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Design and Production of a Single Screw Fish Feed Extruder

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Abstract

The design and production of a single screw fish feed extruder was carried out. The first step was the design concept aimed at designing and producing a robust machine for rural fish farmers to help them extrude fish feed pellets from local feed materials available to them. The machine's detailed parts were designed using design analysis methods, which informed the material selection and specification. Each detailed component design was produced sequentially from the frame to the hopper before final assembly into the fish feed single screw extruder. No-load and load tests were carried out on the machine to assess its performance as well as the extruded feed it produced, in comparison to imported fish feeds. The comparison showed that some of the foreign fish feed had a longer floating time, but the floating time of 0.39 minutes to 1 minutes for the locally extruded fish feed met specification to some extent, but need incorporation of some floaters to extend their floating time. The feed material was a composition of soybean, maize and other additives. The machine was operated at three speeds 254 rpm, 505rpm and 761rpm. And the material extruded was tested at six moisture content levels of 15%, 20%, 25%, 30%, 35% and 40% (wet basis, wb). The power required to run the machine was 2014W. The results show that the machine had an output of 63.2kg/hr compared to the theoretical output of 114.38kg/hr. The efficiency of the extruder was 54%; this was below the imported but efficient to provide alternative to the imported and to save foreign exchange. The total output was 500kg/day when the machine worked 8hrs/day. The optimum speed and moisture content for highest yield was 761rpm and 25% moisture content (wb) in the mix respectively.

Keywords: Fish feed pellets, Single screw extruder, Local production, Extruder design, Fish farming.

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1|Introduction

Economic crisis in Nigeria has brought difficulties to every sector of the Nigerian economy. The devaluation of the Nigerian currency called the Naira has led to uncontrolled inflation which is making it very difficult for businesses to survive. The Nigerian economy is import-depended and most businesses are operated on imported raw materials. This informs why most businesses are folding-up today; the exchange rate of the Naira to the Dollar as of today is $1 to ₦1600 [1]. The exchange rate is however, not stable as the volatility in the exchange market is very high. The Agricultural Sector, particularly the animal farmers' subsector has not been finding it funny in Nigeria. The prices of animal feeds have risen astronomically to levels that most farmers are unable to feed their fishes and other animals. The poultry farmers are complaining and even big farms are folding up. What do we do to survive and remain in business? Creativity and ingenuity is required at this point and this project topic "Design and Production of a Single Screw Fish Feed Extruder" is a creative effort towards circumventing the closure of fish farms in Nigeria. We must at this point look inwards; technologically and economically to develop local technologies based on our local raw materials to produce nourishing feeds for our fish farms that will be affordable for our fish farmers. Expensive fish feeds are no longer affordable by most small and medium scale fish farmers. 1 kg of cat fish cost three thousand and five hundred Naira, which is around $2.19 very big amount in Naira but very small amount in dollars [1].

Since 1999, there has been a switch to domestic livestock production in Nigeria. This production was due to the control of the importation of livestock and frozen food by the Nigerian government using the National Agency for Food, Drug Administration and Control (NAFDAC). The result was a shift to local livestock farming. Also, there has been a move from significant poultry farming to fishery and others. The most commonly available fishes in Nigerian Aquaculture are the African catfish, the carp fish, Nile tilapia, Bonga fish (Fimbriata), Shad (Ilisha Africana), and Sadine (Sadinella Spp). However, the most domestically farmed is the African catfish.

In Nigeria today, most fish farmers depend on fish feed available in the market which is usually at very high cost and has very streamlined formulae in which it is produced. Fish in different forms unilaterally contributes on the average 15% source of protein per meal intake by Nigerians and could be as high as 40% in coastal communities [2]. Tobor [3] and Ajana [4] reported that the average annual demand for fish in Nigeria between 1995 and 2000 was estimated at 1.22 million metric tonnes and that this might increase to about 1.425 million metric tons, by the year 2010. FAO [2] estimated the projected population and fish demand from 2006 to 2025, with domestic fish production by the year 2007 as 0.77 million tones The demand-supply index of fish in Nigeria is 1.0 million metric tonnes. From the above analysis, less than 50% of the total annual fish consumed by Nigerians are produced locally. Good quality fish will depend on the availability of high quality feed at an affordable price to the farmer. There is, therefore, the need to bridge the gap between the farmer and the high cost of currently available feed in order to maximize fish production [5].

