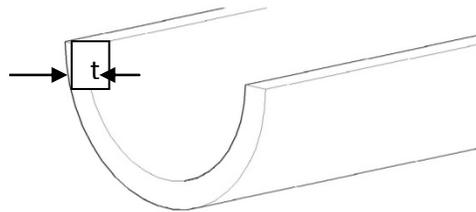
pressures due to the compressive action of the pistons against the materials inside them. Therefore, in order for the cylinders to withstand the shear stress that would be generated at the walls of the cylinders, appropriate thickness of the materials (for the construction of the cylinders) has to be selected. For this design that the



**Figure 4.** X-section of the cylinder showing circumferential stresses on the cylinder walls.



**Figure 5.** Longitudinal Stress.



**Figure 6.** Compaction cylinder thickness.

maximum design pressure required is less than 30 MN/m, a thin cylinder is used. In order to determine the expected thickness of the cylinder, the circumferential and longitudinal stresses (Figure 4) were first determined as follows (Rajput, 2006):

(i) Circumferential Stress:  $\sigma_c = \frac{\text{total pressure}}{\text{resisting section}} = \frac{pd}{2t}$  (1)

Where,  $\sigma_c$  = Circumferential stress,  $l$  = length of the shell,  $d$  = diameter of the shell  
 $t$  = thickness of the shell,  $P$  = intensity of internal pressure

(ii) Longitudinal stress

Considering the same cylindrical shell subjected to the same internal pressure as shown in (Figures 4a and b), the cylinder also has a tendency to split into two pieces due to internal pressures as shown in (Figure 5). The longitudinal stress was determined as reported by Rajput (2006).

Longitudinal stress:  $\sigma_l = \frac{\text{total pressure}}{\text{resisting section}} = \frac{P \times \frac{\pi}{4} (d)^2}{\pi dt} = \frac{pd}{4t}$  (2)

Where,  $P$ = intensity of internal pressure,  $d$ = Diameter of the cylinder,  $t$ = Thickness of the cylinder wall

Maximum shear stress ( $\tau_{max}$ ) =  $\frac{\sigma_c - \sigma_l}{2}$  (3)

Substituting

$\sigma_c = \frac{Pd}{2t}$  and  $\sigma_l = \frac{Pd}{4t}$ ,  $\tau_{max} = \frac{\frac{Pd}{2t} - \frac{Pd}{4t}}{2} = \frac{Pd}{8t}$   
 i.e.  $\tau_{max} = \frac{Pd}{8t}$  (4)

Where,  $\sigma_c$  = Circumferential stress,  $\sigma_l$  = Longitudinal stress,  $P$  = Intensity of internal pressure  
 $d$  = Diameter of the cylindrical shell,  $t$  = Thickness of the cylindrical shell

**Thickness of cylinder wall**

It is observed that the circumferential stress is greater the longitudinal stress, the thickness of the cylinder wall (Figure 6) was obtained as reported by Rajput, (2006) and is given as

$\sigma_c > \sigma_l$

$\sigma_c = \frac{Pd}{2t}$  (5)

But, since  $\sigma_c$  cannot exceed the permissible tensile stress ( $\sigma_t$ )

i.e.  $\sigma_c \leq \sigma_t$ ,  $\frac{Pd}{2t} \leq \sigma_t$

$t \geq \frac{Pd}{2\sigma_t}$  (6)

**Determination of change in cylinder volume due to pressure**

The cylinder is bound to experience change in volume due to the combined actions of both circumferential and perpendicular forces. This is expressed in form of volumetric strain as follows: The volumetric strain ( $e_v$ ) = Algebraic sum of net strains in all axes.

$e_v$  = net longitudinal strain + 2 x net circumferential strain

i.e  $e_v = e_l + 2e_c$  (7)

Direct strain due to  $\sigma_c = \frac{\sigma_c}{E}$  and Direct strain due to

$\sigma_l = \frac{\sigma_l}{E}$  (8)

Net circumferential strain ( $e_c$ ) = Direct strain – Lateral strain due to direct strain

i.e.  $e_c = \frac{\delta d}{d} = \frac{\sigma_c}{E} - \frac{\mu\sigma_l}{E}$   
 $e_c = \frac{Pd}{2tE} (1 - \frac{\mu}{2})$  (9)

Where, Direct Strain due to Circumferential Stress,  
 $\sigma_c = \frac{\sigma_c}{E}$ ,

Direct strain due to lateral stress,  $\sigma_l = \frac{\sigma_l}{E}$

Net longitudinal strain ( $e_l$ ) = Direct strain – Lateral strain due to direct strain  $\frac{\sigma_c}{E}$

$e_l = \frac{\delta l}{l} = \frac{\sigma_l}{E} - \frac{\mu\sigma_c}{E}$  (10)

$e_l = \frac{Pd}{4tE} (1 - 2\mu)$  (11)

The volumetric strain ( $e_v$ ) =  $e_l + 2e_c$  (12)

But,  $e_v = \frac{\delta V}{V} = [\frac{Pd}{4tE} (1 - 2\mu) + 2 \times \frac{Pd}{2tE} (1 - \frac{\mu}{2})] \times V = \frac{PdV}{2tE} (\frac{3}{2} - 2\mu)$  (13)

Where,  $l$  = Length of the cylinder,  $V$  = Volume of the cylinder,  $E$  = Young’s modulus for cylinder material,  $\mu$  = Poisson’s ratio.

