Equipment Design, Production and Characterisation of Clean Briquette fuel from composite agro-plastic wastes

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Abstract

Large quantities of agricultural and plastic wastes are generated annually in Ghana. Plastics possess high calorific value and when combined with agricultural wastes will not only serve as alternative fuel but also address the plastics waste disposal problems. This article dealt with the production of clean composite briquette from plastic wastes and agro residues for household and industrial applications. Coconut shells was carbonized, mixed with shredded plastic waste in the ratio of 10:3 and densified in a cylindrical mould into briquetting fuel. Physicochemical properties of the briquettes were determined by standard methods. The briquettes have average compressed density of 1711.82kg/m^3, relaxation ratio of 2.7 and burning time of 143mins. It has a relatively low porosity index (0.03%) and high relaxed density (662.43kg/m^3) indicating that the briquette has a low tendency to attract less moisture and can also withstand long exposure to the weather with little deterioration. The high shattering index (98.76%)) suggests that the briquettes have the ability to produce low amount of fine particles during handling. Typically, as an organic based fuel, it possesses a low ash content (2.62%) and high organic content (97.38%), responsible for the high heating value of 32839.38kJ/kg. The physical properties of the composite briquettes are desirable and hence, incorporating plastics waste into biomass as an energy source has undoubtedly improved the heating value of briquettes for its use domestically and industrially. A screw briquetting machine was also designed with throughput of 68 tons/day which requires a motor power of 2.23kW (3hp).

Keywords: Carbonized coconut shells, plastic waste, briquette fuel, physical properties, briquetting machine

1.0 Introduction

Energy is a pre-requisite for development in the world today. It does not only offer comfort to modern life but has also become a necessity of human beings (Grover *et al.*, 1994). In developing countries such as Ghana, where many people cannot afford conventional fuels such as liquefied petroleum gas, kerosene or electricity, firewood and charcoal have become the main cooking fuels for majority of households in rural and peri-urban communities. This has multiple negative impacts at the local, national and global level. The use of charcoal and firewood is perceived to have devastating ecological and environmental effects, compelling governments, public forestry institutions and non-governmental organizations to take diverse measures in order to check the growing menace of deforestation.

Most users of firewood and charcoal spend considerable amount of time both collecting firewood and cooking in confined and badly ventilated buildings. The associated harmful environmental, health and social effects with the use of traditional firewood and charcoal coupled with the high cost of petroleum-based fuels and electricity from the national grid, have generated growing interest in the search for alternate cleaner and cheaper source of energy. Globally, biomass is regarded as a third primary energy source after coal and oil, and thus, an important contributor to the world energy mix (Demirbas, 2010). Biomass refers to non-fossil biodegradable organic material from plant, animal and microbial origin. Fortunately, large quantities of agro-waste including rice-husk, palm kernel shell, coconut shell, bagasse, sawdust, and grass are available in Ghana. However, apart from the difficulty of transportation, storage, and handling, the direct burning of loose biomass in conventional grates is associated with very low thermal efficiency and widespread air pollution. Biomass resources are renewable, naturally occurring and can be properly harnessed without significant depletion of their sources. As an energy resource, biomass may be used directly as solid fuel (Kim et al., 2001), or converted into liquid or gaseous forms via a variety of technologies such as pyrolysis and gasification (Sengar et al., 2012) for electricity generation, process heating, steam generation, and mechanical or shaft power applications (Grover & Mishra, 1996). Biomass waste when converted to a clean energy fuel can substantially reduce the overdependence on fossil fuel and the emissions of greenhouse gases (Sugumaran and Seshadri, 2010). Clean biomass fuels present attractive potentials for domestic as well as medium to large-scale industrial applications.

The consumption of plastic materials has been growing steadily in view of the advantages derived from their versatility, relatively low cost, and durability compared with paper materials. Plastics have now become indispensable materials, and the demand is continually increasing due to their diverse and attractive applications in Ghana. This has resulted in huge plastic waste which poses a serious environmental challenge because of its non-biodegradable nature. Fortunately, the low calorific value of biomass can be augmented by incorporating plastic waste. Biomass consists mainly of cellulose, hemicellulose, lignin, extractive/volatiles and ash and therefore has relatively low calorific value because of the relatively high content of oxygen and ash. Plastic waste possess relatively higher fuel value and can be combined with biomass as modified alternative fuel. Briquetting, an appropriate technique, of the composite materials does not only increase the fuel value of the biomass but also addresses the disposal problems of the plastic waste. Briquetting is a technology used to compact biomass/agro residues into high density briquettes (Kim *et al.*, 2001). To minimize smoke emission during combustion, the biomass is first carbonized into char before densifying it to a compact mass using briquetting technology (Sengar *et al.*, 2012). This article discusses the production and characterization of composite briquette fuel from carbonized coconut shells and plastic waste as well as the design of briquetting machine for household cooking and industrial applications.

2.0 Materials and Methods

2.1 Production of Carbonized Briquette

Materials

Main materials used were coconut shells, plastic waste and cassava starch.

Methods

Agro-residues Feedstock Preparation

Coconut husks, mostly considered as waste were sourced from coconut sellers around Kumasi Technical University main campus. Sorting of the coconut shells were done and sun dried for seven (7) days to remove excess moisture for effective carbonization. The dried coconut shells were further shredded to increase the surface area.

