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Development of a Medium-Size Fish Feed Pelletizing Machine

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Abstract:
Background: The cost of fish feed is a major challenge militating against expanding fish farming in Nigeria, as it accounts for about 60-80% of input costs. Large percentage of the floating fish feeds with good water stability marketed in Nigeria is imported with relatively high cost of purchase; the actual extruding machine for floating feed such as Insta PRO 2000 is very expensive. There is need to develop a local technology to produce floating fish pellets with good water stability at a comparative lower cost than the imported ones, this will reduce dependence on the importation of fish feeds.
Materials and methods: A motorized pelletizing machine with the following component parts; hopper, shaft, barrel, die mouth end, frame, and pulley drive was developed. The machine was designed to vary its barrel length (140, 280 and 420 mm) and die size (4, 5, 6 mm) to enable investigating the effect of these machine parameters on the floatability, water stability and the pelletizing efficiency of the pellets produced. The floatability and water stability were determined and recorded. The experimental design was a 3^2 factorial design which was replicated 3 times. The data collected was analyzed using design expert 10.0.1 version software historical data and the confidence interval was 95%.
Results: The optimum throughput capacity obtain was 96.2% which was possible at 140 mm barrel length and 6 mm die size.
Conclusion: A low cost pelletizing machine has been developed and the best combination of the machining parameters which gives a good floatability and water stability of 280 mm barrel length and 5 mm die size was determined.
Keywords: Pelletizing Machine, Barrel Length, Die Size, Throughput capacity.

I. INTRODUCTION

Production of feed for fish rearing is an important issue to be considered in both subsistence and commercial fish farming as it has influence on the growth and feed wastage (Tsevis*et al.*, 2000). The last decade marked an increase in the use of extruded diets for feeding fish. Extruded feeds have improved water stability, enhanced floatation, ease digestibility, zero water pollution, optimized labour usage and zero wastage of raw materials (Amalraaj, 2010). Sinking of pelleted fish feeds can lead to wastage of raw materials and water pollution, and impaired growth are usually noticed during the use of non-floating feeds (Johnson and Wandsvick, 1991). Pelletizing technology is one of the recent developed sectors of aquaculture particularly in Africa and other developing countries of the world (FAO, 2003). Fish farming development in Africa is insignificant compared to the rest of the world (Changadeya *et al.*, 2003). According to Hetch (2000) the entire continent contributed only 0.4% to the total world aquaculture production for the period 1994 to 1995. In the year 2000, it contributed a mere 0.97% of the total global aquaculture (FAO, 2003). Feed is one of the fundamental challenges facing the development and growth of aquaculture in the African continent (Holm and Walther, 1988). Fish feed development in Nigeria has not made a significant progress in aquaculture as expected (Olomola, 2008). The floating feeds available are majorly imported while the few produced locally are too small to meet the farmers' need. Extruded floating feed cost is significantly more expensive than locally produced dried and sinking pellets (Lovell, 1988).The actual extruding machine for floating feed such as Insta PRO 2000 is very expensive and all efforts to procure the machine by the National Agricultural Research Project (NARP) proved abortive (Falayi, 2009). Most of all the pelletizing machines and some of the ingredients are being imported. The greatest proportion of the floating feeds in Nigerian markets is imported from United States of America and other western European countries (Falayi, 2009). There is a dire need to develop a local technology to produce floating fish pellets with good water stability at a comparative lower cost than the imported ones. This will reduce the nation dependence on the importation of fish feeds (Adesina, 2012).

II. MATERIAL AND METHODS

Design Considerations

The following considerations were made during the design process of the machine; High efficiency, high production capacity, availability and expenses of construction materials. Other considerations included; the development of a cylindrical barrel to accommodate the required quantity of feed stock, and the design of the shaft for maximum feed conveyance to enhance extrusion of the pellet feeds. Consideration was also given to a strong mainframe to ensure structural stability and strong support for the machine against vibration.

Galvanized materials were used as fabrication materials, because of the following reasons.

i. Hardness for abrasion resistance
ii. The ability to retain their hardness at high temperature.
iii. Toughness to withstand any shock due to load impact.
iv. It is less corrosive.

Other considerations for the design were: Power source, Speed of extrusion and pitch space of shaft.

