Journal of the Nigerian Association of Mathematical Physics
***Volume* 18 (May, 2011), pp 555 – 562**

Development of a Livestock Feed Cubing Machine from Locally Sourced Materials

Oyawale, F. A[1]., Odior, A. O.[2*] Oyetunji O. R.[3], and Saliu L.[4]

**[1,3,4]Department of Industrial and Production Engineering,
University of Ibadan, Nigeria.
[2]Department of Production Engineering,
University of Benin, Nigeria.**

Abstract

Forage is not available all the year round and even when available, the preparation is usually labour intensive. The objective of this research is to design and fabricate a machine for processing of grass feedstock/cassava using available local material. The machine consists of the shredding and cubing units with a capacity of 7386.67cm³ and 15547.73cm³ respectively. The shredding unit has three cutting blades 5mm thick and 360mm long attached to a rotating shaft of 40mm diameter feeding a sieve plate 2mm thick containing 13mm diameter holes. The cubing unit comprises a shaft of 60mm diameter carrying an auger and die plate with 15mm square holes for the extrusion of the cube. The cubes are ejected under pressure using a 5 horse power prime mover. The machine has an average capacity of 120kg per hour for the shredding and the cubing units. The machine was developed using locally sourced materials such as; galvanized sheet metal, thick metal plate and a metal pipe material.

Keywords: Cubing Machine, Grass Feedstock, Extrusion, Shredding, Local Material

1 Introduction:

The cubing machine converts grass and other non radioactive agricultural waste into small cubes. The cubing process comprises compressing whole grass into compact units by condensing chopped grass, grinding and compressing. It has been utilized extensively in the agricultural industry in the United States of America to process hay into compact high density cubes to reduce storage volume and cost. It is also used to process waste by converting the combustible portion into cubes for incineration for combustion [1, 2]. Cubing provides opportunity for storage of hay/grass, preservation, transportation and distribution in farms and kraals at the time that livestock are kept in enclosures. Most of the imported threshers are very costly and hence beyond the reach of Nigerian small-scale farmers. Some have been found unsuitable for threshing the local varieties [3,4].

Probably, the best known of the early American machines was developed by Hiram and John Pitts of Winthrop which combined the threshing, separating and winnowing processes in a single machine [5]. The threshing machines of the period 1790 - 1840, with it's complex gearing was exceedingly elaborate piece of equipment and could occupy two floors of a barn. The more elaborate it was, the greater it's potential usefulness seems to be and the greater the doubts expressed by some farmers [6]. Researchers continued their work on improving threshing machines until the 'COMBINE' was invented but the needs of the small scale farmers remained unmet. This was because the small holdings do not justify investments in such big machines [7]. If there has to be increased production of livestock feed, farmers have to be provided with the means by which their products can be processed with minimum drudgery and cost and yet achieving good quality products [1].

The cubing machine or thresher can be used for a variety of crops such as cassava, grass and corn. Despite these efforts, rural and poor farmers in Nigeria continue to face challenges in accessing cubing machines because of prohibitive costs of the machines or because the machines are not locally available [4]. There is need therefore to experiment with threshing unit designs that provide lower costs and yet achieving good quality products. The objectives of this research are (i) to source for locally available materials, (ii) design and fabricate a cubing machine for the processing of grass and cassava feedstock using the locally sourced raw materials.

[2*]Corresponding authors: ***Odior, A. O.***: E-mail: waddnis@yahoo.com, Tel. +2348038204274

Cubing Geometry and Stability

Hay pellet products are cylindrical, rectangular or cube shaped patterns with various diameters and dimensions. They are best done at moisture contents less than 20%. Research has shown that forage fibers properly oriented can internally strengthen a compacted product adding to its stability [8]. The geometry of pellet determines the fiber arrangement produced by various shapes. The shapes of pellet may have desirable effect on handling characteristics and forming pressure requirement. According to [9], two major processes - briquetting and pelletizing are used to form compressed shapes. Briquetting is a closed die extrusion process used to produce compact briquette materials, while pelletizing is an open-die extrusion process. Forage under extreme pressure is forced out of a die in an extrusion process and the most common extrusion processes are the ram and the screw types [10, 11].