Carbonization

A 55-gallon steel oil drum was converted into a carbonizing reactor and used to char coconut shells. One large square hole was cut on the top of oil drum (this is a loading hole) using a hammer and chisel. The edges of the loading hole was 8cm from the edge of the drum, this gives enough resting space for the lid. Nine (9) small round air holes were made at the bottom of the drum for a good flow of air through it. The air holes were placed 8cm apart from each other with one air hole at the center. A large square lid was used as a cover for the loading hole in the oil drum. A small amount of dried leaves were stacked into all of the 9 holes in the bottom of the drum, with about 20 cm sticking out, to allow for easy igniting and carbonization of the material from the bottom of the drum. Carbonization was initiated by lighting fire at the bottom. The air gaps were sealed for carbonization to occur for about 30 minutes in a limited amount of air. The content was allowed to cool and the char collected for briquetting.

Grinding and Sieving

A mortar and pestle were used to grind the charred material to particle sizes passing through sieve aperture of 1.7mm. The plastic wastes (polyethylene terephthalate (PET)) was cleaned, sun-dried and shredded into small sizes.

Binder Preparation

Cassava starch was used as a binder for this study since it is readily available in Ghana and also relatively cheap compared to starch from other sources. Twenty five grammes (25g) of extracted starch was weighed and mixed with 100ml of hot water, to form a thick, smooth homogeneous solution.

Mixing of the Samples

Twenty-five millilitres (25ml) starch solution was mixed with charred coconut husks and (PET) samples in the ratio of 10:3. Thirty millilitres (30ml) of fresh cold water was added to the mixture and

stirred to uniform consistency. The binder strength was then checked by squeezing the resulting mixture. The final mixture was then stored ready for briquetting.

Figure 2.2: Packaged briquettes

Briquetting, Drying and Packaging

The briquette was produced from a 55.3 mm internal diameter × 52.5 cm of cylindrical height mould. A mass of ninety grammes (90 g) of each biomass material was weighed and filled into the cylindrical mould and pressed with a briquetting wooden lever press. A period of 60 seconds was maintained during the pressing, this proceedure was repeated for all the briquette samples.

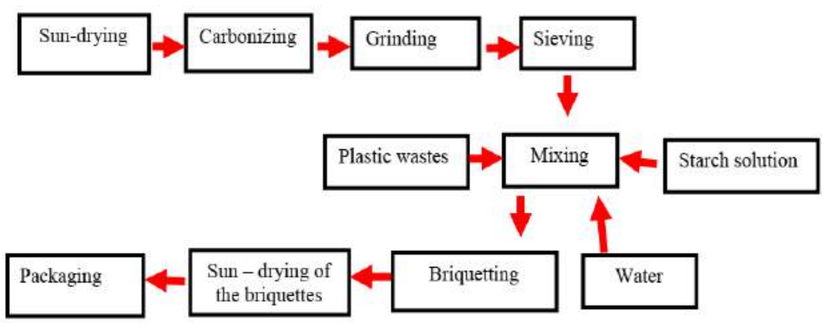


Fig. 2.3: Simplified flow chart of the manual method of briquetting

Determination of physical characteristics of the Briquette

Compressed density

The compressed density of the briquettes was determined immediately after ejection from the mould using a Standard Method (ASTM Standard E711-87, 2004). The weight of the briquette was also determines using an analytical balance (Shimadzu electronic balance type ATY124). The volume of the briquette was determined using the equation bellow:

$$V = \pi r^2 h$$ (Emrich, 1985),

Where: V is the cylindrical volume of the briquette, h is the height of the briquette and r is the radius of the briquette.

$$Compressed\ Density = \frac{mass\ of\ sample\ after\ ejection\ from\ the\ mould}{volume\ of\ sample}$$

Relaxed density

After 14 days sun dried, the relaxed density (RD) of the briquettes was determined (Olorunnisola, 2007).

$$Relaxed\ Density = \frac{mass\ of\ sample\ after\ 14\ days}{volume\ of\ sample}$$

Relaxation ratio

The stability of the briquettes is determined by the relaxation ratio, which is the ratio of the compressed density to the relaxed density of briquettes.

$$Relaxation\ ratio = \frac{compressed\ density}{Relaxed\ density}$$

Porosity Index

The amount of water the briquette can absorb is used to determine the porosity of the briquette. The briquette was soaked in water for 10sec and then removed. The porosity index was calculated as:

$$Porosity\ Index = \frac{mass\ of\ water\ absorbed}{mass\ of\ the\ briquette\ immersed}$$

Ignition time

The ignition time is described as the time taken by the briquette to catch fire (Mitchual *et al.*, 2014). It was determined by igniting the bottom edge of the briquette with fire from a Bunsen burner. The time taken for the briquette to catch fire was recorded as the ignition time using a stopwatch.

Burning time

The time taken for briquette sample to completely burn to ashes is termed burning time (Mitchual *et al.*, 2014). It was obtained by subtracting the ignition time from the time the briquette completely burnt into ashes.

Water boiling test

The water boiling test was used to determine the cooking efficiency of the briquettes. Two hundred and fifty millilitres (250ml) of water was cooked with 357.5g of the briquette using small stainless cups and domestic briquette stove. (Kim *et al.*, 2001) and the time taken for the water to boil was recorded.

Shattered Index of Briquettes

The Shattered Index was used to determine the durability of the briquettes as described by Suparin *et al. (*2008). The briquette samples were repeatedly dropped from a specific height of 1.5m onto a solid base. The fraction of the briquette retained was used as an index of briquette breakability. The durability rating of the briquette was expressed as:

$$Percentage\ weight\ loss\ = \frac{Initial\ weight\ before\ shatter - weight\ after\ shatter}{\text{Initial weight of briquette before shattering}} \times 100$$

Shatter resistance = 100 - %weight loss (Ghorpade and Moule, 2006)

Determination of Combustion Characteristics of the Briquette

IS: 1350 Method (on as received basis, wt. %) was used to determine the proximate composition of briquette.

