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Development of a Biomass Extruder

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Abstract

Energy from biomass forms an important part of the world economy in form of traditional fuels. It continues to be significant fuel in many countries, especially for cooking and heating, particularly in developing nations. These wastes on the other hand, if densified, can become compact to transport in addition to giving them regular shapes and sizes which can also be tailored for efficient combustion. One of the methods of compacting biomass into a product of higher density than the original raw material is known as briquetting. A biomass screw extruder was developed using locally sourced materials. The machine has an overall dimension of 360,000 mm, screw volume of 0.000422 m^3, die volume of 0.0068 m^3, screw pitch of 0.0256 m, pitch angle of 0.307°, pulley diameter of 586.67 mm, belt length of 380 mm and was made effective by a 5Hp/3phase electric motor. The machine produced briquette in a continuous operation and can be harnessed to curb agro residues indiscriminate disposal thus protecting the environment from pollution and invariably, turning waste to wealth. It can be easily maintained without any technicality and all materials

used for the fabrication are locally available in the case of worn - out parts.

Introduction

Energy from biomass forms an important part of the world economy, especially in the form of traditional fuels. It continues to be an important fuel in many countries, especially for cooking and heating, particularly in developing nations. Biomass resources include, agricultural waste residues (rice husk, coffee husk, coir pith, jute sticks, bagasse, groundnut shells, mustard stalks and cotton stalks) and forestry waste products (sawdust, a milling residue). Many of the developing nations generate huge quantities of these wastes in form of agro residues most of which are left to rot on farmlands, encouraging leachate and emission of methane when burnt openly in readiness and preparation of the land for the next planting season (Alves *et al.*, 2019).

These wastes on the other hand, if densified, can become compact to transport in addition to giving them regular shapes and sizes which can also be tailored for efficient combustion. One of the methods of compacting biomass into a product of higher density than the original raw material is known as briquetting (Oyedepo *et al.,* 2019). Briquetting also known as densification is a process which involves compressing biomass material into a product of higher density than the original raw material (Bajwa *et al*., 2018).

Briquette has attracted much attention as an alternative fuel for domestic (cooking, heating, barbequing) and industrial purposes (agro-industries, food processing) in both rural and urban areas as it pose no harmful threat to the society while in use because it is eco-friendly, environmentally acceptable and can be domestically produced. One of the means of converting biomass into briquette is through screw extrusion. According to Sunday *et al.* (2020) screw extrusion technology is based on the pressure of a special screw that pushes raw material within a chamber that becomes progressively narrower. He further stated that compared to piston press technology, the production process of a screw press and quality of the extruded logs are quite superior. In this research, a biomass screw extruder was developed and tested.

Materials and method

The main components of the briquetting machine include: the frame which supports other machine parts, barrel which houses the bearings and screw shaft, the screw shaft which provides the compressive force on the briquetting material, the die which serves as a mould, electric motor which provides driving power to the extruder. The exploded view of the biomass screw extruder is as shown in Figure 1.

