DEVELOPMENT OF A CASSAVA PELLETING MACHINE

C.C. Ugoamadi

DEPARTMENT OF MECHANICAL ENGINEERING, MICHAEL OKAPRA UNIVERSITY OF AGRICULTURE, UMUDIKE, ABIA STATE.
Email: ugoamadi01@yahoo.com

Abstract

A cassava pelleter comprising of a feed hopper, screw conveyor, barrel, 4hp electric motor, extrusion plate and a pelleting knive was designed and developed using standard and locally sourced materials. The performance test analysis indicates that its pelleting capacity is 80.46 kg/h with an efficiency of 80.31% at an optimum operational speed of 250 rpm. The pelleting capacity increased with the mass of pre-conditioned cassava while the efficiency of the pelleter decreased with increase in mass of pre-conditioned cassava in some cases. The estimated cost of the machine was ₦32,350:00.

Keywords: cassava, pelleting capacity, screw conveyor, feedstock, pelleting machine

1. Introduction

Cassava is a major source of carbohydrate in most developing nations of the world. Cassava (manihot esculenta crantz) is a short-lived perennial tropical shrub growing from about 1.0–3.5m tall. It is believed to be first domesticated in South America; its cultivation has spread through the humid tropics and subtropics [1]. World production of cassava root was estimated to be 184 million tones in 2002, with about 99.1 million tones being produced in Africa alone [2]. Between 1965 and 2001 the total yield of cassava in Africa increased from 35 to 99.1 million tones with Nigeria having the highest increase from 22% to 35% of African total production [3] Nigeria, the crop can be processed into garri, lafum, paki pupuru, fufu, cassava chips and pellets, etc. for the direct human/livestock consumption. In Ghana, it is eaten boiled; it could be pounded to be eaten with soup in addition to some of the processed form in Nigeria [4]. Apart from its traditional uses in Africa, cassava root is extensively used in the production of livestock and fish feed production in most developed countries of the world [5]. Due to the numerous uses of cassava root, its demand has been on the increase world wide. But due to the poor processing methods always used by most nations in its processing, countries like Nigeria have not been able to fully utilize the products export capacity. Also, in Nigeria, fish farming is an industry that is growing rapidly due to the amount of investors venturing into the industry, but major problem facing the local farmers is in the rise of price of fish feed which is a product processed from cassava tuber and other required components. Local farmers are now producing feed for their fishes by themselves, since they cannot afford to buy feed in the market because of the scale of their farming and the capital they are operating with.

For export purposes, cassava tubers can be processed into raw cassava chips, but because of environmental concerns, over 90% of cassava chips that are exported to the European union (EU) enter as pellets [2]. Pelleting is an extrusion process which is simply the operation of shaping a plastic or dough-like material by forcing it through a restriction or die. Examples of hand operations for pelleting food includes the rolling of modles and pie crust dough, finger stuffing of chopped meat through animal horns into natural casings, pressing of soft foods through hand ricers to produce string-like particles, and cranking of hand-powered meat grinders. As stated above, a pelleting machine can be used to pellet any food item that can be formed in dough-like fashion manner, including cassava. Cassava pellet is an unfermented dried cassava product obtained by compressing raw cassava chips under appropriate processing conditions resulting in the formation of dried bulky product suitable for the animal feed industry with an average length of 3cm and also for easy transportation and exportation [6]. The pelleting of cassava is becoming increasingly popular because it decreases volume by about 25 percent. This simplifies transport, handling and storage, and it produces uniform product, which is less fragile for overseas shipment than raw cassava chips [7].