Fish farming has generated a lot of interest in Nigeria in the last two decades. Many investors have rushed into commercial fish farming with the aim of maximizing profit on investment. However, only very few have been successful. Many others have abandoned their farms due to the high cost of fish feed [6].

Although, there has been a lot of research work on production of fish feeds to meet the nutrient requirements of culturable fish in Nigeria [7, 8], good quality fish feed pellets are still sparingly used by farmers. This is due to the fact that there are few commercial fish feed producers in the country, a lot of farmers depend on imported fish feed which are expensive and not affordable. This increases their cost of production and reduces their profit margin.

In order to reduce the cost of production of fish, there is the need for more commercial fish feed producers in the country. Having more fish feed manufacturers will also reduce the dependency on highly expensive imported fish feed. There are different types of equipment used to produce fish feed pellets and one of such is a single screw extruding machine. The design and production of a fish feed extruding machine will fulfill the need of having more commercial fish feed produced by the farmers in Nigeria and the privilege of blending their own feed to suit the growth rate of their fish and other special nutritional requirements [1].

The Nigerian rural and subsistence fish farmer finds is difficult to contend with unavailability of extruded or pelletized fish feed for his farm either because the product is not available to him or he has no means of processing the feed materials around him to feed that can be fed to fish in ponds. This leads to stunted growth of the fish, because he can't achieve market size at a specific age, leading to huge losses in his investment and shrinking profits. The cost of acquiring the extrusion technology to produce his specialized feed is very high. If fish must be ready for the market on time, then quality fish feed is key [9–11].

The desire to improve the appearance, digestibility and palatability of man and animal feed led to the development of the cocking extruders in the 1940s and the marketing of the first widely accepted modern dry dog food [12–16].

The objective of this paper is to design and produce a single screw fish feed extruder for small and medium scale fish farmers in Nigeria who are struggling to survive because of high cost of fish feed in the open market.

2 | Materials and Method

2.1 | Materials

The following materials are used in the production and testing of the single screw extruder.

I. Mild steel sheet 2-4mm thickness.

II. Angle iron bars 50mmX50mm wide.

III. Metal plate with thickness 20mm for the die construction.

IV. Ball Bearings.

V. Electric motor.

VI. Pulleys.

VII. A screw shaft.

VIII. A plane shaft.

IX. Belts various sizes.

X. A metal Pipe.

XI. Hot water.

XII. Maize flour.

XIII. Soya Bean meal.

XIV. Wheat flour among other feed making materials as shown in *Fig. 8* below.

Fig. 1. Feed meal raw materials for fish feed processing.

The materials selected are subject to machine design analysis and considerations such as expected load and stresses, performance under load conditions among other factors. Construction of the machine was carried out in a metal fabrication workshop (JSTU) using equipment such as;

I. The lathe machine.

II. Power drill with drill bits of different sizes.

III. Grinders and filing machines.

IV. Electric-Arc welding machine.

V. Sheet bending machine.

VI. Bolts, Nuts and washers of different sizes.

2.1.1 | Material Selection for the Production of the Extruder

Materials for the construction of the machine were selected based on some considerations of hardness, vibrations and strength and power requirement among other factors. The material selection criteria are presented in *Table 1* below.

Table 1. Material Selection Criteria for Extruder Construction.