Design selection

The machine on which the extruding materials were wounded was designed based on the following selection consideration;

i. The machine was driven by electric motor based on design calculations.

ii. The power transmission was achieved with the use of v-belts running at linear speed of between 5 m/s and 25 m/s to prevent high centrifugal belt tension (i.e. minimum and maximum belt speed)

iii. The central distance of the pulleys was chosen to be 800 mm and the corresponding length of belt was determined. This was intentionally meant to reduce the speed transmitted to the machine.

iv. Pulley diameter for the electric motor was chosen as 120 mm and that of the gearbox input spindle was 250 mm. The speed transmitted is reduced by approximately 0.5.

vi. The shaft diameter for the auger was determined based on the design analysis which was a factor of maximum permeable shear stress of steel and torque on the shaft.

Design Analysis

The pelletizing machine is made up of stationary parts and moving parts. The moving parts were driven by an electric motor via V-belts. It was required that the machine be relatively inexpensive and uncomplicated in design and operation so as to meet the needs of small and medium scale fish farmers and other farmers using pellets to feed their animals.

Power transmission system design

The power transmitted was determined by;

Determination of energy required for pelletizing

The energy required for pelletizing was given by;

$$\text{Energy (E)} = \text{Work done (W)} \quad (1)$$

$$\text{Work done (W)} = \text{F} \times \text{d}$$

$$\text{F} = \text{compression force}$$

$$\text{d} = \text{distance traveled by feed to form pellet}$$

$$\text{Force} = \text{Pressure} \times \text{Area}$$

For a mash cassava of moisture content of 43%, pressure value of 48,300 N/m^2 was obtained (Kolawole, *et al.*, 2007).

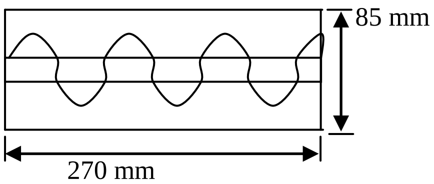

Figure 1: Area Covered by the Auger

(a)

$$A = 2\pi rl$$

$$A = 2 \times \pi \times 0.0425 \times 0.27$$

$$= 0.0721 \text{ m}^2$$

Therefore; (b)

$$= 48{,}300\ \mathrm{N/m^2} \times 0.0721\ \mathrm{m^2}$$
$$\mathrm{Force} = 3482.43\ \mathrm{N}$$

Therefore;

$$\text{Energy required} = \text{Force} \times \text{distance} \qquad (2)$$
$$= 3482.43\ \mathrm{N} \times 0.27\ \mathrm{m}$$
$$= 940.26\ \mathrm{Nm}$$

Assuming time taken for the work done to be 1sec.

Then for this design; (c)

$$\text{Power required} = 940.26\ \mathrm{Nm/1sec} = 940.26\ \mathrm{W} = 1.26\ hp$$

A medium range electric motor between 1.5 hp and 3 hp was selected based on the above, while speed of motor rotation$N = 1440$ rpm, diameter of motor pulley$d = 55$ mm, diameter of pelletizing machine pulley $Dm = 180$ mm

Belt selection for pelletizing machine

The belt was selected based on the equation 3;

$Dm < C < 3(Dm + d)$ (Khurmi *andGupta* ,2008) (3)

Where;

$$C = \text{Centre distance (mm)}$$
$$180 < C < 3(180 + 55)$$
$$180 < C < 3(235)$$
$$180 < C < 705$$

A centre distance of 500mm was considered adequate for open belt drives, belt length is given by

$$L = \pi(Rm + r) + \frac{(Rm - r)2}{C} + 2C \qquad (4)$$

$$Rm = \text{Radius of pelleting machine pulley(mm)}$$
$$r = \text{Radius of motor pulley(mm)}$$
$$C = \text{Centre distance(mm)}$$
$$L = \pi(90 + 27.5) + \frac{(90 + 27.5)2}{500} + 2(500)$$
$$L = 1396.8\ \mathrm{mm}$$

Based on this, a selection of ‘A’ belt with nominal pitch length 1420mm, top width 13mm and thickness 8mm was selected.