Cassava pellets can be produced from; raw cassava root, and cassava chips. Production of cassava pellets from raw cassava root involves the essential operations which include; sorting and weighing the harvested cassava tubers, washing and peeling with knife to remove the skin which contains hydrogen cyanide (HCN), grating, dewatering, pelleting, cooling and packaging. While production of cassava pellets from raw cassava chips involves; sorting and weighing the cassava chips, grinding, conditioning, pelleting, cooling and finally packaging. Although, arrangements are far advanced to build the first pelleting factory in the country. However, cassava pellets production has received little attention in Nigeria. To generate employment and to sustain our livestock/fish farm industries, it is necessary to encourage local production of cassava pellets, so that our livestock and fish farmers can afford to buy cassava pellets from local producers or as well purchase a cassava pelleting machine for the production of their own pellets, cassava pellets being one of the major feed used in the fishing and livestock industries [8]. Therefore, the development of a cassava pelleting machine becomes an important venture.

Pelleting, also known as extrusion is the process of forcing material through a specifically design opening. Extrusion as a process has been known since the late eighteen century. Joseph Branmah in 1797 in England built a hand-operated piston press for lead pipes [9].

The first food extruders were based on the use of piston and ram. In Italy, single-screw extruders were used in the mid-1930s for pasta products. They employed low shear, deep flight screws and operated at low screw speeds [10]. The resulting products were not fully cooked. Moist dough was compressed by turning screw and shaped by the orifice through which the dough was expelled. In addition, this single-screwed pelleting machine ,were very expensive and produced low tonnage of pellets.

Simple inexpensive extruder were later developed in the United State in the 1960s for-on-the farm cooking of soybeans, cereals and cassava feeds. This low cost extruder design were quickly adapted in the mid 1970s for use in nutrition intervention projects In many less-developed countries [11]. When later modified in early 1980s,the machine became more reliable and were widely used to processing different foods and crudely texturized food; although numerous mechanical problems were experienced [12].

The objective of this research is to design and fabricate a cheap and more efficient cassava pelleting machine for small scale farmer and testing the machine for performance during operation. Fig.1 represents a flow diagram of the cassava pelleting machine.

Cassava tubers

↓

Sorting and weighing

↓

Washing and peeling

↓

Grating

↓

Dewatering
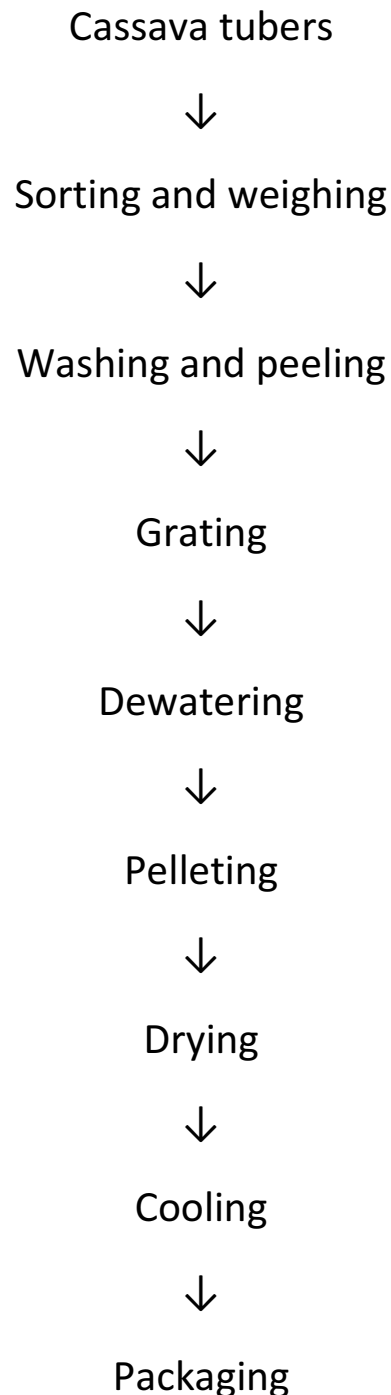
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Pelleting

↓

Drying

↓

Cooling

↓

Packaging

Figure 1: Flow diagram for the cassava pellets from ram cassava root.