S/No	Material/Component	Selection Criteria	Quantity
1	Mild steel sheet	Hardness and strength at 4mm	1
2	Angle iron bar (50mm X50mm width)	Strength to support extruder	1
3	Metal plate 20mm thick	Strength against extrusion force	1
4	Electric motor	Theoretical design capacity	1
5	Plane shaft	Steel	1
6	Screw shaft	Steel	1
7	Belts	V-belts	2
8	Pulleys	Cast iron	2
9	Metal pipe	Strength and hollow cavity	2
10	Feed materials	Availability and nutritional value	12kg

2.2 | Design of a Single Screw Extruder

2.2.1 | Design considerations

The extruder is designed based on the following factors:

Ergonomic factors: an operator only needs to feed in material and collect the extrudate. Other operations of the machine are automated.

Strength criteria: the maximum strength requirement of the extruder walls especially during flow of materials in the extrusion and conditioning chamber is as seen from the turnkey feed processing machine developed in china is 4mm.

Corrosion: mild steel when painted is resistant to corrosion, the galvanized sheet is best especially since heat is involved in the feed processing and is healthier for food processing to avoid the contamination due to paint chemicals.

Functionality: a single phase electric motor is used especially for locations where 3 phase electrical connections are not available.

2.2.2 | The mechanical power of the extruder

The mechanical power was calculated as the rate of working at the interface between the material in the screw channel and the barrel. Power consumption is related to material viscosity, shear rate at the barrel wall, barrel diameter, shaft rotational speed and barrel length [17].

Power to Operate Extruder, P_e

$$P_e = \mu\gamma\pi^2 D^2 NL, \quad (1)$$

Where,

P_e = power consumption, w.

μ = material viscosity, Nsm^{-1}.

γ = shear rate at barrel, s^{-1}.

D = diameter of the barrel, m.

N = speed of shaft, rpm.

L = length of the barrel, m.

The appropriate viscosity to use in calculating power is given by the following formula [17].

$$\mu = \mu_o \left(\frac{\gamma}{\gamma_o}\right)^{n-1} \exp[-b(T_b - T_o)]. \quad (2)$$

Also, the appropriate shear rate to use in the calculation of viscosity is given by the following equation, [1, 18].

$$\gamma = \frac{V_z}{H}, \quad (3)$$

Where,

γ = mean shear rate, s^{-1}.

V_z = velocity, ms^{-1}.

H = channel height, m.

The velocity is given by:

$$V_z = \pi DN\cos\varphi = \pi x 0.05 x \frac{761}{60}\cos 17.66^o = 1.9ms^{-1}.$$

$$\gamma = \frac{V_z}{H} = \frac{0.9}{0.01} 190s^{-1}.$$

$$\mu = \mu_o \left(\frac{\gamma}{\gamma_0}\right)^{n-1} \exp[-b(T_b - T_o)]. \quad (4)$$

The viscosity, μ_o, at a reference temperature, T_o, and reference shear rate, γ_o, is determined from a plot of viscosity against shear rate of defatted soy flour and the value is 27.4 Nsm^{-2} at a temperature of 75°C and shear rate of $1s^{-1}$.

The temperature of the barrel, T_b, is chosen as 92.7 Nsm^{-2}, the power law number, n, is chosen as 1.1 and the temperature coefficient of viscosity at constant shear rate, b, is chosen as 0.01 C^{-1}.

$$\mu = 27.4 \left(\frac{190}{1}\right)^{n-1} \exp[-0.01(92.7 - 75)] = 38.79NMs^{-2}.$$

$$P_e = \mu\gamma\pi^2 D^2 NL = 38.79 \times 190 \times \pi^2 \times 0.073^2 \times \frac{760}{60} \times 0.3 = 1475W.$$

Power to operate the conditioner chamber, P_c

The power requirement for the conditioning chamber (a propeller stirrer mixing a material inside a vessel) is given as a function of the Reynolds number as follows [19]:

$$P_c = a(R_e)^b, \quad (5)$$

Where,

P_c = power required by the conditioner, hp.

