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Development and Performance Evaluation of a Screw Press Biomass Briquetting Machine Using Sugarcane Bagasse

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Abstract: *The aim of this study was to design, fabricate and evaluate a low cost briquetting machine that would convert biomass material into briquettes for domestic use. This study was birthed as a result of the potentials of the sugarcane bagasse in large quantities that has not been tapped in Zaria and its environs thereby offering numerous benefits such as waste management, source of energy, employment and entrepreneurship, pollution control and preservation of forest resources. Components of the briquetting machine include hopper, frame, screw shaft, bearings, compression chamber and pressing cylinder or die. A 3 hp electric motor was used to drive the machine. It was evaluated using sugarcane bagasse mixed with cassava starch as binder at different biomass-binder ratio of 7:2.5, 7:3 and 7:4 by volume. The physical characteristics of the briquettes produced were also evaluated according to the proportion of the starch binder used. Results obtained shows that the mean output capacity of the machine was 4.1 kg/h, 3.5 kg/h and 3.67 kg/h with the three biomass-binder ratios respectively. Briquette at binder ratio 7:2.5 was observed to crumble more easily than the others binder ratios. Flame test also shows that the rate of burning decreases as the binder content increases. The briquettes produced was burnt without sparks, smokeless and does not produce irritating smell. They also ignite easily and took relatively long before they were extinguished. The study found sugarcane bagasse briquette as suitable replacement for wood fuel.*

Keywords: *Briquette, Binder, Biomass, Screw Press, Sugarcane Bagasse*

INTRODUCTION

Traditionally, wood in the form of fuel wood, twigs and charcoal had been the major sources of renewable energy in Nigeria, accounting for about 51% of the total annual energy consumption (Akinbami, 2001). The demand for fuel wood has been on steady increase due to increase in population and urbanization (Bello, 2010).

However, fuel wood extraction is one of the causes of climate change and thus becomes one of the primary causes for deforestation in developing countries (Ayuba and Dami, 2011). Deforestation is major contributing causes of erosion, flooding, loss of soil nutrients, poor agricultural produce, global warming, climate variability, climate change and desertification (Audu, 2012).

Many of the developing countries produce huge quantities of agro-residues that are used inefficiently causing extensive pollution to the environment. Major residues are rice husk, jute sticks, bagasse, groundnut shells, sawdust and cotton stalks (Grover and Mishra, 1996). Agricultural wastes are non-product outputs of production and processing of agricultural products that may contain material beneficial to human but whose economic values are less than its cost of collection, transportation, and processing. Estimates of agricultural waste arising are rare, but they are generally thought of as contributing a significant proportion of the total waste matter (Obi, *et al* 2016). These residues have limited use in developing countries becomes difficult to manage giving rise to serious cases of environmental pollution. If utilized, such waste could ease the strain on forest trees, provide a better means of disposing refuse and cheaper source of fuel for cooking and heating (Agamuthu, 2009). With the decreasing availability of fuel wood, coupled with the ever rising prices of kerosene and cooking gas in Nigeria, there is need to explore alternative sources of energy for domestic and cottage level industrial use in the country (Olorunnisola, 2007). For this reason, a transition to a suitable energy system is urgently required in the country. This study, therefore, intends using sugarcane bagasse in order to replace the wood fuel as an alternative fuel as well as protect forest reserves from the deforestation process and environmental pollution.

Briquetting, as an alternative energy source, improves the handling characteristics of biomass materials and enhance its calorific value, reduce transportation cost, and produces clean, uniform and stable fuel, (Bamigboye and Bolufawi, 2008). Briquetting of biomass materials requires high pressure as additional force needed/required to overcome the springiness of the materials. This gives briquettes greater advantages over fuel wood in terms of heat intensity, cleanliness, convenience in use and relatives small store space requirement.

MATERIALS AND METHODS

2.1 Design Concept

The briquetting machine designed was a screw press type (conical screw type). Its main parts are the electric motor, pulleys and belts, screw, compression chamber, frame and briquette die. Power is transmitted through pulleys and belts from the 3hp motor to the screw. After starting the motor, raw material was fed into screw that compress and extrude it through the die. Design considerations were based on forces required to drive the shaft, diameter of the screw shaft, the dynamic load on the bearing transmitted by the screw shaft, power required to compact pulverized feedstock as well as extrude the resultant briquette from the die. Other considerations include determination of dimensions and shapes of components for smooth operation.

2.2 Materials Selection

The following materials were selected based on their mechanical strength as regards the type of forces acting on the machine members, its operational environment, cost the material and its availability locally.