2. Materials and Methods

2.1. Design considerations

With reference to the comparative characteristics of various pelleting methods, it is evident that a single screw-pelleting machine is the most applicable for cassava pelleting [10]. The following design considerations form the basis of this design:

- the machine is to handle cassava that has been grated, dewatered and has moisture content of 8-30%.

- the hopper is shaped in such a way as to allow easy flow of the grated and dewatered cassava mass.

- the slip at the barrel wall is reduced to prevent pellet material from turning with the screw, a phenomenon referred to as "drag flow" [13].

A continuous screw channel incorporated serves as a path for "pressure induced flow" as the pressure behind the die is usually much higher than that at the inlet. "leakage flow" also occurs in the clearance between the screw top and barrel wall, energy inputs and moisture levels at this stage are usually present in sufficient amounts so that as the material approaches its melt transition temperature, the feedstock will exibit a rubbering texture similar to very warm dough.

Standard and locally sources non toxic materials/components were used in the fabrication of the machine to ensure affordability and easy maintenance, and to avoid food poisoning. The machine is to be powered by a 4hp electric motor or a gasoline engine in local areas or places where there is no electricity supply.

2.2. Description and operation of the cassava pelleter

The major components of the cassava pelleter are the hopper, transmission and pelleting unit. The machine is powered by a 4hp single phase electric motor. The hopper is shaped as pyramidal frustum with the walls sloping at 62° angle. It is made of mildsteel. Below the hopper is a barrel made of mild steel cylindrical shell with opening in the beginning where the hopper is being welded upon. It is from this opening that the feedstock enters the barrel of the machine.

The transmission unit of the pelleter consists of a shaft carrying the screw conveyor of varying pitch mounted in the barrel. The pitch of the screw conveyor at the inlet (i.e. directly below the opening where the hopper is mounted) is larger to maximize transportation of feedstock as it enters the barrel, while at the middle end (i.e. kneading and final cooking zone) the pitch is decreased so as to increase the temperature for cooking the pellets and increase the

pressure for uniform forming of pellets in the die or extrusion plate. The shaft with the screw conveyor is mounted on the machines frame with a roller bearing at the feed end and a self-aligning similar bearing at the beginning of the shaft for better support. At the free supported end of the shaft is keyed a pulley through which a v-belt is used to transmit power from the electric motor to the shaft. The pulley reduces the speed transmitted to the shaft from the electric motor to the operational speed of the screw conveyor. The motor is mounted on a sit that is welded vertically below the shaft. A spherical plate with little openings in it called the die or extraction plate is screwed on to the end part of the barrel. The die is attached to the end of the barrel by a circular flange point weld in place by five (5) bolts, so that the plate can be changed with other plates having different holes diameter for producing different sizes of pellets and for maintenance and cleaning of the machine. There is a knife arrangement at the face of the die that can be adjusted to cut pellets of different lengths as they are coming out of the machine. The entire machine is seated on a frame made of a v-section (angle iron) mild steel bar having four legs. Fig.2 shows a detailed isometric drawing of the machine while fig.3 shows the orthographic of the machine.

2.3. Design analysis

The bulk density of the pre-conditioned cassava is given by;

$$B_c = \frac{W_2 - W_1}{V} \text{(kg/m3)} \qquad (1)$$

Where; W_2 = weight of container + weight of sample = 0.85kg, W_1 = weight of container = 0.1kg, V = volume of the cylinder. i.e barrel = 0.000636 m³.

Selection of belts and pulleys for an actual design power rating of 4hp (2984 W) and speed 1500 rpm, type "A" belt is required [14]. The exact length of belt, L required for the shaft and motor drives was determined as 839mm using equation 2 given by:

$$L = 2C + 1.57(D_2 + D_1) + \frac{(D_2 - D_1)^2}{4C} \qquad (2)$$

Where; C = center distance between the adjacent pulleys = 240mm, D_1 = diameter of driving pulley = 75mm, D_2 = diameter of driven pulley = 150mm.