Machine development

Although, numerous cubing machines for different purposes have been produced and marketed, the rural and poor farmers in Nigeria continue to face challenges in accessing cubing machines because the machines are not locally available. The prohibitive costs of imported cubing machines make them unaffordable to the local farmers. The three types of cubing-machines include: roller type, tapered screw and the reciprocating or plunger types. In this design, the tapered screw type was used since it allowed gradual extrusion of the material (grass or cassava).

The machine consists of a feed hopper, an over hanging screw shaft, a barrel housing and an extruder die pipe. The screw shaft is mounted at one end by ball bearings and the other end is over hanging freely. The barrel assembly has been housed over the screw shaft and mounted on a stand. The free end of the screw shaft is tapered to a length of 30 cm and housed inside an extruder pipe of same length. The screw shaft is coupled directly to a reduction gear unit (10:1) and is driven by a 5 hp electric motor.

Feeding

The first important factor in the extruder operation is a stable and consistent introduction of feedstock into the machine. The material is fed into the machine through the feed hopper.

Single screw extruders are generally volumetric feeding types while co-rotating extruders are in general starve fed. This is due to the fact that the conveying capacity of the extruder exceeds the rate at which the material is fed into it.

The Hopper.

The hopper is the component of the machine which receives the materials to be extruded before discharging them into the extruding zone. Extrusion does not take place in the hopper as it is only for the materials intake.

Hopper flow characteristics

The coefficient of mobility (ψ) is the measure of the degree of force applied for material flow down the hopper. It is calculated from the expression

$$\psi = 1 + 2\mu_i^2 - 2\mu(1+\mu_i^2)^{\frac{1}{2}} \qquad (1)$$

Where

ψ = coefficient of mobility

μ_i = is the coefficient of internal friction of hopper.

For ease of flow of the material through the opening of the hopper, the size of the opening must be carefully selected to avoid the clogging of the material. The general equation as given by [1] is

$$d_{min} = 2T_o \frac{1 + Sin\ \phi}{k\rho} \qquad (2)$$

where

k = opening shape factor.

ρ = bulk density of material

T_o = initial shear stress of the material

The hopper side wall slope must be greater than the angle of material friction and is given by

$$x \le 45^o + \frac{\tan^{-1}\phi}{2} \qquad (3)$$

Where

ϕ = angle of internal friction

x = hopper sidewall slope

Construction Material

The hopper was fabricated using a locally sourced galvanized sheet metal of 2mm thick. The rotor shafts were designed and constructed from squared hot rolled steel of dimensions 65mm and 45mm, while the shredding chamber was fabricated using locally sourced metal plate of thickness 5mm. The die and sieve were fabricated from 2mm thick metal plate. The cubing chamber was fabricated from a pipe which is 5mm thick with a diameter of 100mm. The compression screw was then fabricated by welding a 10 mm square rod round the shaft to form a thread with decreasing pitch towards the tapered end of the shaft.

Operation of the Machine

The hay/grass is mixed with some water and placed in the hopper of the shredding unit and the power is switched on. The hay/grass is then shredded into the hopper of the cubing unit where it is extruded through the die.

DESIGN CONSIDERATIONS

Power Requirement for Shredding Unit

The power required for shredding is given as [12]:

$$\text{Power } (P) = Fr.\ V \tag{4}$$

Where Fr is the total weight of rotating parts.

$$Fr = (M_p + M_s + M_n + M_c + M_f)g \tag{5}$$

Where M_p - mass of pulley
M_s - mass of shaft
M_n - mass of bolts used to fasten die
M_c - mass of cutter
M_f - mass of material in the hopper
g - acceleration due to gravity

V is the tangential velocity of the rotating parts (m/s) and is given by

$$V = \frac{\pi D_s \ x \ N_s}{60} = \frac{\pi D_e \ x \ N_e}{60} \tag{6}$$

Where
N_s – Rotational speed of shaft rpm
N_e – Rotational speed of motor (rpm)
D_s – Diameter of pulley on the electric motor shaft
D_e – Diameter of pulley on the cuber machine.