Velocity of the belt

Velocity of the belt was given in equation 5 by Khurmi *andGupta* (2008)

$$V = \frac{\pi d_1 N_1}{60} \qquad (5)$$

$$= \frac{\pi \times 0.12 \times 1440}{60}$$
$$= 9.0478\ \mathrm{m/s}$$

Determination of Angle of wrap and Belt tension

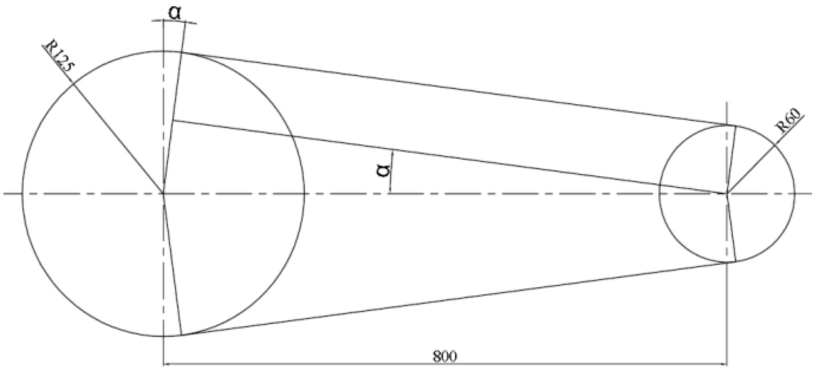

Figure 2: Pulley showing angle of wrap

$\sin \alpha = \frac{r_1 - r_2}{x}$ (Khurmi $and Gupta, 2008$) (6)

Where r_1 = Radius of the driver pulley;
r_2 = Radius of the driven pulley;
x = Centre distance between the pulleys

$$\alpha = \sin^{-1}\left(\frac{125 - 60}{800}\right) = 4.66°$$

∴ the angle of lap or contact between the belt and the pulley was given by Kurmi and Gupta, (2008) as

$\theta = (180° - 2\alpha)\frac{\pi}{180}\,\mathrm{rad}$ (7)

$$= [180° - 2(4.66)] \times \frac{\pi}{180}\,\mathrm{rad}$$

$$= 2.9789\ \mathrm{m/s}$$

The load carrying capacities of a pair of pulleys was determined by the one with the smaller value of $e^{f\alpha/\mathrm{Sin}\,1/2\theta}$

$$f = \text{coefficient of friction between belt and pulley}$$

$$\alpha = \text{Angle of wrap of belt in pulley (radian)}$$

$$\theta = \text{grove angle (degree).}$$

Coefficient of friction for rubber belt or dry mild pulley $f = 0.3$ (Mandal, 2003)

$$\theta = 400$$

For driver pulley,

$$e^{\{0.3\times(165.64/180)\pi\}/\mathrm{Sin}\,20} = e^{2.54} = 12.68$$

For driven pulley,

$$e^{\{0.3\times(194.36/180)\pi\}/\mathrm{Sin}\,20} = e^{2.98} = 19.69$$

Hence, the driver pulley determines load carrying capacity was given by Kurmi and Gupta (2008) as.

$$\frac{T_1 - MV^2}{T_2 - MV^2} = e^{f\alpha/\mathrm{Sin}\,1/2\theta} \qquad (8)$$

$$T_1 = \text{Maximum belt tension (N)}$$

$$T_2 = \text{Minimum belt tension (N)}$$

$$V = \text{belt speed}(ms^{-1})$$

$$M = \text{mass per unit length of belt } (kgm^{-1})$$

$$T_1 = \sigma_\omega A \dots\dots\dots\dots\dots.(v)$$

$$M = \rho bt \dots\dots\dots\dots\dots\dots (vi)$$

$$\sigma_\omega = \text{Allowable stress for belt material}$$

$$A = \text{Belt Cross Sectional Area}$$

$$\rho = \text{Belt density}$$

$$b = \text{Belt width}$$

$$t = \text{Belt thickness}$$

$$\sigma_\omega = 1.2 \times 10^6\ Mm^{-2} \text{ for rubber and } \rho = 1250\ kgm^{-3}$$

