Design and Fabrication of a low cost briquetting machine

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Abstract: Developing countries are faced with the huge problem of sawmill residues management. These residues are burnt on roadside or dump yards, which results in environmental pollution.This waste management problem has necessitated the need for turning such waste into a product that will provide alternative energy to the people rather than constituting environmental problems. In order to solve this problem, a low-cost briquetting machine that converts this sawdust into dense briquette for domestic use was designed and fabricated. The machine was designed so as to compress sawdust. The machine comprised a hopper, die/barrel, compaction chamber, feed screw housing, feed screw extruder, power transmission shaft and the frame.The machine was designed to produce briquette at the rate of 7 kg/hr. The briquetting machine designed has production efficiency of about 80 % and can be operated by one operator. The design parameters include: a power requirement of 10hp, belt tensions of 215.78 N and 19.6 N, and shaft diameter of 35mm with screw and die diameter of 70 mm and 50 mm respectively. The machine produced briquettes which have high resistance to mechanical action, better handling and fuel characteristics for household use. The machine was tested by producing sawdust briquette. The briquettes produced are strong; easy to handle and well compacted.

Keywords: Briquette, Sawdust, Fabrication, Densification, Heated die, Screw.

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1 Introduction

The problems associated with waste management and agro-residues are being faced daily by developing countries [1]. Pushpa and Pramod (2010) [2] reported that sawmill residues are usually burnt on dump sites which results in pollution. In addition, the increase in the need for energy in the form of fuel keeps increasing on a daily basis and the problem of non- renewable nature of fossil fuel has been the major concern worldwide. Developing countries have been facing an energy crisis over the past years despite every attempt to solve the problem [3]. There has been an acute shortage of petroleum and allied products, which affect the economy and standard of living. According to Inegbedion and Francis-Akilaki (2022) [4], incessant increase in petroleum products price is another phenomenon associated with shortage of fuels. People especially those in the rural areas cannot afford the high price of fuels such as kerosene to meet their daily domestic needs. Several efforts have been made by governments to reduce all these problems; but have not yielded any result particularly in the area of hike in prices.

Due to this, much attention has to be given to the search for alternative energy sources that are renewable such as solar energy, wind, geothermal, water and biomass. Among all the renewable energy, biomass which is the generic name given to all dry plant materials and organic waste has found more recognition. The reason is that its development always results in a cleaner environment and at the same time can provide the means to recycle wastes to some valuable products. Another advantage of biomass over other sources of renewable energy according to Adekoya (1989) [5] and Adenuga (1998) [6] is its readily available and energy conversion techniques that are not so expensive. Biomass can be derived from plants and animal materials through a variety of conversion and end use [7]. Examples of biomass include; sawdust, rice husk, palm kernel shell, paper and animal dung.
According to Pushpa and Pramod (2010) [2], many agro-residues are produced by many of the developing countries but they are inefficiently

used, causing extensive pollution to the environment.This concern has called for alternative ways of generating energy through agro-residues such as sawdust. Production of briquette from these agro-residues according to Kishan *et al.* (2016) [8] can solve this pollution problem with the advantage of using them as a source of non-conventional energy. This production is facilitated by the availability of sawdust which at present constituting a waste and the need to find a way of converting these residues into useful product.The waste can be converted to a solid fuel through production of briquette by improving the calorific value and ensuring a clean and bluish smoke free flame suitable for cooking. The end use of briquette is for replacing coal in industry for heat applications, generation of power through gasification and for domestic uses.

2 Materials and methods

The machine was designed for continuous extrusion of briquettes. This terminated in a die surrounded by a heating jacket to give a dense and high caloric value briquette.

2.1 Machine description and fabrication process

The screw type briquette machine was designed and fabricated with the following components; hopper, feed screw, barrel or die, heating jacket and tray as shown in Figure 1. The hopper is made up of four welded mild steel sheets slanting towards the smaller opening which connects it to the feed screw housing. The flow of sawdust down the hopper was influenced by gravity. The hopper feeds the raw materials into the compression chamber and they are conveyed to the die by feed screw where it is compressed and converted to briquettes.

The feed screw extruder which was made from a single mild steel shaft creates pressure and high temperature on the raw materials as it passes through the die to produce the briquettes.

The barrel or die made of mild steel had a die clearance and the taper angle which determined the performance or production rate of the briquetting machine. The power transmission shaft transmits power from the electrical motor through a system of pulleys to the feed screw extruder. The frame is the support on which the machine rests. Its function is to hold all other parts of the briquetting machine and to resist vibration while working.