Table-1 Machine parts and material requirement

S/No	Machine part	Materials	Specifications
1	Hopper	Mild steel sheets	2mm
2	Frame	Angle iron	2½'' x 2½''
3	Pressing cylinder	Mild steel circular pipe	100mm diameter x 500mm length
4	Briquette Die	High carbide steel	150mm x 125mm Ø 100mm
5	Power screw shaft	Mild steel round rod	50mm x 700mm
6	Motor	-	Single phase electric motor; 3hp, 1420 rpm
7	V-Pulley		150mm Ø

Other equipment used for production and characterization of the briquettes were: Hammer mill; Gallenhamp oven for drying residue materials; digital weighing machine for measuring the mass of samples; vernier calliper for measuring diameters and height of briquettes; stop watch for measuring time during briquetting process; desiccator is a device used to prevent heated sample from absorbing moisture; electric heater for boiling water to prepare the binder; measuring cylinder to measure the quantity of water for preparing binder; and infrared thermometer for measuring the temperature of briquettes

2.3 Evaluation of Briquette Making Machine

Sugarcane bagasse was the material selected for the production of the briquettes due to the availability of sugarcane in large quantity the northern parts of the country Jemima *et al*., (2011). Similarly, chewable sugarcane is consumed in large quantity as a snack in most places in northern Nigeria. Therefore, its bagasse could be collected in large quantity at relatively no cost and could thus be used instead of allowing it to litter the environment.

2.4 Design Calculations

Size of Briquettes

Briquette size required is important in determining the machines die dimensions. For the circular hollow briquette, an outer diameter of 150mm, inner diameter of 125mm and length of 100mm was chosen so as to enable the briquetted burn effectively in the conventional domestic charcoal stoves (commonly called coal pot). The diameter of the briquettes is usually kept between 100 and 150 mm as suggested by Edwards and Smith (2004).

Weight and Volume of the Briquettes

Diameter and pitch of last flight of compression zone

$$V_f = \frac{\pi}{4}\{(90)^2 - (50)^2\} \times 46 = 202{,}318.6\, mm^3$$

To calculate pitch of compression zone, assume diameter of last flight of compression zone was 65 mm, and assumed that the compression ratio was 10. So,

$$V_c = \frac{\pi}{4}\{(65)^2 - (50)^2\} \times P = 1354P mm^3$$

$$10 = \frac{V_f}{V_c} = \frac{202{,}318.6}{1354P}. \ P = 149.4\, mm^3$$

The density of feeding material (i.e., sugarcane bagasse) is 120.1 kg/m3, so the mass of material conveyed in one complete revolution of feeding zone was determined from equation (1) (Singh and Singh, 1982):

$$\rho = \frac{Mass\ of Material}{Volume\ of\ Material}$$

m = 120.1 kg/m^3 × 2.02 ×10^{-4} m^3 = 0.024 kg
Assume the efficiency of the screw conveyor is 50%, then mass of material conveyed in one full flight of feeding zone in one revolution was:
m = 0.024 × 0.5 = 0.0121 kg
Now, the density of compacted briquette was assumed, 1000 kg/m3
ρ_b =1000 kg/m3
Volume of briquette was,
$V_b = \pi/4\ \{(60)^2\} \times 100 = 282{,}743.3\ mm^3 = 2.82 \times 10^{-4}\ m^3$

Mass of Briquettes
m_b = 1000 kg/ m^3 × 2.82 ×10^{-4} m^3 = 0.282 kg
Number of revolutions required to make one briquette,
N = 0.282/0.024 = 11.75 revolutions
Capacity of machine was assumed to be 200 kg/h.
Number of briquettes made in 200 kg,
Number of briquettes= 200/0.282 = 709.2 briquettes
709 briquettes were made in one hour (3600 sec) so,

Time required for one briquette = 3600/709 = 5.1 seconds
We know that revolution required for one briquette was 118 so,
Time required for one revolution= 11.75/5.1 = 2.30 seconds
Revolutions per minutes = 2.30 x 60 = 138 rpm 140rpm

2.5 Procedures for evaluating the machine

The biomass material (sugarcane bagasse) was collected from a sugarcane juice vendor beside Usman Danfodio Hostel, Ahmadu Bello University, Samaru campus. It was collected in sacks and transported to the workshop and spread on the bare flow to dry naturally for a week. After drying, it was crushed using hammer mill powered by a diesel engine to particle sizes of 4-6mm. The sample of the crushed sugarcane bagasse was then taken to the laboratory to determine its moisture content. The binder selected was cassava starch which was bought from Samaru market. 2000cm^3 of water and 300g of semi-solid starch were measured. 200cm^3 out of the measured water was used to dissolve the semi-solid cassava starch. The remaining water was put to boil and poured into the already dissolved starch solution immediately and stirred to form the cassava starch paste. The crushed biomass was then mixed with binders (cassava starch) prepared as stated above in the biomass-binder ratios of 7:2.5, 7:3 and 7:4 by volume. The mixed feedstock was used to evaluate the performance of the machine.