Percentage Moisture Content

The AOAC Method 925.40 (1990) was used to measure the moisture content of the samples. Five grammes (5.0g) of finely divided briquette particles was placed in a previously dried and weighed dish. The sample was then dried to constant weight in a thermostatically controlled oven (Gallenkamp, model OV 880, England) at 103°C for 12 hours (Sengar *et al.,* 2012). This was then followed by cooling in a desiccator and weighed without absorbing moisture from the atmosphere. The weight loss expressed as a percentage of the initial weight of sample gives the percent moisture content.

$$\%moisture = \frac{(weight\ of\ crucible + wet\ sample) - (weight\ of\ crucible + dried\ sample)}{weight\ of\ wet\ sample} \times 100$$

Ash content

In accordance with ASTMD3 174-12, the ash content of the briquettes was determined (Mitchual *et al.,* 2014). This was achieved by heating an amount of 2g of oven dried mass of the briquette in the furnace at a temperature of 600˚C for 4 hours. The crucible was immediately transferred together with its contents to a desiccator to prevent absorbing moisture from the atmosphere and allowed to cool. The crucible and its content were reweighed and the new weight noted. The ash content was expressed as a percentage of the ratio of the initial weight of sample and final weight of sample after cooling.

$$\%Ash\ content = \frac{(weight\ of\ crucible) - (weight\ of\ crucible + dreid\ sample\ )}{weight\ of\ wet\ sample} \times 100$$

Volatile matter

Volatile matter can be defined as products given off by a material as gas or vapor excluding that of moisture. In the measure of the volatile matter of the sample, 2g of the oven dry weight to be preheated in the furnace at a temperature of 550°C for 10 min and weighed after cooling in a desiccator to obtain charred weight (Egbewole *et al.*, 2009). In the determination of the volatile matter of the charcoal briquettes, ASTM D3175 was used (Mitchual *et al.*, 2014). This represents a percentage of the ratio of the initial weight of sample and the final weight of sample after it had cooled.

$$\%volatile\ matter = \frac{(weight\ of\ crucible + wet\ sample) - (weight\ of\ crucible + dreid\ sample\ )}{weight\ of\ wet\ sample} \times 100$$

Percentage Fixed Carbon (%FC)

The percentage fixed carbon was determine by subtracting the sum of %Volatile matter and %Ash content from 100 as stated by Bailey and Blankenhorn (1982).

$$Fixed\ carbon = 100 - (\%Volatile\ matter + \%Ash\ content)$$

Organic carbon content

With reference to ASTM D1762, the organic carbon content of the biomass materials was determined (Mitchual *et al.*, 2014). The organic matter content (%) is given by summation of the %Volatile matter and % fixed carbon. That is;

$$organic\ carbon\ content = \%volatile\ matter + \%fixed\ carbon$$

Specific Heat of Combustion (HC)

The Specific heat of combustion was calculated using the formula by Carrel et al. (1981).

$$HC = 2.326[(147.6^{*}\%FC) + (144^{*}\%Vm)]Kcal$$

2.2 Design of Briquetting Machine

This part deals with the theoretical design considerations of briquetting machine for pressing the carbonized biomass and plastic wastes into clean densified solid fuel. In the design of briquetting machine, parameters such as the relationship between screw and barrel geometry and the properties of the feed material, flow rate, pressure drop and power consumption are important. The following design considerations and assumptions in Table 2.1 were made in other to solve the basic flow equations.

Table 2.1: Design considerations* and assumptions *for briquetting machine

Design considerations (Osarenmwinda et al., 201) and (Khurmi and Gupta, 2009)		
i Flow should be laminar. ii Flow should be steady. iii Flow should be fully developed. iv Barrel should be stationary and the screw is rotating. v Slip should not occur at the walls. vi Raw biomass should be incompressible. vii Gravity forces should be negligible and viii Inertial forces should also be negligible.		
Assumed parameters	**Values with units**	**Reference**

Shaft diameter (d)	30 mm	
Screw diameter (D_2)	95 mm	
Thickness of extruder Die	4 mm	
The distance between two pitch of the screw	80 mm	
No. of turns	3	
The thickness of the belt	6 mm	
Working allowable stresses in cotton belt	1.75 MPa	
Correction factor (Fdt)	0.98	Osarenmwinda *et al.*, 2010
Single channel screw (p)	1	
Thickness of the screw (e)	3 mm	
Viscosity of mix at the die (μ)	49.7 NS/m^2	
Screw rpm (N1)	140	

Design details of briquetting machine

From the produced briquette:

Capacity of briquetting machine: 68 tons/day

Bulk density of fresh briquettes: 1711.82 kg m^{-3}

Diameter of the briquettes: 0.0628 m

Length of the briquettes: 0.0367 m

Calculation of velocity of flow

$$mass\ flow\ rate = No.of\ dies \times Area\ of\ die \times Velocity \times density\ of\ fresh\ briquette$$

$$2833.33 = 1 \times \frac{\pi}{4}(0.0628^{\,2}) \times V \times 1711.82$$

$$V = 534.36\, mh^{-1}$$

$$V = 8.9055\, mmin^{-1}$$

The speed of briquette would be abnormally high resulting in high friction resistance and loss of power. This can be brought down to acceptable level by increasing number of dies. Thus, by increasing the 30 number of dies would lower the briquettes rate from **0.2 to 1mmin^{-1}**

$$V = \frac{8.9055}{30} mmin^{-1}$$

$$V = 0.29685\, mmin^{-1}$$

Design of die

The die of extruder was made up of 16 gauge M.S. pipe with 4 mm thickness will be used.

$$Pitch\ circle\ radius = \frac{16.5}{Sin20^0}$$

$$Pitch\ circle\ radius = 48\, mm$$

$$Diameter\ of\ outer\ circle\ (D1)\ =\ 48\, X\, 2\ +\ (62.8\ +\ 4\ +\ 4)$$

$$Diameter\ of\ outer\ circle\ (D1)\ =\ 166.8\, mm$$

$$Diameter\ of\ outer\ circle\ (D1)\ \approx\ 167\ mm = 1.67\ cm$$

Therefore, 167 mm diameter of barrel and total length of the barrel 350 mm will be used for screw press as per the screw requirement.