Fig. 1: Pictorial side view of the briquetting machine

2.2 Design calculations

2.2.1 Hopper

The Hopper was designed using mild steel plate and the volume is $1.203\ x\ 10^{-2}\ m^3$. It can contain 18.05 kg at a time assuming the density of over dried wood particles is 1500 kg/m^3.

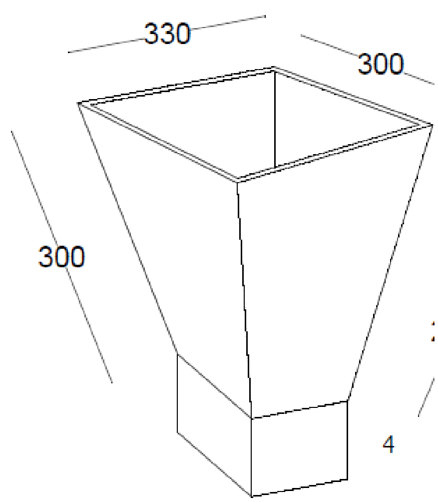

Fig. 2: Hopper

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2.2.2 Compression Screw

The compression screw was designed to extrude the biomass through a straight wall die.

The complete screw with all the screw flights was fabricated by machining a single mild steel round rod of 35 mm diameter on a lathe. After machining, the first two flights of the screw were hard-faced by welding the surface with a general electrode. The screw has a length of 400 mm; length of threaded portion is 350 mm, outer diameter of 70 mm and mild steel washer of 4 mm thick.

2.2.3 Barrel

The barrel is a cylinder of diameter 50 mm with thickness of 3 mm in order to withstand the compression of the screw against the die for extrusion. For marking out the position of the hopper, the cylinder was clamped into a convenient position and a square hole was cut out after which the hopper with connector was positioned for welding to the barrel.

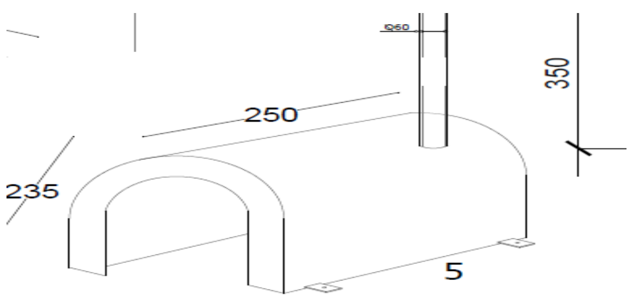

Fig. 3: Barrel cover

2.2.4 Heating stove Jacket

The heating jacket was made of mild steel with a combustion chamber of size $250\ mm\ x\ 250\ mm\ x\ 150\ mm$, the exhaust from the jacket passes through a chimney attached to it at the top and is finally exhausted to the atmosphere.The die of the briquetting machine passes through the combustion chamber, exposing its outer surface to the flames inside the chamber.Whenever the die temperature reaches $250^{o}C$, the briquetting machine is started. To keep the temperature high, the jacket must be fed with fuel periodically nearly every 5 minutes. Good quality briquette is obtained at die temperature of around $200\ ^{o}C$ or even lower temperature than this. It takes some time around 35 to 40 minutes to bring the die temperature to a higher value, after which briquetting could be started.

2.2.5 Briquette die

The die was made of cast iron, and machined on a lathe to the required dimensions. Grooves were provided on the inner surface of the die to prevent twisting of the briquette, which would otherwise happen due to screw rotation. The briquette die was made of length 120 mm with diameter of 50 mm and thickness of 3 mm.