$$b = 13\ mm$$

$$t = 8\ mm$$

$$T_1 = 1.2 \times 10^6 \times 0.5(0.013 + 0.01312)0.008$$

$$T_1 = 93.6\ N$$

$$M = 1250 \times 0.013 \times 0.008$$

$$M = 0.13\ kgm^{-3}$$

$$V = \frac{\pi dn}{60} = \frac{\pi \times 55 \times 1440 \times 10^{-3}}{60}$$

$$V = 4.147\ ms^{-1}$$

$$\frac{93.6 - 0.13(4.147)^2}{T_2 - 0.13(4.147)^2} = 12.68$$

$$T_2 = 9.44\ N$$

Power transmitted by pelletizing machine belt

This was given by Khurmi and *Gupta*(2008)as;

$P_m = (T_1 - T_2)V$ (9)

$$P_m = (93.6 - 9.44)\ 4.147$$

$$P_m = 427.3\ N$$

Total Power
Assuming a factor of 2 to take account of power losses not catered for during transmission.

$$\text{Total Power} = 427.3 \times 2 = 854.6 \text{ W}$$
$$= 0.855 \text{ KW}$$

Thus a prime mover of 1.5 hp to 3 hp is considered adequate.

Power transmission shaft design
The diameter of shaft receiving power from the prime mover to the pelletizing machine should be such that resist torsion and bending loads due to the weights of the pulleys and the worms (uniformly distributed) on the pelletizing machine shaft and loads due to belt tensions and other operating conditions.
Assuming no axial loads, shaft diameter is given by (Mott, 2004) as;

$$d = \frac{16}{\pi \sigma_s} \sqrt{(K_b K_b)^2 + (K_t K_t)^2} \qquad (10)$$

σ_s = allowable stress (MPa)
K_b = combined shock and fatigue factor applied to bending moment
K_t = combined shock and fatigue factor applied to torsional moment
M_b =bending moment (Nm)
M_t = torsional moment (Nm)

$$M_t = \frac{9550 \times kw}{N}$$

N = shaft speed (rpm)

Bending Moment Analysis of Pelletizing Machine Shaft
The vertical forces on the pelletizing machine shaft will mainly be due to the weight of the pulley, weight of the uniformly distributed worms and bearings reaction (neglecting the weight of the shaft).
Pulley diameter = 180 mm
Worms disc diameter = 85 mm
Pulley thickness = 25 mm
Worms disc thickness = 3 mm (when combined = 15 mm)
Mass of pulley m = ρv (kg)
Where ρ = density of pulley material (Mild steel)
V = volume of pulley (kgm^{-3})

$$m_p = \pi(0.09)^2 \times 0.025 \times 7840 = \pi r^2 t\rho = 4.99 \text{ kg}$$

Weight of pulley 4.99 x 10 = 49.9 N
Mass of the worm disc (assuming material lost during futes is negligible) is given by;

$$M_w = \pi r^2 l \qquad (11)$$

Where;
l = t (thickness)