Design of screw extruder

Calculation of helix angle

The helix angle is the angle that helical flights with the vertical. The helix angle for the screw design mainly depends on the diameter of the screw and the pitch of screw press.

Assume

Shaft diameter (d) = 30 mm

Screw diameter (D_2) = 95 mm

The helix angle is given in the formula below:

$$\theta = \tan^{-1}\frac{S}{\pi \mathrm{D2}}$$

Where,

θ = helix angle, ^{O}

S = pitch of the screw, m

D_2 = screw diameter, m

After substituting the values considered above the helix angle is

$$\theta = \tan^{-1}\frac{0.08}{\pi \times 0.095}$$

$$\theta = 15.00541181$$

$$\theta \approx 15^{O}$$

Screw pitch lies between 0.5 to 1.0 times the diameters of screw. (Mechanical Engineering Department, Carlos III University)

Therefore,

It was assumed that the distance between two pitch of the screw = 80 mm

Assume No. of turns = 3

Therefore,

Extruder screw length = 3 X Pitch

= 3 X 80

= 240 mm

Thus, the total length of the screw 350 mm is require for screw press briquetting.

Calculation of Geometric constant (K) for circular cross – section

$$K = \frac{\pi R^4}{8 \times L_d}$$

Where,

Diameter of the die (D_3) = 6.28 cm = 0.0628 m

Radius of die (R) = 0.0314 m

Length of die (L_d) = 3.67 cm = 0.0367 m

$$K = \frac{\pi \times 0.0314\ ^4}{8 \times\ 0.0367}$$

$$K = 1.04 \times 10^{-5}$$

Calculation of Geometric constant

$$G_1 = \frac{\pi^2}{2} {D_1}^2 H \left(1 - \frac{ep}{\pi D_1 \sin\theta}\right) \sin\theta \cos\theta$$

$$G_1 = \frac{\pi^2}{2} 0.13^2 \times 0.0175 \left(1 - \frac{0.003 \times 1}{\pi \times 0.13 \times \sin 15}\right) \sin 15 \cos 15$$

$$G_1 = 7.06\ X\ 10^{-4}$$

$$G_2 = \frac{\pi^2}{2} {D_1}^1 H^3 \left(1 - \frac{ep}{\pi D_1 \sin\theta}\right) \sin^2\theta$$

$$G_2 = \frac{\pi^2}{2} 0.13 \times 0.0175^3 \left(1 - \frac{0.003 \times 1}{\pi \times 0.13 \times \sin 15}\right) (\sin 15)^2$$

$$G_2 = 7.1\ X\ 10^{-8}$$

Calculation of pressure

$$P = \frac{G_1 \times\ N\ \times F_{dt}}{\frac{K}{\mu \times D_2} - \frac{G_2 \times F_{dt}}{\mu \times L}}$$

Where,

Viscosity of mix at the die (μ) = 49.7 NS/m^2 reported by Srivastava et al., 1990

Diameter of the barrel (D_1) = 13 cm = 0.13 m

Diameter of the screw (D_2) = 0.095 m

Length of the screw (L) = 0.35 m

Thickness of the screw (e) = 3 mm = 0.003 m

Screw rpm (N_1) = 140

Single channel screw (p) = 1

Clearance between top of the screw and barrel (H) = 1.75 cm = 0.0175 m

Correction factor (F_{dt}) = 0.98 reported by Srivastava et al., 1995 for helix angle 15°.

$$P = \frac{7.1\ X\ 10^{-8} \times\ 140 \times 0.98}{\frac{1.04 \times 10^{-5}}{49.7 \times 0.095} - \frac{7.1\ X\ 10^{-8} \times 0.98}{49.7\ \times 0.35}}$$

P= 6016347.78 N/m^2 = 61.34 kg/cm^2 = 6016.38 KPa

Calculation of force

$$Force = \ Pressure \times Area$$

$$Force = \ Pressure \times \frac{\pi}{4} {D_1}^2$$

Where,

Diameter of the barrel (D_1) = 13 cm = 0.13 m

$$Force = \ \ 6016347.78 \times \frac{\pi}{4} 0.13^2$$

$$Force = \ F \ = \ 79815.87\ N \ = \ 79.81\ kN$$

Calculation of power requirement

$$Power\ input = Force \times Velocity$$

$$Power\ input = 79.81\ \times\ 0.29$$

$$Power\ input =\ 23.14\ kN - m/min$$

$$Power\ input =\ 0.3857\ kN - m/sec$$

$$Power\ input =\ 0.3857\ kW$$

For large pitch but high friction due to material combination, thread efficiency of the order of 40 per cent would be reasonable. Considering 40% thread efficiency,

$$Power\ input = \frac{0.3857}{0.40}$$

$$Power\ input =\ 0.9642\ kW\ =\ 964.2\ W$$

Then, considering 20% frictional losses,

$$Power\ required\ =\ 964.2\ \times\ 1.20$$

$$Power\ required\ =\ 1157\ W$$

$$Power\ required\ = \frac{1157\ W}{746}$$

$$Power\ required\ ==\ 1.55\ hp\ =\ 1.155\ kW$$

Also considering 70% belt drive efficiency of cotton belt (Khurmi and Gupta, 2009)

$$Total\ power\ required = \frac{1.55}{0.70}$$

$$Total\ power\ required =\ 2.22\ hp\ =\ 1.655\ kW$$

Thus, the 3 phase, 3 hp, 1440 rpm electric motor will be used.