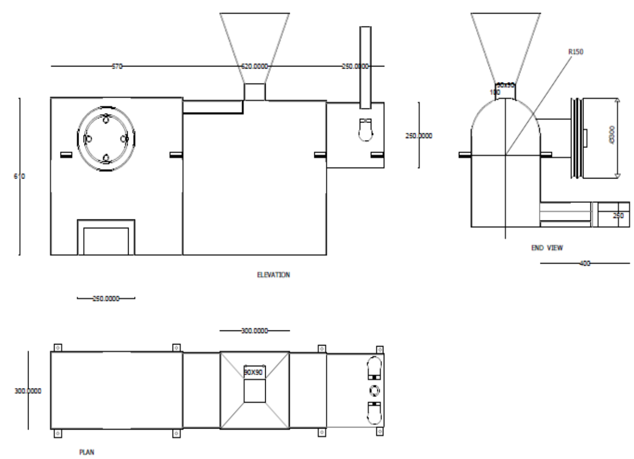

Fig. 4: Machine's plan, elevation and end view

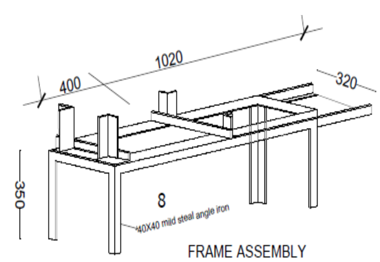

Fig. 5: Frame Assembly

2.2.6 Power requirement

The power required to drive the briquetting machine can be estimated as a function of the power required to overcome the inertia of the load of the rotating parts and materials in the hopper.

Nawsher (2004) [9] and Adedeji (2000) [1] used the same method to evaluate the crushing impact of an incinerator. The power required was calculated using:

Power (P) = F_r*. V* …………………… (1)

Where

F_r = total weight of rotating parts in (kg)

V = tangential velocity of the rotating parts m/s

Total weight of rotating parts in (F_r)

$F_r = (M_p + M_s + M_f) \times g$

Where

M_p = mass of pulley = 5kg

M_s= mass of shaft = 12kg

M_f = mass of material in the hopper = 2kg

g = acceleration due to gravity = 9.81m/s^2

$F_r = (M_p + M_s + M_f) \times g$

$F_r = (5 + 12 + 2) \times 9.81$

$F_r = 19 \times 9.81$

$F_r = 186.39N$

Tangential velocity (V)

$$V = \frac{\pi D_e N_e}{60}$$

$$V = \frac{3.142x0.1x1460}{60}$$

$$V = 7.645m/s$$

Estimated power

$P = F_r x V$ ………………. (2)

P = 186.39 x 7.645

P = 1424.95 Watts

P = 1.42 kW

Estimated power P = 1.42 kW

Where V = tangential velocity (m/s)

D_s – Diameter of pulley on the shaft.

D_e = Diameter of pulley on the electric motor shaft

N_s – Rotational speed of the shaft (rpm)

N_e – Rotational speed of motor (rpm)

With a speed ratio of 1:7

Speed ratio, $R = \frac{N_e}{N_s} = \frac{D_s}{D_e} = \frac{7}{1}$

N_e = 1460 rpm

$$\frac{N_e}{N_s} = 7$$

$$\frac{1460}{N_s} = 7$$

$$N_s = \frac{1460}{7}$$

N_s = 208.5 rpm

$\propto = 19.46^{o}$

2.2.7 Angle (α) between unequal pulley

For an unequal pulley of pitch radii R_1 and R_2, the angle α is given by

$$\sin\alpha = \frac{R_2 - R_1}{C}$$

$$\sin\alpha = \frac{150 - 50}{300}$$

$$\sin\alpha = \frac{100}{300}$$

$$\sin\alpha = 0.333$$

$$\alpha = \sin^{-1} 0.333$$

$$\propto = 19.46^{o}$$

2.2.8 Angle of contact

$\theta_1 = \pi - 2\alpha\ rad$ ………………. (3)

$\theta_1 = 3.14 - (2\ x\ 0.149)$

$\theta_1 = 3.14 - 0.299$

$\theta_1 = 2.842\ \ rad$

2.2.9 Centre distance

This can be calculated by;

$C = 3R_1 + R_2$ ………………….. (4)

Where R_1 is the radius of the smaller pulley and R_2 is the radius of the larger pulley.

Hence, C = 3(50) + 150

C = 300 mm

Since R_1 = d/2 and R_2 = D/2

Where d represent the diameter of smaller pulley and D represent the larger pulley.

$R_1 = \frac{100}{2} = 50\ mm$ and $R_2 = \frac{300}{2} = 150\ mm$

2.2.10 Belt length

With diameter of larger pulley, Ds = 300 mm, De = 100 mm and C = 300 mm.