R_s = Reynolds number.

a and b are constants

Eq. (5) is rewritten to make it linear thus,

$$\text{Log}P_c + \text{Log a} + \text{Log } R_e. \quad (6)$$

The values of the power requirement of a propeller shaft mixer for five different values of Reynolds numbers were given by Toledo [19] in *Table 2* and the values were used to calculate for log P and log Re as presented in *Table 3*. A graph of log P against log Re was plotted as shown in *Fig. 2* and this was used to get the values of a and b as 0.2 and 0.2 respectively. The Reynolds number is given as follows:

$$R_e = \frac{\rho VD}{\mu}, \quad (7)$$

Where,

P = density of the material, kgm^{-3}.

v = velocity of the material, ms.

D = diameter of the propeller stirrer, m.

μ = viscosity of the material, Nsm^{-1}.

Table 2. Power requirement of a propeller mixer.

Power(hp)	Re
0.23	2
0.32	10
0.40	30
0.49	70
0.51	100

*Source: [20].

Table 3. Calculated values of Log P and Log Re.

Power(hp)	Re	Log P	Log Re
0.23	2	-0.64	0.30
0.32	10	-0.50	1.00
0.40	30	-0.40	1.50
0.49	70	-0.31	1.80
0.51	100	-0.29	2.00

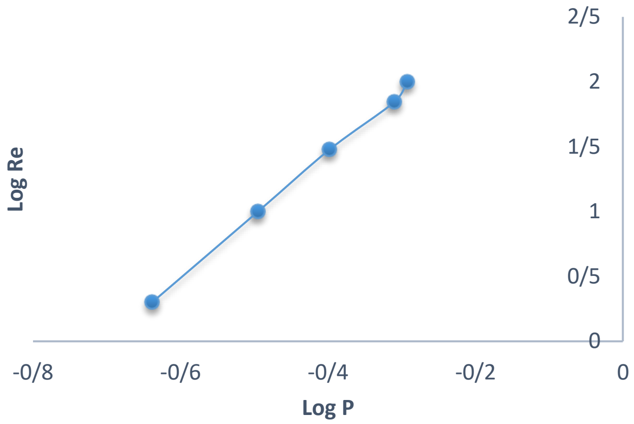

Fig. 2. Log Re plotted against log P.

Scale: 1:-0.1 on Log P axis and 1:0.5 on Log Re axis.

The shear rate and viscosity for the power are calculated as follows

$$\gamma = \frac{V}{L}, \tag{8}$$

Where,

γ = shear rate, s^{-1}.

V = velocity, ms^{-1}.

L = distance between the shaft and the cylinder.

$$\gamma = \frac{v}{L} = \frac{6}{0.065} = 92.3s^{-1}$$

$$\mu = \mu_o \left(\frac{\gamma}{\gamma_0}\right)^{n-1}, \tag{9}$$

Where,

γ = shear rate, s^{-1}.

γ_o = shear rate at reference temperature, s^{-1}.

μ = viscosity, Nsm^{-1}.

μ_o = viscosity at reference temperature and shear rate, Nsm^{-1}.

$$\mu = \mu_0 \left(\frac{\gamma}{\gamma_0}\right)^{n-1} = 27.4\left(\frac{94.3}{1}\right)^{0.2-1} = 0.734Nsm^{-1}.$$

$$R_e = \frac{\rho VD}{\mu} = \frac{750 \times 0.1 \times 6}{0.734} = 613.$$

$$p_c = aR_e^b = 0.2 \times 613^{0.2} = 0.722h.p = 0.722 \times 746 = 539.$$

Total power to operate extruder and the conditioner, P_t, is given as

$P_t = P_e + P_c = 1475 + 539 = 2014W.$

The extruder design is assumed to develop a maximum pressure of $15.4MNm^{-1}$ at the screw end of the extruder. This pressure produces compressive force which acts on the screw, circumferential stress which acts on the barrel wall and longitudinal stress acting on the die plate. The other units of the extruder are designed and or selected as described below.

2.2.3 | The frame

The frame supports the entire weight of the machine and serves as a carrier of all the components. The stand was constructed using angle iron. The angle iron bar is 50mm X 50mm wide. The height of each supporting leg is 500mm.