Using a speed ratio $\frac{N_e}{N_s} = \frac{D_s}{D_e} = 2$, we have:

$$V = \frac{\pi \ x \ 0.20 \ x \ 1400}{60} = 14.67\, m/s$$

F_r = 169.71N,
P = 169.71 x 14.67 = 2488.01 watts (Estimated power)

$$\text{Nominal power} = \frac{Estimated \quad Power}{Design \quad factor} \tag{7}$$

Using a design factor of 0.95

$$\text{Nominal power} = \frac{2488.01}{0.95} = 2619.96\, w$$

Design power = Nominal power x service factor [12],
∴ Design Power = 2619.96 x 1.2 = 3143.95 watts
The design power for the shredding unit is 3.144 Kilowatts.

Belt Selection

The relationship between the belt tensions T_1 and T_2 is given as [13]:

$$\frac{T_1 - mv^2}{T_2 - mv^2} = e^{f\alpha} \tag{8}$$

Where
T_1 = Initial belt tension
T_2 = Final belt tension
f = coefficient of friction between belt and pulley
α = angle of wrap of belt on pulley

m = mass , v = velocity
For open belt drive, angle of wrap [13]

$$\alpha = 180^o \pm 2\sin^{-1}\frac{(R+r)}{c} \quad (9)$$

while for crossed belt, angle of wrap

$$\alpha = 180^o + 2\sin^{-1}\left(\frac{(R+r)}{c}\right) \quad (10)$$

where R = radius of bigger pulley, r = radius of smaller pulley and c = distance between pulleys.
For design, the pulley with smaller value governs the design; therefore the angle of wrap for the open belt drive was chosen because it was lower i.e.
T_1 = 196.5N, T_2 = 17.87N
Resultant belt tension is $T = T_1 + T_2$ (11)
$= 214.37N$

Power Capacity per Belt

The power capacity per belt can be determined from the following equation [13],
Power per belt = $(T_1 - T_2)v$ (12)
= 214.37(14.67) watts
= 2.62kw

Required Number of Belts

The number of belts required = $\frac{Design \quad power}{Power \quad per \quad belt}$ (13)

$$= \frac{2985 \ .6}{2620 \ .5} = 1.14 \cong 2$$

Shaft Design

The Shaft diameter was calculated as follows [13]:

$$d^3 = \frac{16}{S_s}\sqrt{(K_b M_b)^2 + (K_t M_{tb})^2} \quad (14)$$

where
K_b = combined shock and fatigue factor applied to B.M (Bending Moment) = 1.5 for rotating shafts (see Table 1).
K_t = combined shock factor applied to torsional moment =1.0 for rotating shafts, (Table 1).
S_s = Allowable for steel shafts = 55MN/m^2
M_t = 3.73Nm, M_b = 33,9Nm
d= 26.8mm.
Checking shaft based on torsional deflection

$$\theta = \frac{584 M_t L}{G d^u} \quad (15)$$

where θ (deflection angle) = 3^0
M_t = torque in Nm
L = length of shaft = 1.38m
G – Modulus of rigidity 200 Gps

$$d = \frac{584 \, x \, 35.73 \, x \, 1.38}{3 \, x \, 200 \, x \, 10^9} = 15mm$$

Table 1: Combined Shock and Fatigue Factors Applied to Bending and Torsiona Moments

Type of Shaft	**K_b**	**K_t**
For Stationary Shafts:		
Load gradually applied	1.0	1.0
Load suddenly applied	1.5 – 2.0	1.5 – 2.0
For Rotating Shafts:		
Load gradually applied	1.5	1.0
Load suddenly applied (minor shock)	1.5 – 2.0	1.0 – 1.5
Load suddenly applied (heavy shock)	2.0 – 3.0	1.5 – 3.0