Drive mechanism

The briquetting machine will be drive by electrical motor with the help of pulley drive. The driving pulley will be mount on motor shaft and drive pulley mount on the connecting rod for power transmission to obtain desire speed for operating the briquetting machine.

Bearings

The briquetting screw normally support with a bearing at the screw end and also drive pulley end. A significant rearward thrust must be absorbed in the bearing to compensate for the force imparted to the briquetted material as it is being moved forward along the length of the screw. Thus, the total two numbers of bearings (512 FK) will be used.

Briquetting stand

The base is important component in which all other components viz. screw assembly; the drive bearing and briquetting barrel will be fitted. The material for briquetting stand is 16 gauge M.S. sheet with 5 mm thickness and total weight of 15 kg. Total numbers of 12 bolts with size of 1 cm diameter and 15 cm height for fitting briquetting frame.

Main shaft

The main shaft is use for transmitting the power from driven wheel to screw press. The diameter of 30 mm, length of 900 mm and total weight of 5 kg of the main shaft will be used. The dimensions of housing is 80 mm X 80 mm with 25 mm thickness will be used.

Belt

The cotton belts required little attention, therefore cotton belts are mostly used in farm machinery and belt conveyor etc. (Khurmi and Gupta, 2009). The cotton belt was selected on the basis of 70 per cent efficiency. The thickness of the belt was 6 mm. The length of the belt was determined by using following formula.

$$L1 = \frac{\pi}{2} \times (D4 + D4) + \frac{(D4 - D5)^2}{4 \times C} + 2 \times C$$

Where,

L_1 = length of the belt, m

C = center to center distance between two pulley, m

D_4 = diameter of driving pulley, m

D_5 = diameter of driven pulley, m

$$L1 = \frac{\pi}{2} \times (0.1 + 1) + \frac{(0.1 + 1)^2}{4 \times 2.10} + 2 \times 2.10$$

L_1 = 6.023 m

Thus, the total length of the belt 6.023 m will be used to run the briquetting machine.

Working stresses in cotton belt

It had been shown by experience that under average conditions an allowable stress of 2.8 MPa or less will give a reasonable belt life. An allowable stress of 1.75 MPa could be expected to give a belt life of about 15 years (Khurmi and Gupta, 2009).

Design of feeding hopper

For ensuring smooth and continuous flow, following condition must be satisfied:

$$\theta_h \geq \theta_1$$

Where,

θ_h = Angle of inclination of the feed hopper to the horizontal, degrees

θ_1 = Angle of repose of biomass, degrees

Calculation of Angle of repose

The angle of repose is the angle between the base and the slope of the cone formed on a free vertical fall of the granular material to a horizontal plane. In other words this is the specific angle to the horizontal surface beneath the pile of biomass. This property of biomass is useful in the design of hopper.

$$\theta 1 = \tan^{-1}\frac{2h}{d}$$

Where,

θ_1= angle of repose, degree

h = height of hip of biomass, cm

d = diameter of hip of biomass, cm

$$\theta 1 = \tan^{-1}\frac{2 \times 8}{38}$$

θ_1= 22.83°

The size of hopper was selected by considering 30 to 40 per cent of biomass (char) material could be fed at the time of the total capacity of the machine. The hopper area was 800 X 540 at top and its slope 23° which allowed free flow of biomass to the barrel. It had a rectangular opening (130 X 90 mm) through which material is supplied and it is made of 2 mm GI sheet.

Calculation of Volume of feed hopper

The trapezoidal shaped feed hopper is provided for feeding biomass. The volume of the hopper was calculated by the following equations.

$$A_1 = \frac{1}{2} \times l \times h_1$$

$$A_2 = l \times h_1$$

$$A = A_1 + A_2$$

$$V = A + W$$

Where,

A_1 = Area of triangle, mm^2

A_2 = Area of rectangle, mm^2

A = Total area, mm^2

l = length of hopper, mm

h = height of the hopper, mm

W = width of hopper, mm

V = Volume of hopper, mm^3

$$A_1 = \frac{1}{2} \times l \times h_1$$

$$A_1 = \frac{1}{2} \times 800 \times \ 120$$

$$A_1 = 48000 \, mm^2$$

$$A_2 = l \times h_1$$

$$A_2 = 800 \times 120$$

$$A_2 = 96000 \ \ mm^2$$

$$A = A_1 + A_2$$

$$A = 48000 \, mm^2 + 96000 \ \ mm^2$$

$$A = 144000 mm^2$$

$$V = \ A + W$$

$$V = \ 144000 + 540$$

$$V = 77.76 \times 10^4 mm^2$$

Total capacity of hopper = Volume X Bulk density of raw biomass (Average)

$= 77.76\times10^4/10^8 \text{ X } 220 = 17.10$

≈ 17 kg

3.0 Results and Discussion

3.1 Characterization and Analysis of briquetted fuel

Figure 3.1 presents a picture of the composite briquette products while Table 3.1 and 3.2 give a summary of the physicochemical properties and proximate analysis respectively.

Fig. 3.1: Solid briquettes produced.

Compressed density, relaxation ratio and relaxed density.