**Determination of the mean breaking stress of the piston rod**

This was computed in order to apply appropriate force that would yield tolerable stress on pistons (Rajput, 2006).

Assuming the crippling load ( $P_c$ ) =  $\sigma_c A$

Where,  $\sigma_c$  = Maximum possible compressive stress,  $A$  = Sectional area

From Euler’s equation  $P_{Euler} = \frac{\pi^2 EI}{l_e^2} = \frac{\pi^2 EAK^2}{l_e^2}$  (14)

Where,  $P_{Euler}$  = Euler’s equation for critical load,  $E$  = Modulus of elasticity,  $I$  = Least moment of inertia of section of the rod,  $l_e$  = Equivalent length of the rod,  $A$  = Area of cross section of the rod,  $k$  = Least radius of gyration

Note  $I = AK^2$

From Rankine hypothesis

$\frac{1}{P} = \frac{1}{P_c} + \frac{1}{P_{Euler}}$  (15)

Substituting  $\frac{1}{P} = \frac{1}{\sigma_c A} + \frac{1}{\pi^2 EA (\frac{k}{l_e})^2}$

$P = \frac{\sigma_c A}{1 + \alpha (\frac{l_e}{k})^2}$  (16)

Where,  $\alpha = \frac{\sigma_c}{\pi^2 E}$ ,  $l_e = \frac{l}{2}$ , since both ends are fixed.

**Determination of the equivalent length of the piston rod**

The determination of the permissible length of the pistons is necessary in order to avoid failure in form of deformation or breakage. By equating Euler and Rankine formulae

**Table 1.** Compressive Ratios of Materials: Sugarcane Bagasse, Rice Husk and Sawdust in different Binder Concentrations.

Raw Materials	Compressive ratios			
	10%Binder Concentration	20%Binder Concentration	30%Binder Concentration	40%Binder Concentration
Sugarcane bagasse	1 : 2.5	1 : 2.6	1 : 2.8	1 : 2.8
Rice husk	1 : 2.2	1 : 2.3	1 : 2.5	1 : 2.5
Sawdust	1 : 2.7	1 : 2.8	1 : 3.1	1 : 3.2

**Table 2.** Bulk Densities of Sugarcane Briquette, Rice Husk and Sawdust Briquettes in different Binder Concentrations.

Briquettes	Bulk Densities (kg/m <sup>3</sup> )			
	10%Binder Concentration	20%Binder Concentration	30%Binder Concentration	40%Binder Concentration
Sugarcane bagasse	3.6	4.0	4.1	4.7
Rice husk	2.5	2.8	3.5	3.8
Sawdust	3.7	4.2	4.8	5.2

**Table 3.** Compressive Strengths of Sugarcane, Rice Husk and Sawdust Briquettes in different Binder Concentration.

Briquettes	Compressive strength (KN/m <sup>2</sup> )			
	10% Binder Concentration	20% Binder Concentration	30% Binder Concentration	40% Binder Concentration
Sugarcane bagasse	0.3	0.1	1.3	1.5
Rice husk	0.26	0.8	0.9	1.2
Sawdust	0.35	0.95	1.4	1.8

$$P_{Euler} = PP \tag{17}$$

$$\sigma_c A l_g^2 - \frac{\pi^2 E I a l_g^2}{k^2} = \pi^2 E I \tag{18}$$

Since  $I = AK^2$

$$l_g = \left( \frac{\pi^2 E K^2}{\sigma_c - \pi^2 E \alpha} \right)^{1/2} \tag{19}$$

$K =$  constant depending on its length and breath  $\left(\frac{b}{a}\right)$ ,  $b =$  breath of the plate  
 $a =$  length of the plate,  $E =$  modulus of elasticity of the plate

**Determination of the thickness of the bottom plate**

This is necessary in order to select the appropriate thickness that would be able to bear the applied load. The bottom plate can be assumed to be clamped at the four corners and the centre is subjected to concentrated loading from the base of the hydraulic jack. The thickness of the bottom plate is given by the formula;

$$t = \sqrt[3]{\frac{KFb^2}{E\delta^2}} \tag{20}$$

Where,  $t =$  thickness of the plate,  $\delta =$  maximum displacement,  $F =$  concentrated load

**Testing of machine**

**Experimental setup**

Five kg each of sugarcane bagasse, sawdust and rice husk were obtained from factories producing these wastes in Minna town, Niger State, Nigeria.. Three (3) starch solutions of 10%, 20%, 30% and 40% using water heated to 100°C were prepared. The starch solutions were then mixed with the sugarcane bagasse, rice husk and sawdust in separate plastic containers. Each of the specimens was fed into the machine to produce briquettes by actuating the hydraulic lever until enough resistance is posed to the upward movement of the piston. The samples were dried in the sun until the moisture content reached 5% moisture content. The briquettes were analysed for the following parameters to enable their qualities to be compared as presented in (Tables 1 to 3).