$$M_w = \pi(0.0425)^2 \times 0.015 \times 7840 = 0.667 \, Kg$$

Total weight of worm discs = 6.67 N

Vertical bending moment analysis for pelletizing machine shaft

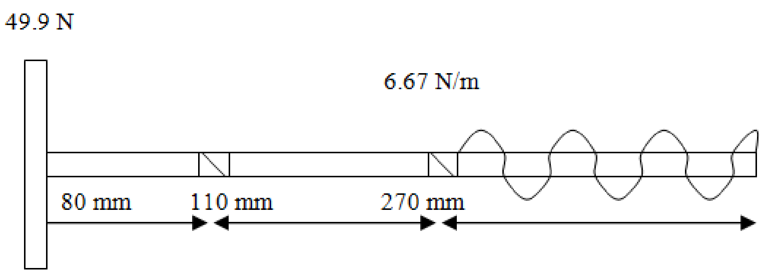

Figure. 3a. Vertical Load Diagram

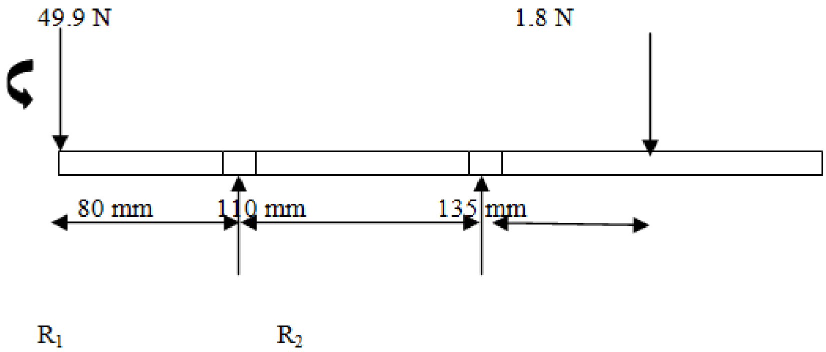

Figure 3b: Vertical Load Diagram

$$MR_1 = 49.9 \times 0.08 + R_2(0.11) - 1.8(0.11 + 0.133)$$
$$= 3.992 + 0.11R_2 - 0.441$$

$$R_2 = \frac{-3.551}{0.11} = -32.3N$$
$$R_1 + R_2 = 49.9 + 1.8$$
$$R_1 = 49.9 + 1.8 - 32.3$$
$$R_1 = 19.4\ \text{N}$$

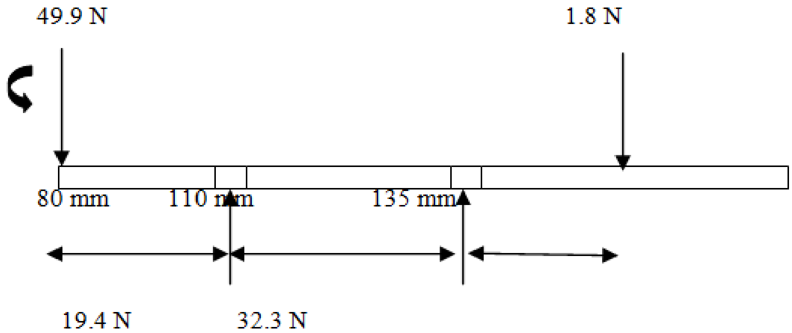

Figure 4a: Vertical Loads

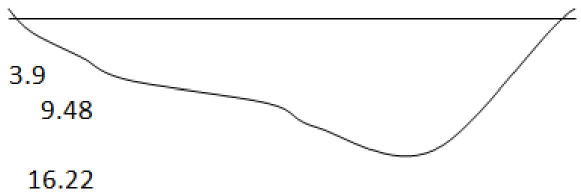

Figure 4b: Vertical bending moment diagram

ii. Horizontal bending moment analysis for pelleting machine shaft
A horizontal load was mainly due to belt tension total.
Horizontal load = sum of belt tension
= 93.6 + 9.44 = 103.04 N