The length can be calculated from:

$L = 2\alpha + R_1 (\pi - 2\alpha) + R_2 (\pi + 2\alpha)$

On expansion it becomes

$$L = 2C + \pi(R_1 + R_2) + \frac{(R_2 - R_1)^2}{C} \dots (5)$$

$$L = 2(300) + 3.142(50 + 150) + \frac{(100)^2}{300}$$

$$L = 600 + 3.142(200) + \frac{(10{,}000)}{300}$$

L = 600 + 628.4 + 33.3
L = 1261.7 mm
L = 1262 mm

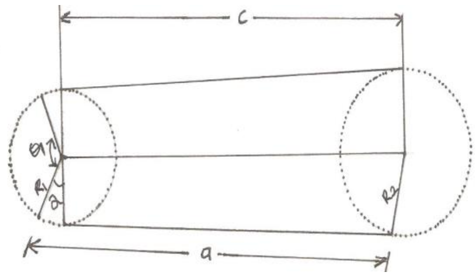

Fig. 6: Belt length, centre distance and contact angle

2.2.11 Tension in belt

The tension T_1 acting on tight side of the belt and the tension T_2 acting on the slack side of the belt can be calculated using:

$$\frac{T_1 - Mv^2}{T_2 - Mv^2} = \frac{f\alpha}{e^{\sin 1/2 \theta}}$$

Where M = Mass of a unit length of the belt (kg) = 0.11 kg/m, [6].
V = Linear velocity of belt (m/s) = 7.6 m/s,
α = angle of wrap on pulley
F = coefficient of friction between belt and pulley = 0.2 [9].
T_1 = tension in the tight side of belt (N)
T_2 = tension in the slack side of belt (N)
θ = groove angle for v-belt

Tension in belt: $T_1 - T_2 = \frac{60W}{\pi D_e N_e}$

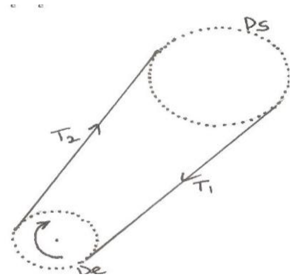

Fig. 7: Tension in belt

Where
T_1 = Tension in the tight side
T_2 = Tension in the slack side
W = Power in watt (Nominal power)
D_e = Diameter of the motor pulley
N_e = Speed of motor

$$T_1 - T_2 = \frac{60 \; x \; 1499.9}{3.142 \; x \; 0.1 \; x \; 146}$$

$$T_1 - T_2 = \frac{89994}{458.732}$$

$T_1 - T_2 = 196.179$ ……… (i)

$$T_1 + T_2 = \frac{60\,W}{\pi D_e N_e} x F_x$$

F_x is the service factor = 1.2 (medium duty machine)

$$T_1 + T_2 = \frac{60 \; x \; 1499.9}{3.142 \; x \; 0.1 \; x \; 1460} x \; 1.2$$

$$T_1 + T_2 = \frac{89994}{458.732} x \; 1.2$$

$$T_1 + T_2 = 196.179 \; x \; 1.2$$

$T_1 + T_2 = 235.4148 \; N$ ………….. (ii)

Adding equation (i) and (ii):

$T_1 - T_2 + T_1 + T_2 = 196.17 + 235.4$

$2T_1 = 431.58 \; N$

$$T_1 = \frac{431.58}{2} N$$

$T_1 = 215.78 \; N$

From equation (ii)
$T_1 + T_2 = 235.41$
$T_2 = 235.41 - 215.7$
$T_2 = 19.61$N

3 Testing

The machine was tested to ascertain its performance, a compacted briquette was produced. A mixture of 6.5 kg of sawdust and 0.5 kg of starch was prepared. Fuel (charcoal) was loaded through the side door of the die heating stove up to the bottom level of the die, ignited using kerosene and matches. When the die temperature was high, the briquette machine was started and the mixture of sawdust and starch was fed into the hopper. The fuel (charcoal) was added periodically (every 5 minutes) to the stove in order to maintain the temperature. Primary air for combustion was entering through the first door which was kept open during operation and secondary air was taken through the fuel door which was also kept open. The mixture from the hopper was conveyed and compressed by the screw that forces it through a heated die and the briquettes were produced. The briquettes produced were collected on a tray (collecting tray).

Fig. 8: Sample of Briquettes produced with the machine

4 Conclusion

The primary objective of this work is to fabricate a low-cost portable briquetting machine that can be used to produce briquettes in the rural areas so as to help in waste management as well as provide a way of reducing the use of fossil fuels. The briquetting machine was designed and fabricated. The briquettes produced by the machine were strong; easy to handle and well compacted. Further investigation should be carried out to obtain a briquette which is more dense and stronger than the one produced by this machine.

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Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)

The authors equally contributed in the present research, at all stages from the formulation of the problem to the final findings and solution.

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Conflict of Interest

The authors have no conflicts of interest to declare that are relevant to the content of this article.