2.6 Moisture Content Determination of Biomass Material

The moisture content of the sugarcane bagasse was determined after crushing using the oven dry method. The samples were oven-dried at temperature of 103°C for 24hours. The weight of the samples was measured and recorded before as (M_1) and after oven-drying (M_2). The moisture content (dry basis) was calculated as ratio of the weight of moisture to the final weight of sample, expressed in percentage as given in the equation (2):

$$Mc_{(db)} = \frac{Mw}{Mf} \times 100 \quad (2)$$

Where $Mc_{(db)}$= moisture content (dry basis) (%)
M_i = Initial weight of the sample (g)
M_f = Final weight of dried sample (g)
M_w = Mass of moisture i.e., M_i- M_f

2.7 Determination of Machine Output Capacit

The machine output capacity according to Obi *et al*. (2016) is the ratio of the mass of briquettes produced to the average time used in producing the briquette. The machine production time components include: biomass loading time (s), biomass compaction time (s), briquette residence time (s), and briquette ejection time (s). That is;

$$\text{Machine output capacity (kg/s)} = \frac{\text{mass of briquettes(kg)}}{\text{briquettes'production time (s)}} \quad (3)$$

2.8 Burning Rate

This determines the rate at which a specified amount of the briquette is combusted in the air. Samples of briquettes of known weight are placed on wire gauze and ignited. This process, as recommended by Ndirika, (2002), was closely monitored until the briquette if burnt and constant weight is attained.

$$B_r = \frac{Q_r - Q_2}{T} \quad (4)$$

where,

$B_r = Burning\ rate, \frac{g}{min}$
$Q_1 = Initial\ weight\ of\ the\ brequtte, g$
$Q_2 = Final\ weight\ of\ the\ brequtte, g$
$T = Total\ Time, min$

RESULTS AND DISCUSSION

Having procured all required materials and parts, the designed screw extruder biomass briquetting machine was successfully fabricated (Fig. 1 and Appendix 1). Its evaluation was then carried out.

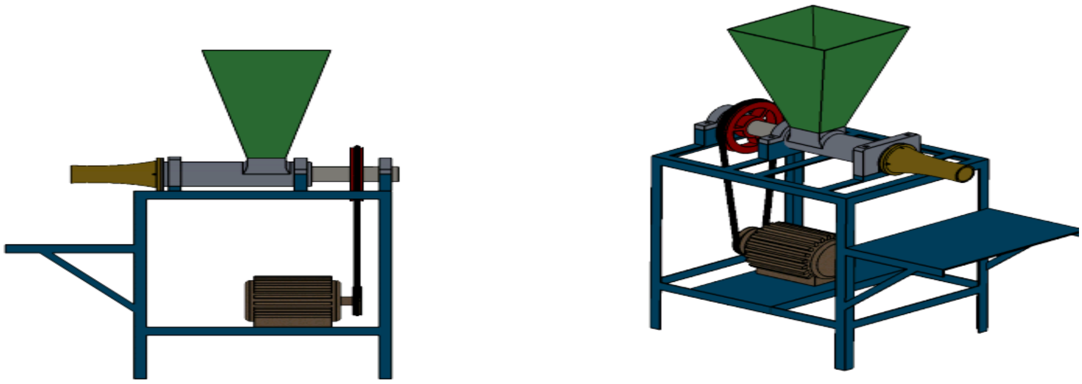

Fig. 1 Isometric Views of the Designed Machine

Machine Evaluation Analysis

The machine evaluation was carried out using sugarcane bagasse crushed to particle sizes of 4-6mm with cassava starch as binder at ratios 7:3, 7:4 and 7:2.5. The parameters determined for each binder ratios are: time taken to produce a briquette, weight of briquette produced, sample inlet temperature, and sample outlet temperature. The machine was observed to exhibit a very high temperature of the die in the beginning of the operation; however, the temperature appears to drop with time (Table-2). The briquettes produced using the developed briquetting machine is presented in Fig. 2.