According to [14], the belt speed can be determined using the expression :

$$V = \frac{\pi N_2 D_2}{60} \qquad (3)$$

Where N_2 is the speed of the driven pulley.

Due to its availability, cost and performance, cast iron pulleys were selected. The groove angle of the pulley (2β) was measured as 35deg, i.e. $2\beta = 35$ deg while the coefficient of friction, $\mu = 0.25$ between the
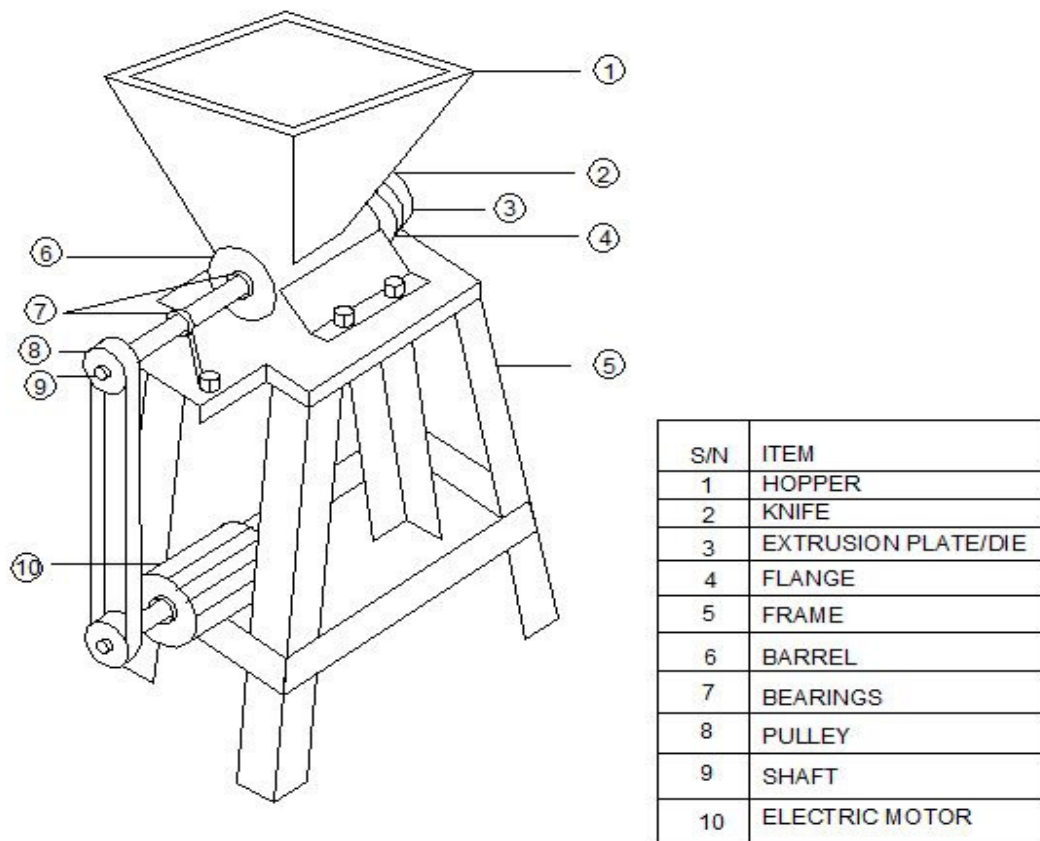
S/N	ITEM
1	HOPPER
2	KNIFE
3	EXTRUSION PLATE/DIE
4	FLANGE
5	FRAME
6	BARREL
7	BEARINGS
8	PULLEY
9	SHAFT
10	ELECTRIC MOTOR