The density of briquette is directly proportional to the energy/volume ratio. The compressed density of the briquette is determined immediately after forming the briquette, whiles that of the relaxed density is determined after the briquette has endured stability over a period (Oladeji and Enweremadu, 2012). Relaxation ratio, however, reflects the stability of the briquette. After the ejection from the mould, as the relaxation ratio increase, the stability of the briquettes also decreases (Khardiwar *et al.*, 2013). The compressed and relaxed densities of the briquette obtained are 1711.82kg/m^3 and 662.43kg/m^3 respectively as shown in *Table 3.1*. These values when compared to that of corn cobs briquettes are higher, with maximum compressed and relaxed densities values between 533kg/m3 to 981 kg/m3 and 307kg/m^3 to 417kg/m^3, respectively, as reported by Oladeji and Enweremadu (2012) and for the relaxed density of sawdust briquette of 214.17kg/m3 to 421.05kg/m^3

(Nasiru *et al.,* 2015). Indicating that the briquettes produced in this work have higher resistance to crumble during transportation, handling and storage. The respective relaxation ratio (2.6) and density ratio (0.38) of the briquettes from in this study, nonetheless, in relative to the ratio of 2.88 for corn cobs (Obi *et al.,* 2013), and density ratios of coconut fiber (0.71), palm fiber (0.41) and peanut shell (0.25) as reported by Chin and Siddiqui (2000). Additionally, the physical nature of the briquettes shows a rough external surface, compact, homogenous and black cross sectional area, which are good properties for the efficient burning of the briquettes.

Table 3.1: Physical analysis of the Briquette

PARAMETERS	VALUES
Briquette height (m) (wet)	0.0367
Briquette diameter (m) (wet)	0.0628
Briquette Mass (kg) (wet)	0.1946
Volume (m^3) (wet)	$1.1368x10^{-4}$
Compressed Density (kg/m^3)	1711.82
Briquette height (m) (dry)	0.036
Briquette diameter (m) (dry)	0.062
Briquette Mass (kg) (dry)	0.072
Volume (m^3) (dry)	$1.0869x10^{-4}$
Relaxed Density (kg/cm^3)	662.43
Relaxation Ratio	2.6
Density Ratio	0.38

Colour	Black
Shattering resistance (%)	98.76
Porosity index (%)	0.03
Ignition time (sec)	65
Burning time (mins/kg)	143
Water boiling time (mins)	10

Table 3.2: Proximate analysis of the Briquette

PARAMETERS	VALUES
Volatile matter (%)	70.77
Ash content (%)	2.62
Moisture Content (%)	3.82
Fixed carbon (%)	26.55
Organic carbon (%)	97.38
Specific Heat of Combustion (Heating Value) (KJ/Kg)	32839.4

Shattering resistance

The shatter resistance of 98.76% obtained in this study is slightly higher than reported values of 92.80% of 95.23% for sole briquette and 77.27% to 96.26% for the combined briquette (Jyoti *et al.*, 2013). A high shatter resistance is an indicator that, very low disintegration of the briquette will occur during packing and long distance travel (Sotannde *et al.*, 2010; Obi *et al.*, 2013).

Burning time and water boiling time

The combustibility rating/burning time observed was as long as 145mins/kg. The briquettes burned without sparks, smoke and also retained its original shape. The water boiling time was 10 mins. This shows that, the coconut shell char-plastic briquette could be a better alternative to the use of charcoal or firewood as also observed that briquettes improve health as it provides a cleaner burning fuel and a better alternative to firewood (40% more efficient, better and longer burning time. It also help to protect the environment by reducing deforestation, reported by Emerhi (2011).

Porosity index

The lower value of porosity index (0.03%) suggests that the briquettes have a tendency to attract less moisture and also will stand long exposure to the weather with little deterioration.

Volatile matter

Volatile matter refers to that part of the biomass that is released after heating to a temperature of 400 to 500°C. This causes the decomposition of the biomass into volatile gases and solid char, with the volatile matter representing the carbon components, hydrogen and oxygen present in the biomass briquette which turns to vapor when heated. It is usually a mixture of long and short chain hydrocarbons. Generally, a high volatile matter content of about 70% to 86% and low char content are contained in biomass, making biomass a highly reactive fuel with a faster combustion rate during the depolarization phase as compared to fuels like coal (Loo *et al.*, 2008). Low-grade fuels, such as dung, usually have low volatile content that results in smoldering, as reported by Chaney, (2010), with authors like De Souza and Sandberg (2008) describing as an incomplete combustion which leads to a notable amount of smoke and the release of toxic gases. The coconut-plastic composite briquette recorded a volatile content of 70.77%, an indication that during burning, most part of the formed briquettes will volatilize and burn as gas in the cook stove. This relatively high value is shows an easy ignition of the briquette and an equal increase in the flame length as suggested by *Loo et al.* (2008). The volatile matter obtained in this study was, however, relatively low compared to biomass briquettes produced corncobs, yam peels, groundnut shells and sawdust briquette with 86.53%, 82.87%, 88.49% and and 91.69% respectively (Oladeji, 2012), (Obi *et al.,* 2013).

Ash content

Ash content is the powdery inorganic matter residue left after the complete combustion of the charcoal briquette. It comprises non- combustible materials (e.g., minerals). As reported by Kim *et al* (2001), ash has a notable effect on the heat transfer to the surface of a fuel as well as the diffusion of oxygen to the fuel surface during char combustion. Since ash is an impurity that will not burn, fuels having low ash content are more suited for thermal utilization than fuels with high ash content. A fuel with higher ash content usually results in higher dust emissions and affects the combustion volume and efficiency. According to Loo *et al.* (2008), a higher the value of ash content, the lower the calorific value. The percent ash (2.62%) obtained in this study is slightly higher than 2.35 and 1.63% reported by Oladeji and Enweremadu (2013) for palm kernel cake and sawdust and *Obi et al.* (2000) for sawdust only respectively.

Moisture content

The briquette had a moisture content of 3.82%. This falls within the upper limit of 15% as recommended by Wilaipon (2008) and <10% by DIN 51731 for briquetting of agro-residues. The low moisture content is an indication that briquette may have a good shelf life (storability) and is less susceptible microbial activity.