Item No	Part No
1	Frame
2	Flange
3	Shaft barrel
4	Screw
5	Bearing housing

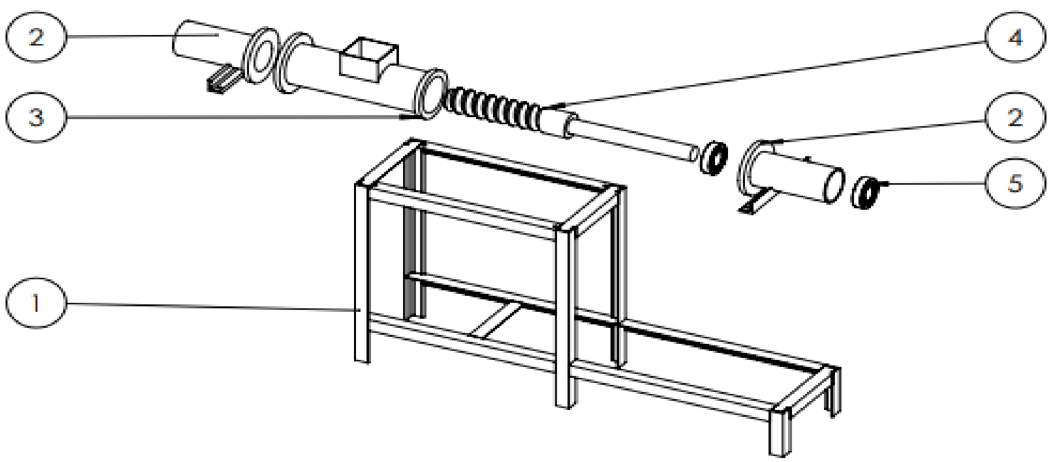

Fig.1: Exploded view of the biomass screw extruder

Working Mechanism of the Machine

Power is transmitted through pulley and belt from the electric motor which converts electrical energy into useful rotational motion of the screw. During extrusion, the biomass moves from the hopper which is conical in shape and welded to the screw barrel which houses the screw. The screw conveys, grinds and compresses the material into the die with substantial pressure with the help of a rotating screw through the barrel and compacts it against a die which causes substantial pressure build-up and friction, along the screw owing to biomass shearing.

Machine Frame

The frame is a structure upon which the main units of the machine tools were assembled. It was designed to accommodate the screw, die, screw barrel, bearing housing, electric motor. The frame was made with mild steel angle iron. The area (A) of the frame is given as expressed in equation 1.

$$A = L \times B \qquad 1$$

Where, L, length of frame mm;

B, breadth of frame mm

Therefore, l = 800mm; b = 450mm; A = **360,000 mm**

Design of Volume of Screw Barrel, (V_{sb})

The volume of the screw barrel refers to the internal space within a screw barrel used in applications such as extrusion and injection molding (Zhang *et al*. 2019). It is a critical parameter for determining the capacity of the barrel to hold material during processing. The barrel of the extruder is a mild steel hollow chamber in which the screw operates. The volume of the screw barrel was determined using equation 2.

$$V_{sb} = \pi {r_b}^2 l_b \qquad 2$$

Where r_b, inner radius of the barrel;

l_b, length of the barrel

Substituting r_b = 18.75 mm, π = 3.142, l_b = 140 mm, $\boldsymbol{V_{sb}}$ **= 0.000422 m³**

Design of Volume Occupied by Screw Shaft, (V_{ss})

The volume occupied by the screw shaft was calculated using equation 3

$$V_{ss} = \pi {r_{ss}}^2 l_{ss} \qquad 3$$

Where, r_{ss}, radius of screw shaft;

l_{ss}, length of the screw shaft mm

Substituting π = 3.142, r_{ss} = 15 mm, l_{ss} = 230, hence, volume occupied by screw shaft, $\boldsymbol{V_{ss}}$ **= 0.163 m³**

Design of Volume of Die, (V_d)

The volume of die was calculated using the volume of a cylinder as expressed in equation 4.

$$V_d = \frac{1}{4}\pi d^2 l \qquad 4$$

Where: l, length of cylinder

d^2, diameter of cylinder

Substituting π = 3.142, d^2 = 2,500 mm, l = 230 mm, $\boldsymbol{V_d}$ **= 0.0068 m³**

Design of Screw Geometry

As shown in Figure 2 the screw has three distinct zones namely: feed, compression and metering zones. The screw is essentially a tapered screw conveyor with the volumetric displacement being decreased from the feed zone to the metering end.

Screw pitch, (P)

The screw pitch of a briquetting screw is the distance between two consecutive screw flights, measured parallel to the screw axis. It was calculated using equation 5.

$$P = \frac{l_s}{N} \qquad 5$$

Where: l_s, length of the screw shaft, mm

N, Number of turns on the screw shaft

Substituting l_s = 0.23 m, N =9, hence, screw pitch $\boldsymbol{P}$ **= 0.0256 m**

Pitch angle, (α), Deg

The pitch angle is the angle between the screw flight and the horizontal plane. According to Norton, (2019) it was determined using the expression in equation 6.

$$p = \frac{\pi D tan(\alpha)}{(2n)} \qquad 6$$

Where: p, Screw pitch, m;

D, Screw diameter, m

α, Pitch angle, degrees;

n, number of threads, mm.