2.2.4 | The belt drive selection

Drive between Electric Motor and Screw Belt

The usable power generated by the electric motor is transmitted to the screw shaft by using a V-belt and two pulleys. In order to ensure firm grip between the belt and the pulley, the required length of the belt was determined by using the following equation [18].

$$L = 2x + \pi\frac{(d_2 + d_1)}{2} + \frac{(d_2 + d_1)^2}{4x}, \quad (10)$$

Where,

L = length of belt, m.

D_1 = diameter of the electric motor pulley, m.

d_2 = diameter of the screw shaft pulley, m.

X = distance between centres of pulley, m.

The distance between the centres of pulley was taken as 380mm and the diameter of the two pulleys, d_2 and d_1, were chosen as 152mm and 80mm respectively; these were made based on information from Khurmi and Gupta [18].

$$L = 2 \times 380\frac{(152 + 80)}{2} + \frac{(152 + 80)^2}{4 \times 380} = 1.129.$$

The speed of the screw shaft (N_2) is calculated using the formula as presented below,

$$N_2 = \frac{(N_1 \times d_2)}{d_1}. \quad (11)$$

The rated speed of the electric motor (N) is l450 rpm and the diameter of the pulley attached to the motor is 80mm. The diameter of the pulley on the screw shaft is 152mm.

$$N_2 = \frac{(N_1 \times d_2)}{d_1} = \frac{1450 \times 80}{152} = 761rpm.$$

The tension on the tight and slack sides of the extruder belt is related to power and the velocity of the belt by the following formula [1, 18].

$$P_e = (T_1 - T_2)v, \quad (12)$$

Where,

P = power transmitted by the belt, w.

V = velocity of the belt.

T_1 = tension on the tight side, N.

'T_2 = tension on the slack side, N.

The velocity is given by *Eq. 13* as

$$v = \frac{\pi d_2 N_2}{60}. \quad \textbf{(13)}$$

Also, the tension on the belt is related to the coefficient of friction between the belt and pulley, and the angle of contact at the small pulley by the following equation

$$2.3\text{Log} = \left(\frac{T_1}{T_2}\right) = \mu.\emptyset.\text{cosec}\beta, \quad \textbf{(14)}$$

Where,

μ = co-efficient of friction.

φ = angle of contact.

β = half of the pulley groove angle.

The co-efficient of friction between a dry rubber belt and cast iron pulley is 0.3. From design tables an angle of 45° is chosen as the groove angle of the pulley.

The angle of contact is given by the following equation.

$$\emptyset(180^0 - 2a)\frac{\pi}{180}\text{rad}. \quad \textbf{(15)}$$

α is related to the center distance between the two pulleys and radius of the two pulleys by the following formula [1, 18].

$$\sin a = \frac{r_1 - r_2}{x}, \quad \textbf{(16)}$$

Where,

x = distance between the centers of the two pulleys, m.

r_1 = radius of screw shaft pulley, m.

r_2 =radius of electric motor pulley, m.

$$\sin a = \frac{r_1 - r_2}{x} = \frac{152.4 - 80}{380} = 0.191.$$

$$a = \sin^{-1} 0.191 = 10.98^0.$$

$$\varphi = (180 - 2a)\frac{\pi}{180} = \left(180 - 2 \times 10.98\frac{\pi}{180}\right) = 2.758\text{rad}.$$

$$2.3\log\left(\frac{T_1}{T_2}\right) = 0.3 \times 2.758 \times \text{cosec}.$$

$$T_1 = 8.71T_2. \quad \textbf{(17)}$$

But,

$$v = \frac{\pi d_2 N_2}{60} = \frac{\pi \times 0.1524 \times 761}{60} = 6.073 ms^{-1}$$

$$P_e = (T_1 - T_2)v. \quad \textbf{(18)}$$

$$2014 = (T_1 - T_2) \times 6.073.$$

$$(T_1 - T_2) = 332N. \quad \textbf{(19)}$$

Substituting *Eq. (17)* into *Eq. (19)*,

$$8.711T_2 - T_2 = 332.$$

$$T_2 = 43N \text{ and } T_1 = 375N.$$

Drive between Screw and Conditioner Belt

Also, the tension on the tight and slack sides of the conditioner belt is related to power and velocity of the belt by the following formula [1, 18].