K_b = combined shock and fatigue factor applied to bending moment
K_t = combined shock and fatigue factor applied to torsional moment

Design of Shaft for Lateral Rigidity

The internal rigidity of the shaft was designed using the permissible lateral deflection of 0.02mm for proper bearing operation and the shaft diameter was obtained by two successive integrations of moment equation [12]:

$$\frac{d^2 y}{dx^2} = \frac{M_b}{EI} \quad (16)$$

Where M_b = Bending moment

E = Modulus of elasticity of the shaft

I= Rectangular moment of the shaft

Diameter of shaft was calculated as 41mm based on lateral rigidity.

The calculated diameters of shaft for the shredding and cubing unit were 60mm and 40mm respectively.

Design of Blade

The strength of the blade was determined by modeling the blade as a cantilever beam with a rectangular cross-section under pure bending. The bending stress was determined using bending stress theory [12]

$$\sigma = \frac{FLC}{I} \quad (17)$$

Where σ = Bending stress

F = Applied force

L = Distance of applied forces

C = distance from neutral axis to outer surface

I = Rectangular moment of cross section

For a rectangular cross section $I = \frac{bt^3}{12}$ (18)

Where b = breath of the cross section

t = thickness of the cross section

Hence $\omega = \frac{12FLC}{bt^3}$ (19)

Given F = 2kN, L = 0.15m, c = 0.01m, t = 0.05m, b = 0.2m

σ =1.5mPa

Selection of Bearing

Using an expected life of 20,000 hours, with a dynamic load factor of 2.0 [12], The radial load

$T = 2(T_1 + T_2)$ (20)

The axial load and radial load is determined by taking moment of forces acting on the shaft.

Axial load = 0 while radial load = P = Fr = 0.406 KN

Using the SKF 1989 catalogue and basic rating life equation as

$$L_b = \frac{1000000}{60N_r}\left(\frac{C_r}{P}\right)^K \quad (21)$$

L_b = basic life rating (hrs) = 20,000hrs

C_r = basic dynamic load rating

N_r = Operating speed (rpm) = 1400rpm

P= equivalent dynamic bearing load = 0.406 KN

k = exponent of life equation.

The exponent k is 3 for ball bearings and $\frac{10}{3}$ for roller bearings [14].