Fixed carbon content

The fixed carbon content is the percentage of carbon (solid fuel) which is available for char combustion after the volatile matter is distilled off. Fixed carbon content provides a rough estimation of the heating value of a fuel and also acts as the main heat generator during burning. A relatively high fixed carbon value of 26.55% indicates the tendency to shorten cooking time through high heat release during combustion.

Total organic carbon content

This represents the amount of carbon available in the charred briquettes which could eventually be burned for heat to be released. The organic carbon value determined was 97.38%. This parameter is useful because it determines the amount of solids remaining once the carbonization process has been completed.

Specific Heat of Combustion (Heating Value)

The heating value (calorific or energy value) of the charcoal briquette is the amount of heat released per unit mass. This energy value is adequate to produce the required heat for household cooking and small scale industrial applications. From this study the heating value (32,839.38 KJ/kg) of the briquettes was higher as compared to values of most biomass energy such as groundnut shell briquette, cowpea and soybeans having 12,600 kJ/kg, 14,372.93kJ/kg and 12,953kJ/kg respectively as reported by (Musa, 2007) and (Enweremadu *et al.*, 2004). Other relatively low values reported for different briquettes include a mixture of palm kernel cake (PKC) and sawdust:19,534KJ/Kg, cassava peel: 12765kJ/kg, yam peel: 17348kJ/kg and sawdust of some hardwood species: 18,936KJ/Kg (Oladeji and Oyetunji, 2013), almond shell briquette (19,490 kJ/kg) (Grover *et al.*, 2004), corncob briquette (20,890 kJ/kg) (Oladeji, 2010). The heating value in this study is also above the DIN 51731 minimum of 17,500KJ/Kg for a material to be regarded as having adequate calorific value.

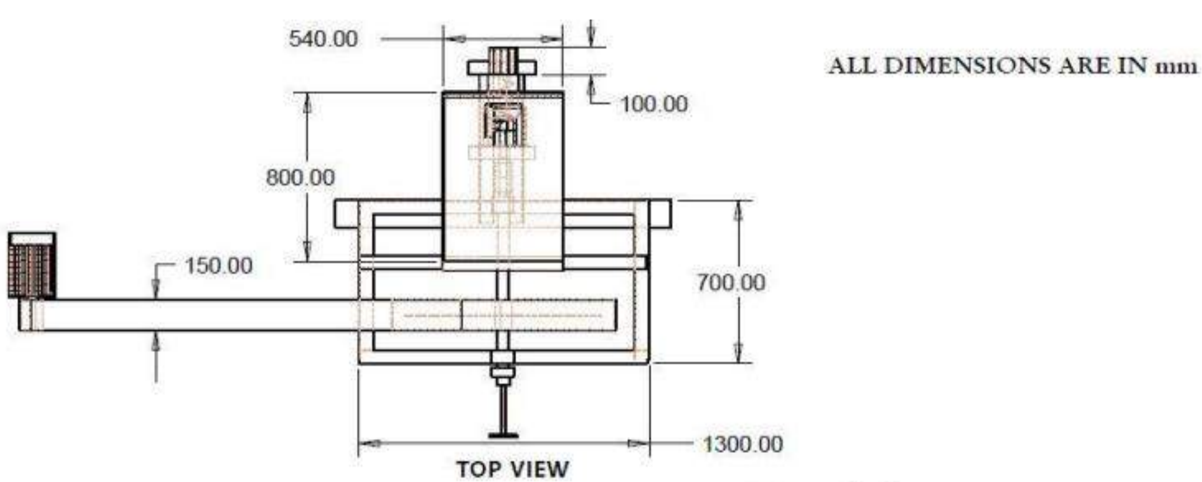
3.2 Briquetting Machine Design Equations and Generated Data

The design equations and data generated are presented in Table 3.3. The mechanical drawings and the isomeric models of the briquetting machine are displayed in Figures 3.2 and 3.3.

Table 3.3: The summary various essential components of proposed screw type briquetting machine.

Design components	Formula	Values with units
Calculation of velocity of flow		
Velocity of flow	$\frac{mass\ flow\ rate}{No.of\ dies\ \times\ Area\ of\ die \times\ density\ of\ fresh\ briquett}$	$0.29685\ mmin^{-1}$
Design of die (Khurmi and Gupta, 2009)		
Pitch circle radius	$Pitch\ circle\ radius = \frac{R}{Sin20^0}$	$48\ mm$
Diameter of outer circle (D_1)	$Pitch\ circle\ radius \times 2 + Briquettes\ size + 2 \times Thickness\ of\ extruder\ Die$	$167\ mm$
Design components	**Formula**	**Values with units**
Design of screw extruder (Khurmi and Gupta, 2009)		
Helix angle	$\theta = \tan^{-1}\frac{S}{\pi D2}$	15^O
Extruder screw length	$3\ X\ Pitch$	240 mm
Geometric constant (K) for circular cross – section	$K = \frac{\pi R^4}{8 \times L_d}$	1.04×10^{-5}
Calculation of Geometric constant	$G_1 = \frac{\pi^2}{2}{D_1}^2 H\left(1 - \frac{ep}{\pi D_1 \sin\theta}\right)\sin\theta\cos\theta$ $G_2 = \frac{\pi^2}{2}{D_1}^1 H^3\left(1 - \frac{ep}{\pi D_1 \sin\theta}\right)\sin^2\theta$	$7.06\ X\ 10^{-4}$ $7.1\ X\ 10^{-8}$
Calculation of pressure	$P = \frac{G_1 \times\ N\ \times F_{dt}}{\frac{K}{\mu \times D_2} - \frac{G_2 \times F_{dt}}{\mu \times L}}$	6016.38 KPa
Calculation of force	$Force =\ Pressure \times \frac{\pi}{4}{D_1}^2$	$79.81\ kN$