Substituting p = 0.0256 m, π = 3.142, D = 0.05 m, n = 10, therefore, $\boldsymbol{\alpha}$ **= 0.307°**

Pulley Diameter

Power is transmitted from the electric motor to the shaft of the extruding unit through belt and pulley. For this purpose, V-belt was selected due to its ability to absorb shocks against the effects of forces of vibration; its flexibility and cost of maintenance (Fadeyibi *et al*., 2016). The diameter of the pulley of the screw shaft was computed as presented in equation 7.

$$\frac{D_1}{D_2} = \frac{N_1}{N_2} \qquad 7$$

Given, N_1, speed of motor, rpm

N_2, speed of the screw shaft, rpm

D_1, diameter of the motor pulley, mm

D_2, diameter of the screw shaft pulley, mm

D_1 = 80 mm, D_2 = 300 mm, N_1 = 2,200, therefore, $\boldsymbol{N_2}$ = **586.67 mm**

Determination of Belt Speed

According to Khurmi and Gupta (2005), the belt speed required to drive the screw shaft and belt length of belt of the extruder was computed using equation 8.

$$V_{belt} = \frac{\pi D_1 N}{60} \quad 8$$

Where, V_{belt} belt speed, m/s

D_1, diameter of the motor pulley, mm

N, speed of the motor, rev/min

π =3.142, D_1 = 80 mm, N = 2,200 rpm, $\boldsymbol{V_{belt}}$ = **0.0092 m/s**

Belt Length

The length of the belt was determined from the measured diameters of driver and driven pulley and also the centre distance between the driver and driven pulley. The centre distance was asummed to be 430 mm. The length of the belt was determined using equation 9 (Khurmi and Gupta, 2007)

$$L = 2C + 1.57 \frac{(D_1 + D_2) + (D_1 + D_2)}{4C} \quad 9$$

Where, L, belt length, mm

C, assumed center distance between pulley, mm

D_1, pitch diameter of drive pulley, mm

D_2, pitch diameter of driven pulley, mm

C = 430 mm, D_1 = 80 mm, D_2 = 300 mm, therefore, $\boldsymbol{L}$ = **380 mm**

Power Requirement for Motor Selection

Khurmi and Gupta (2005), computed the power required by the screw conveyor with the expression shown in Equations 10 and 11

$$P_{sc} = 0.7355 C l Q_f \quad 10$$

where, P_{sc} = power required by the screw conveyor, (KW), C = constant coefficient for conveyed material usually taken to be 0.3, l = length of the screw conveyor, 400 mm; 20 mm was isolated for clearance from the extrusion barrel. The extrusion barrel pressure was computed from using

$$P = \frac{P_{sc}}{Q_f} \quad 11$$

Where, P = Pressure inside the extrusion barrel, (N/m^2), P_{sc}= power available to the screw conveyor, (kW), Q_f = flow rate of material, kg/s.
Hence, the 5 Hp electric motor, 3 phase was selected to power the extruder.

Table 1. Machine parameters and specifications of screw extruder

Parameters	**Values**
Machine frame, mm	360,000
Volume Design	
Volume of screw, m^3	0.000422
Volume occupied by screw shaft, m^3	0.163
Volume of die, m^3	0.0068
Screw Design Geometry	
Screw pitch, m	0.0256
Pitch angle, Deg	0.307
Power and Drive Pulley Data	
Electric motor	**5 Hp/3phase**
Pulley diameter, mm	586.67
Belt speed, m/s	0.0092
Belt Length, mm	380

Testing of the Machine

The design and fabrication of the biomass screw extruder was successfully carried out with locally sourced materials as shown in figures 2. The machine was tested using carbonized maize cob biomass sample. The sample was milled and then mixed with binder (cassava starch) after which it was fed into the extruder which compressed the sample into blocks of cylinderical shaped briquette shown in Figure 3. The machine is very adaptable for local production, operation, repair and maintenance. From the theoretical formulations drawn from the design consideration, the machine parameters and specifications are stated in Table 1.

Fig 2. Fabricated biomass screw extruder

Fig 3. Briquette sample produced

Conclusion

The biomass screw extruder was is principally for converting agro-residues into fuel briquette for energy generation. From the test carried out, the machine is capable of producing briquette in continuous operation which is an advantage over the manually operated hydraulic press. It can be harnessed to curb agro residues indiscriminate disposal thus protecting the environment from pollution and invariably, turning waste to wealth.

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