Figure 2: Isometric view of the cassava pelleting machine.
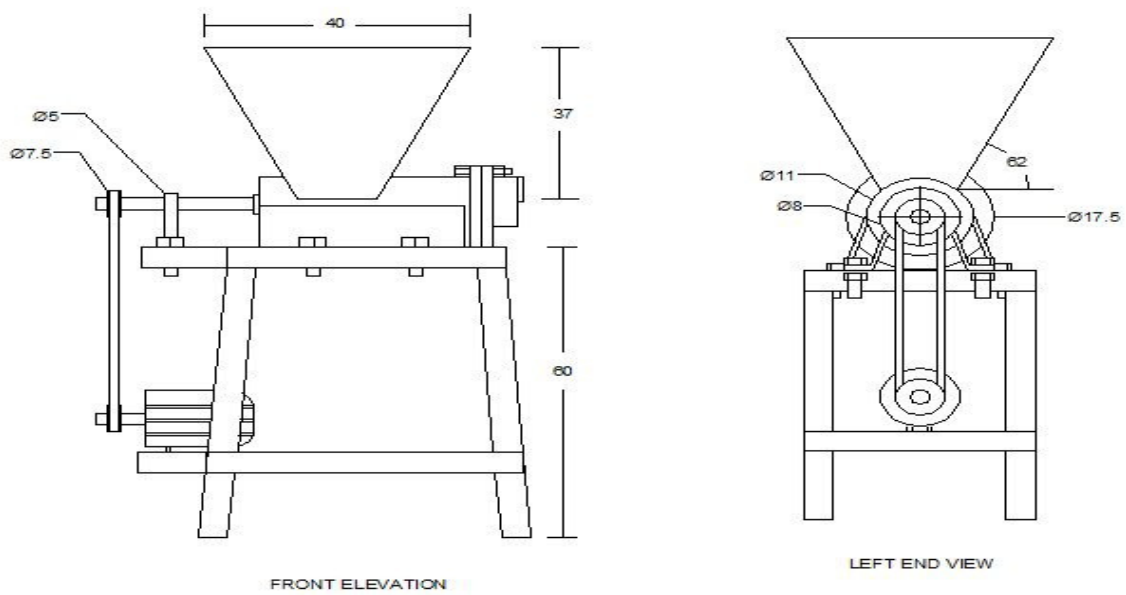

FRONT ELEVATION

LEFT END VIEW

Figure 3: Frond and end elevation views of the cassava pelleting machine.

belt and pulley was obtained from standard table [14]. The angle of contact, θ on the small pulley was determined as 162.02deg (2.83 rad) using equation 4;

$$\theta = 180 - 2\left[\sin^{-1}\left(\frac{D_2 - D_1}{2C}\right)\right] \quad (4)$$

For belt tensions, the following mathematical relations by [14] were used to determine the tensions on the tight (T_1) and slack (T_2) sides of the belt as 924.5 N and 87.69 respectively;

$$T_1 = T_{max} - T_c \quad (5)$$

$$T_{max} = \sigma A \quad (6)$$

$$T_c = M_b V^2 \quad (7)$$

$$2.3 \log\left(\frac{T_1}{T_2}\right) = \mu \times \theta \csc \beta \quad (8)$$

Where; σ = maximum safe stress of the belt = 2.5 N/mm^2, A = cross sectional area of the belt = 375mm^2, M_b = mass per unit length of the belt = 0.375 kg/m^2, θ = 2.83 rad, T_{max} = maximum tension in the belt, T_c = centrifugal tension of the belt.