For equilibrium,
Bearing reaction R = 103.04

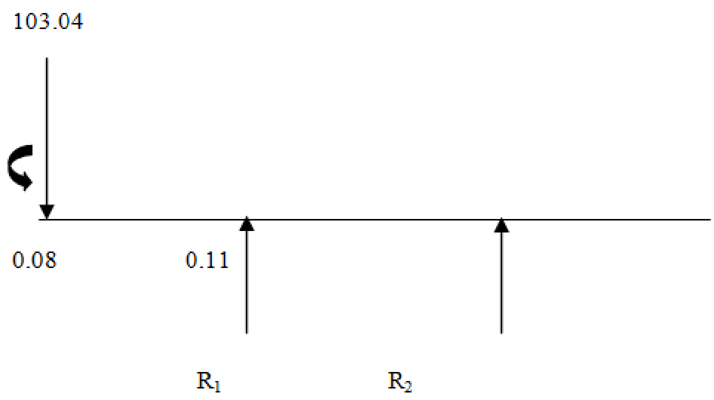

Figure 5: Horizontal loading diagram

$$R_1 + R_2 = 103.04$$

M R2
103.04(0.08 + 0.11) – 0.11R1= 0

$$\frac{103.04(0.08 + 0.11)}{0.11} = R_1$$

R1 = 177.98N
R2 = 103.04 – R1
R2 = -74.94 N

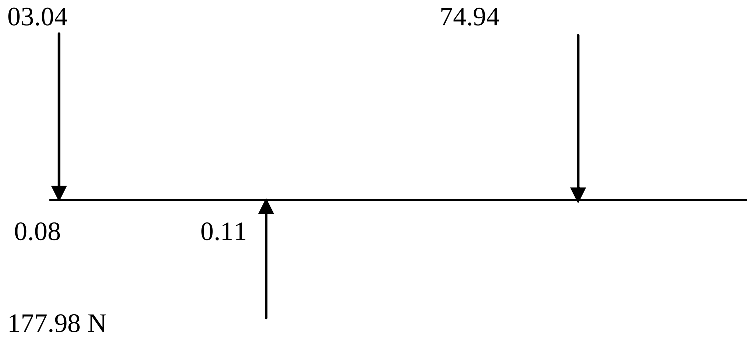

Figure 6a: Horizontal Load

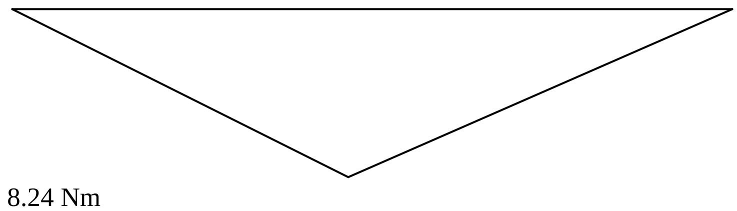

Figure 6b: Horizontal bending moment diagram

Therefore; Bending Moment $M_b = \sqrt{(16.22 + 8.42)^2}$

$$M_b = 18.6\ Nm$$

Torsional moment; $M_t = \frac{9550 \text{ x KW}}{N_s}$

Where N_S was the shaft speed (rpm) and KW was the power transmitted by pelleting machine belt, which was 854.6 W

$$\frac{N_m}{N_s} = \frac{D}{d} \qquad (12)$$

$$\frac{1440}{N_s} = \frac{180}{55}$$

$N_S = 440$

Therefore; $M_t = \frac{9550 \text{ x } 0.8546}{440}$

$= 18.55$ Nm

$K_b = 1.5, \ K_t = 1 \delta_s = 40$ mPa

$$d^3 = \frac{16\sqrt{(1.5 \times 18.6)^2 + (1 \times 18.55)^2}}{\Pi 40 \times 10^{-6}}$$

$d^3 = 4.265 \text{ x } 10^{-6}$

d = 0.0162mm

d = 16.2mm

Barrel Design

The barrel which was cylindrical was considered as a pressure vessel. The circumferential stress was determined with the assumption of a cylinder thickness to be 27 mm using the equation according to Khurmi and Gupta (2008).

$$T = \frac{Pd}{2\sigma_c} \qquad (13)$$

Where: T= Thickness of barrel, (mm)

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 thebarrel (N/mm^2).

The internal pressure which was equal to the extrusion pressure as determined by Ryder (1977) was stated in equation 13:

$$p = \frac{\text{Design extrusion force}}{\text{Bore area } (m^2)} \qquad (14)$$

$$= 1.27\text{x}10^{-3} \frac{N}{mm^2}$$

The inner diameter, d_1=100 mm and the outer diameter, d_2= 110 mm. The cylinder thickness, t = 27 mm. Therefore, inner diameter ratio was calculated as t/d_1= 0.27. A Cylinder with t/d_1less than 0.05 was generally regarded as a thin walled cylinder while greater than or equal to 0.05 was regarded as thick walled cylinder (Ryder, 1977). Thus, this pelletizing cylinder has a thick walled cylinder. The radial stressσ_r and axial stress $\sigma_z$at a diameter, d in the body of the cylinder according to Ryder (1977) are given as:

$$\sigma_r = \left(\frac{d_2^2 - d^2}{d_2^2 - d_1^2}\right) \frac{d_1^2}{d^2} \cdot P \qquad (15)$$

$$\sigma_z = 0$$

For open ends of cylinder when an internal pressure p_1 was applied only. The minimum stresses occur at the cylinder bore, that is at $d=d_1$. Thus from equations 15 and 16 the radial stress at the bore $\sigma_r = p = 1.27\text{x}10^{-3}\ N/mm^2$and from equation 15 the hoop stress σ_h was =$2.35\text{x}10^{-3}\ N/mm^2$. The maximum octahedral shearing stress criterion of failure was used for the design (Ryder, 1977). This criterion according to Ryder (1977) was given by equation 16 as:

$$= {}^1/_3 \sqrt{[(\sigma_h - \sigma_r)^2 + (\sigma_r - \sigma_z)^2 + (\sigma_z - \sigma_h)^2]} = {}^2/_3 Y \qquad (16)$$