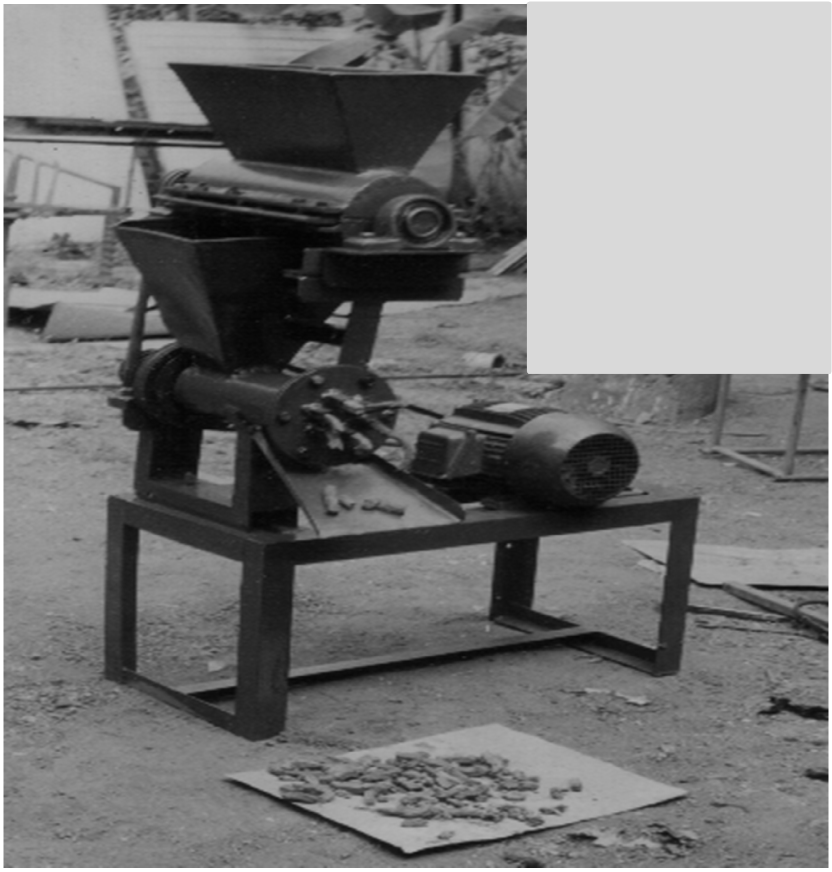

Plate 1: The Fabricated Cubing Machine

Performance Tests

Performance tests were conducted by shredding two materials: grass and cassava peels using different sieve diameters of the shredding unit and different die diameters of the cubing unit as presented in Tables 2 and 3. From Table 2, it is seen that when the wet grass materials were fed into the cubing machine, there was no shredding and the grass blocked the sieve because they were wet. When dry grass and cassava peels were fed in, they were properly cubed. However, 30 non-uniform cubes per minute were produced with the dry grass while 30 uniform cubes per minute were produced with the cassava peels.

Table 2: The Shredding of Different Materials

Material	Shredding Operation	Shredding Rate	Cubing Operation	Cubing Rate
Wet grass	Not shredded initially but as the loading increased the sieve was blocked	-	Not cubed because the sieve was blocked	-
Dry grass	Shredded without blockage	$0.85m^3$ for 30 minutes	Cubed when binder was added	30 non-uniform cubes per minute
Cassava Peels	Shredded without blockage	2kg/min	Cube formed without the addition of binder.	30 cubes per minute

From Table 3, it is seen that when the sieve diameter of the shredding unit is bigger than the die diameter of the cubing unit, there was no formation of cubes. When the sieve diameter of the shredding

Table 3: Comparison of Sieve Diameter of Shredding Unit with Diameter of the Die of the Cubing Unit.

S/No		Sieve Diameter of the Shredding Unit (ϕ mm)	Die Diameter of the Cubing Unit (ϕ mm)	Comment
1	a	8mm	6mm	Little quantity was extruded causing the cube not to form.
	b	8mm	8mm	The quantity extruded increased but cube formation was slow.

	c	8mm	10mm	Good quantity was extruded allowing for building up of pressure for the formation of cubes
2	a	10mm	8mm	Little quantity was extruded causing the cube not to form
	b	10mm	10mm	The quantity extruded increases but cube formation was at slow rate.
	c	10mm	12mm	Good quantity was extruded allowing for building up of pressure for the formation of cubes
3	a	12mm	10mm	Little quantity was extruded causing the cube not to form
	b	12mm	12mm	The quantity extruded increases but cube formation was at slow rate.
	c	12mm	14mm	Good quantity was extruded allowing for building up of pressure for the formation of cubes
4	a	13mm	12mm	Little quantity was extruded causing the cube not to form
	b	13mm	13mm	The quantity extruded increases but cube formation was at slow rate
	c	13mm	14mm	Good quantity was extruded allowing for building up of pressure for the formation of cube
	d	13m	15mm	Good quantity was extruded allowing for building up of pressure for the formation of cubes

unit is the same as die diameter of the cubing unit, little quantity was extruded and there was very slow formation of cubes. When the sieve diameter of the shredding unit is smaller than the die diameter of the cubing unit, good quantity was extruded leading to quick formation of good cubes. This is applicable to both dry grass and cassava peels as the extruding materials.

Wet Grass without Binder

During the shredding of the wet grass without application of binder, the sieve of the shredding unit was blocked due to the wet nature of the grass. The output from the cubing unit was small and could not cube.

Dry Grass without Binder

In the shredding of the dry grass without application of binder, the grass was properly shredded but the cubing unit could not form cube due to lack of binder.