The diameter, d of the shaft was determined using the maximum shear stress relation given by:

$$d = \left\{\frac{16}{\pi\tau}\sqrt{(K_b M_b)^2 + (K_t M_t)^2}\right\}^{1/3} \quad (9)$$

Where;

$$\pi = Pi = 3.142$$

τ = Allowable shear stress of steel shaft with provision for key way = 42 Mpa = 42N/mm^2, K_b = Combined shock and fatigue factor for bending, K_t = Combined shock and fatigue factor for twisting, M_b = Maximum bending moment on the shaft, N-mm, M_t = The maximum twisting moment, Mt on the shaft was determined as 62760 N-mm using the following relation;

$$M_t = (T_1 - T_2)\frac{D_2}{2} \quad (10)$$

The maximum bending moment, M_b on the shaft was determined using standard procedure in which the bearing reactions were calculated first. The total vertical downward load, WT acting on the shaft at the position of the pulley and total vertical downward load, W_{sc} on the shaft due to the screw conveyor were determined as 1891.91N and 1321.26N respectively, using the following relation.

$$W_T = T_1 T_2 + W_A \quad (11)$$

$$W_A = \frac{F_{tA}}{\cos \alpha_A} \quad (12)$$

$$F_{tA} = \frac{T}{R_A} \quad (13)$$

$$W_{SC} = W_{DE} \times \cos \alpha_{DE} \quad (14)$$

$$W_{DE} = \frac{F_{DE}}{\cos \alpha_{DE}} \quad (15)$$

$$F_{DE} = \frac{T}{R_{SC}} \quad (16)$$

Where; W_A = Normal load acting on the pulley = 879.72N, W_{DE} = Normal load acting on the screw conveyor = 1321.26N, F_{tA} = Tangential force acting on the pulley = 826.67N, F_{DE} = Tangential force acting on the screw conveyor = 1321.26N, R_A = Radius of the shaft pulley = 75mm, R_{SC} = Radius of the screw conveyor = 47.5mm, T = Torque on the shaft = constant = 62×103Nm, α_A = 20deg, α_{DE} = 0deg.

Thus, the reactions due to the bearings support were determined by taking moment about B (figure 3 and 4)

$$W_T = W_A + T_1 + T_2$$

R_c = 811.26N, also R_B = 2401.91N. Consequently, the maximum bending moment, M_b on this shaft was computed from figure 4 as 283786.5N-mm.

The compressing of the feedstock by the screw conveyor inside the barrel is gradual and steady, thus K_b = 1.5 and K_t= 10 [14]. Then the diameter of this shaft was determined as 37.36mm using equation 10, therefore a standard 40mm diameter solid shaft was selected for the screw conveyor shaft.

For the screw conveyor, the pitch, P was determined as 11mm using the relation;

$$Q = \frac{\pi}{4}(D_S^2 - d_s^2) \times P \times N \times f \times 60 \quad (17)$$

Where; Q = The conveyor design throughout capacity = 1.13m^3/hr, N = Speed of shaft in rpm = 250 rpm, f = Material feed factor = 1.0, D_s = Major diameter of screw conveyor = 95mm, d_s = Minor diameter of screw conveyor = 28mm.

In designing the hopper it is recommended that the angle of inclination of the hopper walls be 10deg higher than the natural angle of repose of stored material (preconditioned cassava) [6]. This is to avoid tunneling and arching during the discharge of the product.

The hopper shape is that of a frustum of a pyramid. The angle of repose obtained experimentally for the preconditioned cassava was 52deg.

Therefore, an angle of inclination of 62deg was used in designing the hopper. The volume of the hopper was determined as 0.86m3 using the equation by [15] given as:

$$V = \frac{h}{3}\left[A_1 + A_2 + \sqrt{(A_1 \times A_2)}\right] \quad (18)$$

Where; V = Volume of hopper (m^3), A_1 = Area of top (m^2), A_2 = Area of base (m^2), h = Height of the hopper (m).
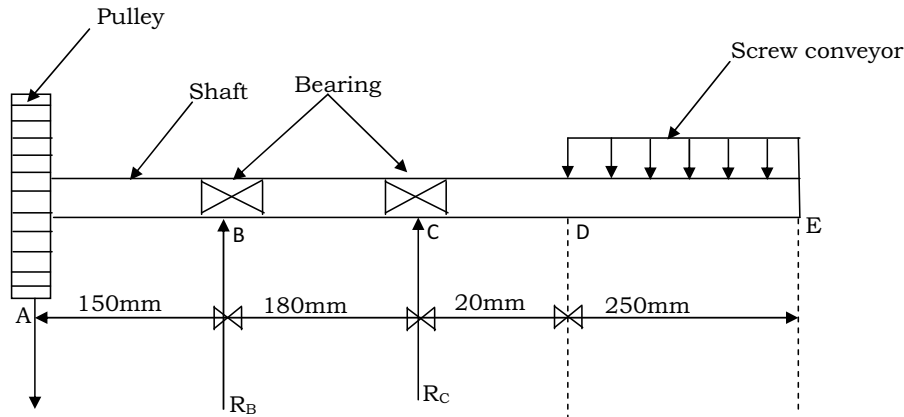
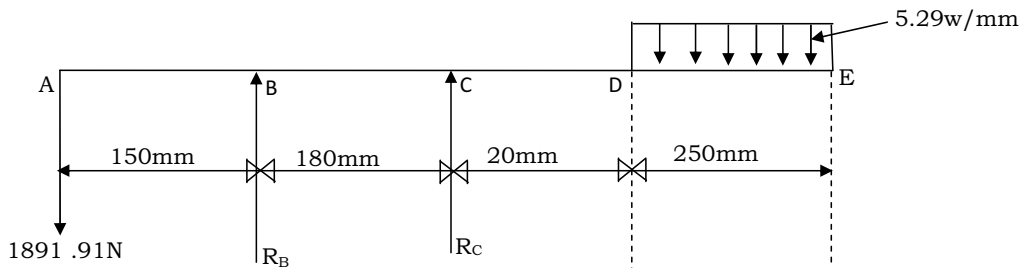Figure 4: Arrangement of components on the conveyor shaft.

Figure 5: Screw conveyor shaft showing forces acting on it.

The barrel of the pelleter which is a cylinder is considered as a pressure vessel. The cylinder thickness t was determined as 4mm using the equation by [14] given as;

$$t = \frac{Pd}{2\sigma_c} \qquad (19)$$

Where; P = Intensity of pressure in the barrel (N/mm^2), d = Internal diameter of the barrel (mm), σ_c = Circumferential stress for the material of the barrel (N/mm^2).

2.4. Capacity of the electric motor

The capacity of the electric motor required to drive the machine was determined based on the torque on the shaft and optimal speed of the shaft. According to [11], the power (P) required to drive the machine is given by

$$P = \frac{2\pi NT}{60} \qquad (20)$$

Where $N = 250$rmp = speed of the shaft, $T = 62$N-m = Torque on the shaft. Thus $P = 1.623$kW $\equiv 2.176$hp.

The design Horsepower = rated horse power × service factor(K_S), where K_S = service factor = 1.875. Design horsepower = 2.176 1.875 = 4hp.

2.5. Performance Tests

In test running the performance of the machine, two different sets of experiments were carried out after the pelleter has been assembled and installed using raw cassava roots procured from Umuahia market. The cassava was first sorted and weighed, washed and peded, grated, and dewatered before being fed to the pelleting machine. In the first experimental plan, the optimal speed of the developed pelleter was determined. Five different samples of the preconditioned cassava weighing 25kg were fed through the hopper for pelleting after starting the machine. In each of the five trails with different operational speed of 230, 240, 250, 260 and 270 rpm a step watch was used to monitor the time taken for the pelleting.

In the second experimental plan, the performance of the machine was evaluated by determining the pelleting capacity, P_c (kg/h) and efficiency, $\eta(\%)$ of the developed pelleter as follows;

$$P_c(\text{kg/h}) = \frac{M_i}{t} \times 3600 \qquad (21)$$

$$\eta(\%) = \frac{M_0}{M_i} \times 100 \qquad (22)$$

where; M_0 = Total mass of pellets formed (kg), M_i = Total mass of pre-conditioned cassava (kg), t = Processing time (sec).