Where Y was the yield stress of the material,

Thus substituting$\sigma_r = 1.27\text{x}10^{-3}\ N/mm^2$, σ_h =$2.35\text{x}10^{-3}\ N/mm^2$ and $\sigma_z = 0$ into equation 3.17 we have Y= $1.44\text{x}10^{-3}\ N/mm^2$ which was less than the yield stress of mild steel (Y=280 N/mm^2) Ryder (1977).

Description of the Pelletizing Machine

The main frame supports the sub-systems of the machine. It is constructed from 1¼ angle bars, cut to specification. The upper part of the main frame was joined by welding and its legs were bolted type, plank was placed on the upper part of the frame to hold the pelletizing machine and the electric motor. Slots were made on the frame through which component parts were bolted. The pelletizing machine was constructed and mounted in position on the main frame (Plate 1). The hopper was cut from a 2 mm thick mild steel plate after marking out had been done with scribe and rule, using shear cutter and it was designed and bolted to its main body. The body was cut from a 100 mm diameter and 6 mm thick mild steel pipe. The drive shaft was turned to dimension between centers on a lathe, pulley was made from a steel blank turned, drilled, bored and grooved mounted between centers on the lathe.

Plate 1: Developed Pelletizing Machine

Cost Analysis of the Pelletizing Machine

The bill of engineering measurements and evaluation of the pelletizing machine is summed up as shown in Table 1

Table 1: Bill of Engineering Measurement and Evaluation (BEME)

S/N	Materials	Part	Quantity	Unit Price (₦)	Cost (₦)
1	Mild Steel	Frame	2	3,000:00	6,000:00
2	Mild Steel sheet	Hooper	1	4,000:00	4,000:00
3	Steel	Pulley	3	3.350:00	10,050:00
4	Steel	Bearing	3	1,500:00	4, 500:00
5	Hard Steel	Cylinder Barrel	3	5,000:00	15,000:00
6	Machining	Curved Parts	10	200:00	2,000:00
7	3HP Electric motor		Bulk	30,000:00	30,000:00
8	Workmanship		Bulk	15,000:00	15,000:00
Total					**86,550:00**

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Pelletizing Throughput capacity

Throughput capacity is the amount of materials that can pass through a machine at a particular time. This can be expressed with the equation given by Khurmi and Gupta (2008).

$$C_j = \frac{W_{JE}}{T} \quad (17)$$

Where,

C_J = throughput capacity of the machine (kg/h)

W_{JE}= Weight of the feed mix fed into the machine (kg)
T = time used for pelletizing (h)

The throughput capacity was determined for each barrel length against the die size and analyzed statistically.

III. RESULT AND DISCUSSION

The throughput capacity of the pelletizing machine was determined with equation 17 and the results obtained are presented in Table 2. The highest throughput capacity obtained was 96.3% which was possible at 140 mm barrel length and 6 mm die size, this can be attributed to the shortness of the barrel combined with the largest size of the die, this two combinations will allow easy passage of the pellet thereby very little quantity will be left in the barrel. However, the observed side effect of this achieved throughput capacity on the pellet formed is low durability, that is the pellet would be weak in terms of formation and less water stability. Hence it is expected to dissolve easily in water. The lowest throughput capacity obtained was 85.2% which was obtained at 420 mm barrel length and 4 mm die size this result could be attributed to the length of the barrel and the size of the die size which restricted the flow of the pellet.

The general observation from the result obtained was that the overall throughput capacity obtained was high and it is economical for the production of pellets. The statistical analysis of the throughput capacity was presented in Table 3.The considered parameters which are the barrel length and die size were found to have significant effect on thethroughput capacity of the pelletizing machine at $P \geq 0.05$. The R^2 is 0.9892, Mean = 91.41, Adj R-Squared = 0.9866, this implies that Model F-value of 91.41 is significant, Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case A, B and B^2 are significant model terms.Values greater than 0.1000 indicate the model terms are not significant. A and B are given as the barrel length and die Size.