Table-2 Results of machine evaluation

S/N	Biomass-binder ratio	Time (s)	Weight of briquette produced (g)	Temp in (°C)	Temp out (°C)
1.	7:3	56	55	25	92.5
2.	7:4	140	143.4	24.8	75
3.	7:2.5	128	145.3	21.1	41

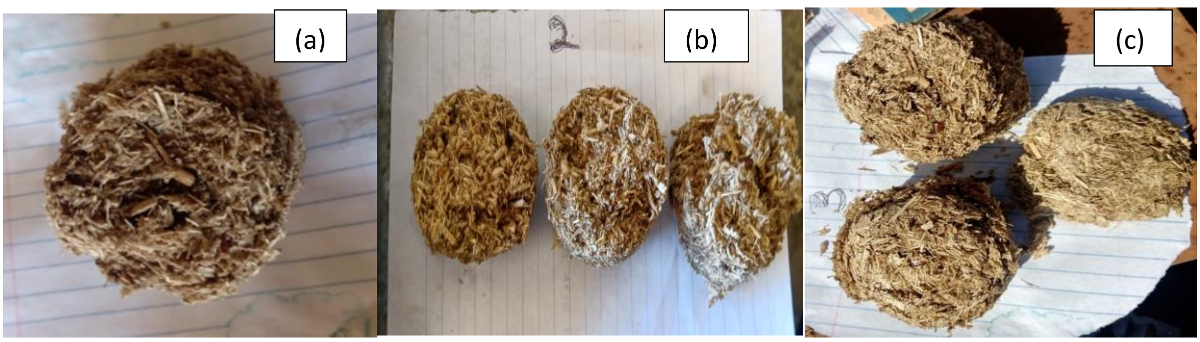

Fig. 2 Briquettes produced from sugarcane bagasse with (a) 7:3 (b) 7:4 and (c) 7:2.5 binder ratios

Results of the study shows that the physical characteristics of the produced sugarcane bagasse briquette differs according to the binder ratios. With increasing biomass binder ratio, the briquette was more firmly bound as the briquette at binder ratio 7:2.5 was observed to crumble more easily than the other ratios. Similarly, lighting the dried briquettes at the same time, it was found that the rate of burning decreases as the binder content increases.

The diameters of the briquettes produced from the binder ratios considered were relatively the same (about 100mm), perhaps because the same outlet diameter was used. However, their respective lengths extruded were observed to differ significantly ranging from 100 – 200mm.

Machine Output Capacity

Results obtained shows that the machine capacity of the briquettes produced differ for different binder ratios. It was observed that the capacity of the machine was at its peak when 7:2.5 biomass-binder ratio was used (Table 3). An average of 4.1 kg/h was obtained at this ratio while the minimum machine output capacity was 3.5kg/h.

Table-3 Machine output capacity

S/N	Binder ratio	Weight (kg)	Time (s)	Capacity (g/s)	Capacity(kg/sec)	Efficiency (%)
1.	7:3	0.055	56	0.98	0.058	94.82
2.	7:4	0.143	140	1.02	0.061	89.37
3.	7:2.5	0.145	128	1.14	0.068	92.39

CONTRIBUTION TO KNOWLEDGE

This study has established that the potentials of the sugarcane bagasse to produce briquette offers numerous benefits such as waste management, source of energy, employment and entrepreneurship, pollution control and preservation of forest resources as against the primitive use of fire wood for direct combustion as an alternative fuel as well as protect forest reserves from the deforestation process and environmental pollution. The technology also improves the handling characteristics of biomass materials and enhance its calorific value, reduce transportation cost, and produces clean, uniform and stable fuel. This gives briquettes greater advantages over fuel wood in terms of heat intensity, cleanliness, convenience in use and relatives small store space requirement.

CONCLUSION

A screw press biomass briquetting machine capable of making circular briquettes to replace charcoal and firewood for domestic cooking and general heating application was designed and fabricated in the main workshop of the Department of Agricultural and Bio-Resources Engineering, Ahmadu Bello University, Zaria. It was evaluated using sugarcane bagasse and cassava starch (binder ratio) of 7:3, 7:4 and 7:2.5. The machine was found to have a peak capacity of 4.1kg/h (0.068kg/sec) and the physical characteristics of the briquettes produced varied with varying binder ratio i.e., the higher the binder, the lesser the briquette crumble and vice versa. From the evaluation, the machine is suitable for production of solid fuels (briquettes) from plant wastes for a small family of five.