### Compression ratio

The height of the briquette samples in each cylinder were taken immediately after the compression processes in order to determine the balance of the cylinder height after compression. This height was computed as ratio to the initial height of the cylinder (80.0mm) as given:

$$Cr = \frac{H_t}{H_t - H_c} \quad (21)$$

Where  $Cr$  = compression ratio,  $H_t$  = Total height of each cylinder,  $H_c$  = Height of briquette after compression.

### Bulk density

The weights of briquettes were determined on the balance in the laboratory. Then, the volumes of briquettes were determined by a simple calculation based on the direct measurement of height, diameter and thickness of the briquettes. The bulk densities of the samples were conventionally calculated as:

$$\rho_B = \frac{M}{V} \quad (22)$$

Where,  $\rho_B$  = Density (kg/m<sup>3</sup>),  $M$  = Mass (kg),  $V$  = Volume (m<sup>3</sup>).

### Compressive test

This is used to determine the compressive strength of materials or the maximum force or load a material can withstand. This test was carried out using the fuel sample of the produced briquettes and a compressive test machine (model C90). The machine consists of a hydraulic jack, a load measuring gauge and a dial gauge. The material was placed in-between two plates of the machine and pressure applied to the hydraulic jack lever which pushed one of the plate upward as it compresses the materials against the second plate until the material starts to fail. The readings on the pressure gauge and dialled gauge were recorded (Thomas et al., 2006).

### Combustion properties

#### Percentage volatile matter

A unit of each briquette sample of sawdust, rice husk and bagasse was placed in a crucible of known weight and oven dried (E.L.E limited-serial number S80F185-Hemal Hempstead Hertfordshire S80F185 – Hemel Hempstead Hertfordshire, England) to a constant weight after which it

was heated in the furnace (Iso temp Muffle Furnace Model 186A –Fisher Scientific) at a temperature of 550°C for 15 min. The percentage volatile matter was then expressed as the percentage of loss in weight to the oven dried weight of the original sample (Gbabo et al., 2015).

$$PVM = \frac{A-B}{A} \times 100 \quad (23)$$

Where A is the weight of the oven dried sample, B is the weight of the sample after 15 min in the furnace at 550°C

## RESULTS AND DISCUSSION

### Compression ratios of the machine using for different materials

The compression ratio of the machine was found to be high for all the materials used for the formation of the briquettes. As shown in Table 1, the compression ratios ranged from 2.5:1 to 2.8:1 for sugarcane bagasse, 2.2:1 to 2.5:1 for rice husk and 2.7:1 to 3.2 for sawdust. Thus, the machine had the highest compression ratio when sawdust was used, while it had the least value for rice husk. It was also observed that the highest values for all the samples were recorded at higher binder concentrations of 30% and 40%.

### Bulk densities of briquettes

The bulk densities of the briquettes produced from sawdust had the highest value of 5.2 kg/m<sup>3</sup> while that produced from rice husk had the least value of 2.5 m<sup>3</sup>/kg as shown in (Table 2). These results seems to correspond with that of the bulk density test where saw dust had higher compression ratio while rice husk had the least value as indicated earlier. Higher compression ratio results into higher compaction and subsequently, higher bulk densities.

### Compressive strengths of bagasse

The compressive strengths of briquettes produced from sugarcane bagasse, rice husk and sawdust had very good compressive strengths as shown in (Table 3). Saw dust had the highest value of 1.8 KN/m<sup>2</sup> at the highest binder concentration of 40% while rice husk recorded the least compressive strength of 0.26 KN/m<sup>2</sup> at binder concentration of 10%.

## CONCLUSIONS

A hydraulically operated briquette production machine

has been designed, fabricated and tested. The following conclusions are made:

The equipment was designed, fabricated and testing and found useful in converting agricultural waste materials like rice husk, saw dust and sugar cane to briquettes that are capable of producing heat energy useful for domestic and industrial applications. The results of testing of the equipment showed that the highest binder concentration ratios, 30% and 40% produced the best briquettes. The compression ratios of the machine for the different materials are of appreciable levels ranging from 1:2.5 to 1: 3.2 with rice husk having the least and saw dust the highest. The bulk densities of the briquettes produced also varied widely with rice husk recording lowest,  $2.5 \text{ kg/m}^3$  and saw dust the highest of  $5.2 \text{ kg/m}^3$ . Also, the compressive strength of the bagasse produced with saw dust was higher,  $1.8 \text{ KN/m}^2$  and that of rice husk lower,  $0.26 \text{ KN/m}^2$

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**Plate 1.** Fabricated hydraulic briquette making machine.