Dry Grass with Binder

During the shredding, the dry grass was properly shredded while appropriate binder (starch) was added at the cubing unit to form hay chips which come out of the die in cylindrical forms (chips) at the rate of 30cubes per minute which are between 7g-9g by weight.

Cassava Peels

In the shredding of cassava peels, moisture was applied to the previously dried cassava peels and they were easily shredded to form cubes at the rate of 30cubes per minute of weight 9g-12g.

CONCLUSION

The fact that the local Nigerian farmers can not afford the prohibitive costs of imported cubing machines, necessitated the fabrication of local cubing machine. The machine was designed and fabricated using locally available materials in Nigeria and this makes it a relatively cheap and affordable to both commercial and local consumers. The machine consists of a feed hopper which is pyramidal in shape, a barrel housing and an extruder die pipe. It also consists of a screw shaft which is mounted at one end by ball bearings while the other end is over hanging freely. The free end of the screw shaft is tapered to a length of 30 cm and housed an extruder pipe of same length. The screw shaft is coupled directly to a reduction gear unit of 10:1 and is driven by a 5 hp electric motor. The material to be extruded is received first by the hopper before discharging them into the extruding zone.

The machine is designed with a cubing rate of 30 non-uniform cubes per minute with the dry grass while 30 uniform cubes per minute were produced with the cassava peels. This is found to be fairly close to the cubing rate of imported machine of same specifications with 50 uniform cubes per minute using cassava peels.

REFERENCES

[1] Irtwange, S. V. (2009). Design, fabrication and performance of a motorized cowpea thresher for Nigerian small-scale farmers. African Journal of Agricultural Research , 4 (12): 1383-1391

[2] Butler, J. L. and McColly, H. F. (1959). Factors Affecting the Pelleting of Hay. Journal of Agricultural Engineering. Research. 40(8):442-446

[3] Choudhury MS, Kaul RN (1978). Alvan blanch threshers. Test report No.DAE/78-4. Department of Agricultural Engineering, Institute of Agricultural Research, Zaria, Nigeria.

[4] Adewumi J. K, Olayanju T. M.A and Adewuyi, S.A. (2007b). Support for Small Rice Threshers in Nigeria. Monograph Series # 23. Making Nigerian, Agricultural Markets Work for the Poor. DFID/PrOpCom. SA II Associates LTD/GTE, 40, Mississippi Street, Maitama, Abuja.

[5] Encyclopedia Britannica (1969). William Benton Publisher, Chicago, U.S.A.

[6] Macdonald S (1975). The progress of the early threshing machine. African Journal of Agricultural Research. 23(1): 63-77.

[7] Ige M. T. (1978). Threshing and separation performance of a locally built cowpea thresher. Journal of Agricultural Engineering. Research. (23): 45-51.

[8] Wachendorf, M., Volkers, K. C., Loges, R., Rave, G. and Taube, F. (2006), Performance and environmental effects of forage production on sandy soils. IV. Impact of slurry application, mineral N fertilizer and grass understorey on yield and nitrogen surplus of maize for silage. Journal of Grass and Forage Science, 61: 232–242.

[9] Singley. M.E. (1958) Handling nonfree flowing materials. Agricultural Engineering Journal of ASAE 39(3): 540-542.

[10] Bruhn, H.D (1955): Pelleting Hay and Grain Mixtures. Journal of Agricultural Engineering Research. 16(l):32-45

[11] Gustafson A.S. and Kjelgaard, W.J. (1963). Hay Pellet Geometry and Stability. Journal of Agricultural Engineering. Research. 44(8): 422-425

[12] Bosoi, E.S., Theory, construction & Calculation of agricultural Machines. Published by Amerind Publishing Co. (1987), New Delhi .

[13] Hall, W. C., Ferral. A.W.,Ripper, A.L. (1986), *Encyclopedia of food Engineering* 2nd edition, AVIPublishing Coy, Inc.WestPort.

[14] Ioannides E., Bergling G. and Gabelli A. “An analytical formulation for the life of rolling bearings.” Acta Polytechnica Scandinavica, ME 137, Espoo (1999).