CONFLICT OF INTEREST

The authors declare no competing interest

ACKNOWLEDGEMENT

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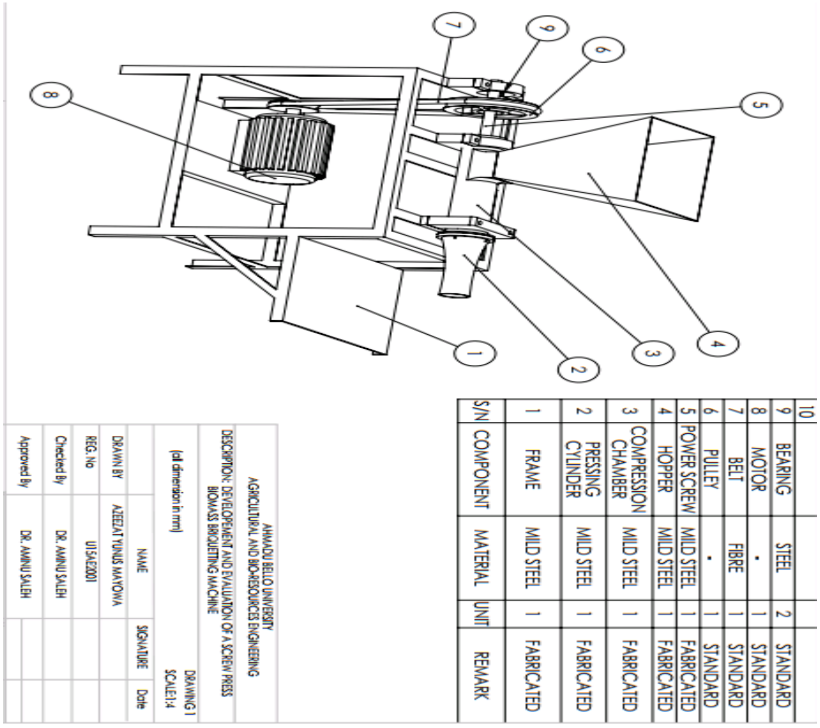
Appendix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9 BEARING STEEL 2 STANDARD
8 MOTOR - 1 STANDARD
7 BELT FIBRE 1 STANDARD
6 PULLEY - 1 STANDARD
5 POWER SCREW MILD STEEL 1 FABRICATED
4 HOPPER MILD STEEL 1 FABRICATED
3 COMPRESSION CHAMBER MILD STEEL 1 FABRICATED
2 PRESSING CYLINDER MILD STEEL 1 FABRICATED
1 FRAME MILD STEEL 1 FABRICATED
S/N COMPONENT MATERIAL UNIT REMARK
AHMADU BELLO UNIVERSITY
AGRICULTURAL AND BIO-RESOURCES ENGINEERING
DESCRIPTION: DEVELOPEMENT AND EVALUATION OF A SCREW PRESS BIOMASS BRIQUETTING MACHINE
DRAWING 1
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(all dimension in mm)
NAME
SIGNATURE
Date
DRAWN BY
AZEEZAT YUNUS MAYOWA
REG. No
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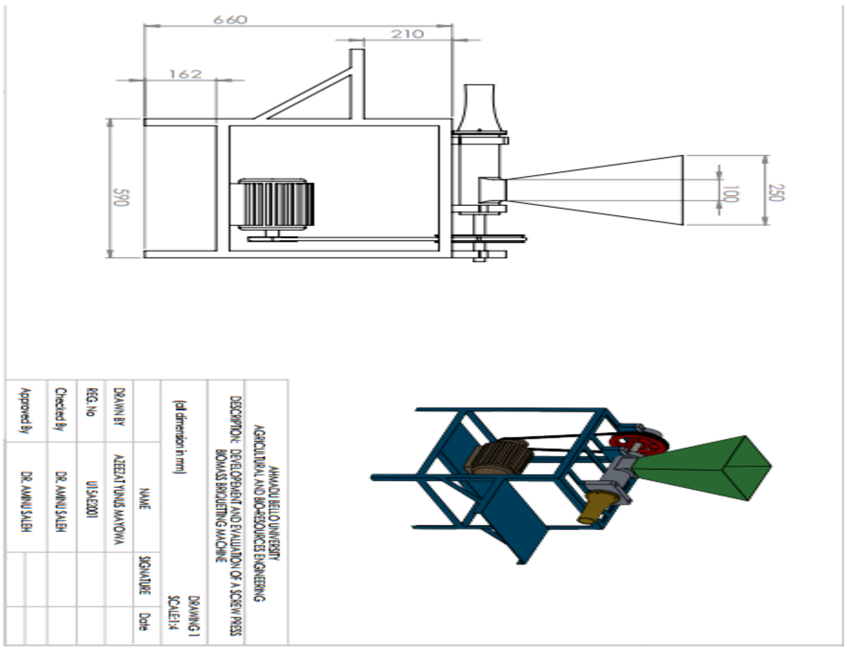
Checked By
DR. AMINU SALEH
Approved By
DR. AMINU SALEH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DRAWING 1
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