Design of feeding hopper (IS:1979) and (Osarenmwinda *et al.*, 201)		
Area of triangle, A_1 Area of rectangle, A_2 Volume of hopper, V Total capacity of hopper Angle of repose	$A = \frac{1}{2} \times l \times h_1$ $B = l \times h_1$ $V = A_1 + A_2 + W$ $Volume\ X\ Bulk\ density\ of\ raw\ biomass\ (Average)$ $\theta 1 = \tan^{-1}\frac{2h}{d}$	$48000\ mm^2$ $96000\ mm^2$ $1.08x10^8 mm^2$ 18.5 kg 22.83°
Calculation of power requirement (Khurmi and Gupta, 2009)		
Power input Total power required	$Power\ input = Force \times Velocity$ $Power\ input = \frac{Force \times Velocity \times 20\%\ frictional\ losses}{40\%\ thread\ efficiency \times 70\%\ belt\ drive\ efficiency}$	$0.3857\ kW$ $2.22\ hp$
Calculation of Belt length (Khurmi and Gupta, 2009)		
The length of the belt	$L1 = \frac{\pi}{2} \times (D4 + D4) + \frac{(D4 - D5)^2}{4 \times C} + 2 \times C$	6.023 m



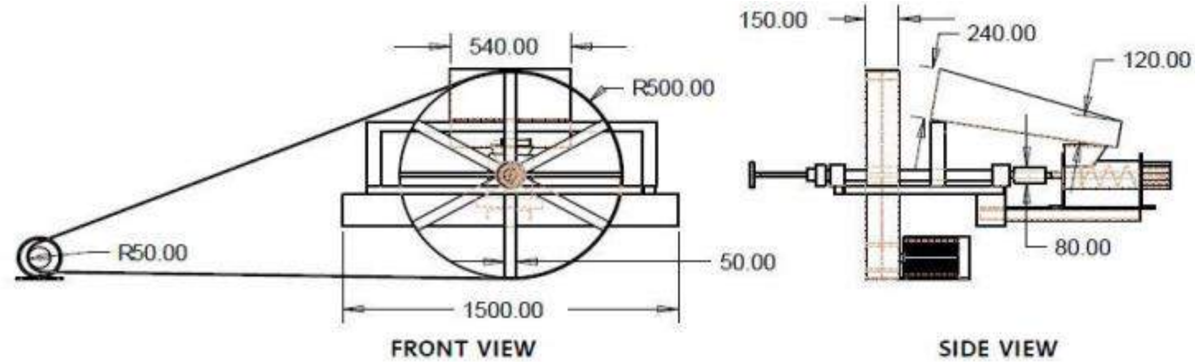


Fig. 3.2: mechanical drawings of the briquetting machine

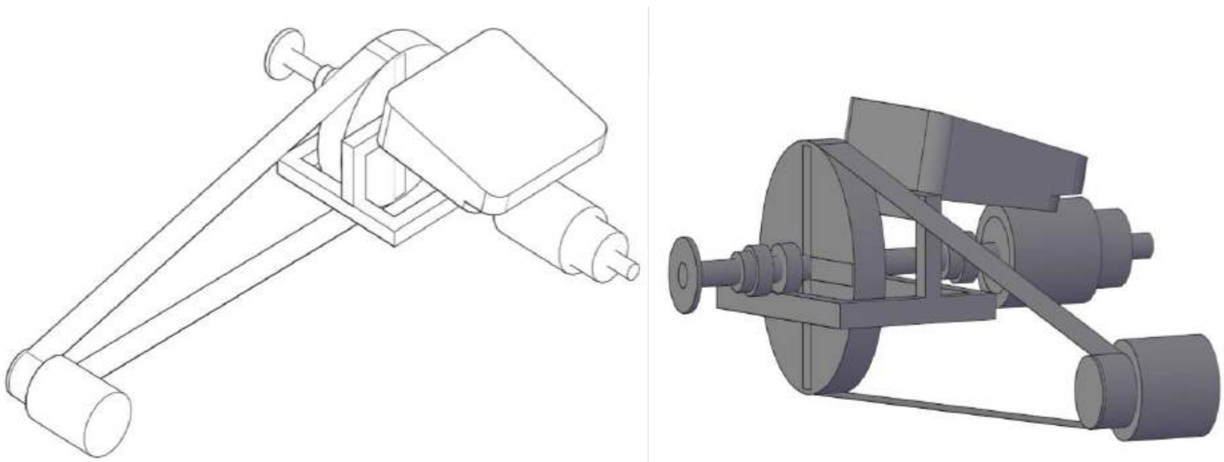


Fig. 3.3: Isomeric models of the briquetting machine

5.0 Conclusions

Based on the physical properties and proximate analysis of briquette products in this study, the following conclusions were drawn:

i. Large quantities of coconut shells and plastic waste in Ghana are potential energy fuel resources for domestic and industrial applications. When converted to fuel briquettes will not only provide a cheap clean energy source but also reduce Municipal Solid Waste deposal and pollution of the environment.

ii. The durability of the briquettes produced was high and could resist long distance travels and storage without easily crumbling because of its high resistance to shatter and also high relaxed density (higher stability).

iii. The high percentage of volatile matter obtained from the study does not indicate decrease in the burning capacity, but rather show an increase the burning capacity by proportionately increasing the flame length, and enable easy ignition of the briquette.

iv. The briquette exhibited high calorific value and therefore incorporating plastics waste into biomass as an energy source can improve the heating value of briquettes for domestic and industrial applications.

A simple briquetting machine was designed to process 58tonnes/day composite briquettes from carbonized biomass and plastic wastes. The machine will be appropriate for medium scale industrial set up.

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