Table 1: Determination of optimal speed of the pelleter.

s/no	Speed (rpm)	Weight of preconditioned cassava (kg)	Time of pelleting (min)
1	230	25	21.5
2	240	25	20.8
3	250	25	19.4
4	260	25	19.2
5	270	25	19.0

Eight different samples of the pre-conditioned cassava weighing 30, 35, 40, 45, 50, 55, 60 and 65 kg were fed through the hopper of the pelleter running at an optimal operational speed of 250 rpm. A stop watch was used to record the processing time taken for each of the eight trials.

3. Results and Discussion

Data from the first experiment shown in table 1 revealed that the optimal speed for the pelleting machine is 250 rpm. This is because from the speed of 250 rpm upwards, the pelleting time is approximately the same. Also the table indicates that as the speed increases the pelleting time decreases. The machine performance results presented in table 2 shows that its efficiency and pelleting capacity are 67.58% and 78.47kg/h respectively. It is also obvious that an increase in mass of the preconditioned cassava increases the processing time and pelleting capacity of the machine.

However, the efficiency of the machine in some cases decreased with increase in the mass of preconditioned cassava, while in most cases there is significant increase in efficiency. This could be attributed to some of the operational parameters of the cassava pelleting machine.

The developed cassava pelleter was found to perform satisfactorily with all the mass of the pre-conditioned cassava poured into it at constant operational speed of 250 rpm when tested. However the highest pelleting efficiency of 80.31% with a pelleting capacity of 80.46kg/h was obtained when a pre-conditioned cassava of mass 65kg was processed, and the amount of pellets formed from this weighed 52.2kg. the machine capacity was purposely made small to achieve the desired objectives. Hence, for large scale production of cassava pellets, the capacity can be increased which may increase its efficiency.

4. Conclusion and Recommendation

4.1. Conclusion

The machine so far developed is easy to operate and affordable to all categories of farmers/processors because of its low production cost of thirty-two thousand three hundred and fifty naira (N32,350.00). Therefore manufacturers should take up this innovation of cassava pelleting machine and implement it in the processing of cassava pellets to enhance mass production of cassava pellets, for export and livestock feed purposes.

4.2. Recommendation

Optimization of the cassava pelleting machine to determine its optimum performance parameters is recommended because many operational parameters of this affects its performance differently at the same level. Farmers and processors at all level are encouraged to patronize this innovation to increase their profit. Adoption of this innovation will attract youths and more investors in this sector as drudgery and tedium has been removed. Petrol or diesel powered engines can be used for the operation of this pelleter in areas of frequent outage of public power supply. Government and other agencies should grant loan to farmers to enable them adopt this important innovation immediately for mass and qualitative production of cassava pellets to meet the growing demand of the nations industries and for export. This will facilitate the achievement of millennium development goals (MDGs) and vision 20:20:20 of the federal government in the areas of agricultural and industrial raw material development, food security and employment.

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Table 2: Determination of the pelleting capacity and the efficiency of the developed cassava pelleter.

Test	Mass of preconditioned cassava M_i (kg)	Mass of pellets formed M_o (kg)	Processing time t (min)	Pelleting capacity P_c (kg/h)	Efficiency η (%)
1	30	19.7	23.65	76.11	65.67
2	3.5	22.5	27.55	76.23	64.29
3	40	23.2	31.26	76.78	58.0
4	45	29.3	35.10	76.92	65.11
5	50	32.7	38.48	76.96	65.40
6	55	38.2	41.34	79.82	69.45
7	60	44.0	44.70	80.54	73.33
8	65	52.2	48.47	80.66	80.31
9	70	56.0	50.15	81.22	80.10
10	75	59.7	52.46	81.76	79.60
11	80	63.04	55.12	82.04	78.80

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