Table 2: Efficiency of the pelletizing machine

Runs	Length of barrel (mm)	Die size (inches)	Efficiency (%)
1	140	4	91.1
2	280	4	88.8
3	420	4	85.5
4	140	5	95.2
5	280	5	91.8
6	420	5	89.9
7	140	6	96.2
8	280	6	93.2
9	420	6	91.1

The final equation in terms of coded factor determined by the statistical analysis is given as;

$$\text{Throughput capacity} = 92.15- 2.63^* A + 2.51^*B + 0.12^*A^* B + 0.23^*A^2- 1.34^*B^2 \qquad 18)$$

Figure 7 showed the effect of barrel length and die size on the pelletizing throughput capacity of the pelletizing machine, the graphical representation showed that with increase in the length of barrel the throughput capacity of the pelletizing machine gradually reduces which also followed the same rudiment with the die size. This implies that the change in barrel length and die size have significant effect on the pelletizing throughput capacity of the machine.

Table 3: Throughput capacity ANOVA for Response Surface Mean model

Source	Sum of Squares	Df	Mean Square	F Value	p-value Prob> F	
Model	248.549	5	49.7098	385.2709	< 0.0001	Significant
A-barrel length	124.2939	1	124.2939	963.3275	< 0.0001	
B-die size	113.0006	1	113.0006	875.7997	< 0.0001	
AB	0.1875	1	0.1875	1.4532	0.2414	
A^2	0.311296	1	0.311296	2.412671	0.1353	
B^2	10.75574	1	10.75574	83.36131	< 0.0001	
Residual	2.709537	21	0.129026			
Lack of Fit	2.02287	3	0.67429	17.67557	< 0.0001	Significant
Pure Error	0.686667	18	0.038148			
Cor Total	251.2585	26				

Std. Dev.: 0.36, R-Squared : 0.9892, Mean : 91.41, Adj R-Squared : 0.9866, C.V. % : 0.39,Pred R-Squared : 0.9826, PRESS : 4.36, Adeq Precision :60.631

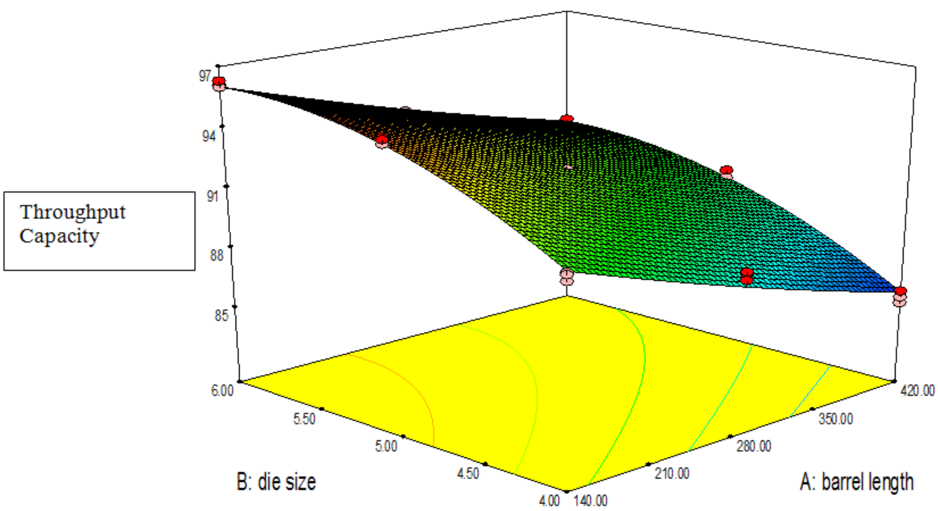

Figure 7: Effect of length of barrel and die size on the pelletizing throughput capacity

IV. CONCLUSION

The design and fabrication of a low cost pelletizing machine was achieved. The optimum pelletizing throughput capacity obtain was 96.2% which was possible at 140 mm barrel length and 6 mm die size

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