$$P_c = (T_3 - T_4)v. \quad \textbf{(20)}$$

$$v = \frac{\pi \times 0.12 \times 761}{6} = 4.782 m/s.$$

$$539 = (T_3 - T_4) \times 4.782.$$

$$T_3 - T_4 = 112.7N. \quad \textbf{(21)}$$

Also, the tensions on the belt are related to co-efficient of friction (between the belt and the pulley) and the angle of contact by the following

$$2.3\log\left(\frac{T_3}{T_4}\right) = \mu.\varphi.\text{cosec}\beta.$$

Equation [1, 18]

$$\varphi = (180^0 - 2a)\frac{\mu}{180}.$$

$$\sin a = \frac{r_1 - r_2}{x} = \frac{0.06 - 0.06}{0.24} = 0.$$

$$a = \sin^{-1} 0 = 0.$$

Substituting T_3 into *Eq (21)* we obtain the value of T_4,

$$\varphi = (180 - 2 \times 0)\frac{\pi}{180} = \pi = 3.14.$$

$$2.3\log\left(\frac{T_3}{T_4}\right) = 0.3 \times 3.14\,\text{cosec}\,22.5^0.$$

$$T_3 = 11.755T_4.$$

We Obtain $T_4 = 10.48N$ and $T_3 = 123.18N$.

2.2.5 | Barrel design

The barrel is a stationery pipe member which houses the screw, die and the die holder. The die was fitted at the extreme end of the barrel for the extrusion process. The barrel is designed to withstand a pressure of 15.4 MPa assumed to be developed by the extruder. The barrel is subjected to the maximum pressure developed at the screw end. The pressure is acting circumferential to the barrel wall. Force acting on the barrel wall

$$(F_a) = \text{Pressure}(P_r) \times d \times l. \tag{22}$$

Where P_r = pressure developed inside the barrel, Nm^{-1}.

d = diameter of the barrel, m.

l = length of the barrel, m.

$F_a = 15.4 \text{ X } 10^6 \text{ X } 0.073 \text{ X } 0.3 = 337{,}260$ N.

$$\text{Total Resisting Force of the barrel wall} = a \times 2t \times l. \tag{23}$$

Barrel thickness is given by *Eq (24)* [1, 18]

$$t = \frac{P_r - d}{2\sigma}, \tag{24}$$

Where P = pressure, Nm^{-1}.

d = diameter of the barrel, m.

σ = permissible stress of the barrel wall, Nm-1.

The following dimensions were chosen for the barrel internal diameter of 73mm and length of 300mm. The thickness of the barrel is calculated as 5mm. The barrel design calculation is as shown below.

Design calculation for the barrel [1, 18].

Barrel thickness, t

$$t = \frac{\tau - D}{2\sigma}. \tag{25}$$

The permissible stress for the barrel material is $112Nmm^{-2}$.

$$t = \frac{15.4 - 73}{2 \times 112} = 5\text{mm}.$$

2.2.6The Die Design

The die is a circular stationary member with 51 holes of 5mm each for shaping the material. The die is designed to withstand the pressure developed by the extrusion process. The pressure of $15.4MNm^{-2}$ assumed to develop in the extruder is acting longitudinal to the die plate. The diameter of the die is chosen to be 80mm and the thickness is 10mm, cut from a steel plate. The design calculations are as shown below.

Design calculations for the die.

Total force acting, Fa = intensive pressure x cross sectional area.

Cross sectional area is the difference between the area of the plate and the total area of die holes. The die holes are 51 in number of 5mm each.

$$\text{Total area of die holes } = \left(\frac{\pi d^2}{4}\right)51 = \left(\frac{\pi \times 5^2}{4 \times 1000^2}\right) = 1 \times 10^{-3}.m^2.$$

Area of die plate $\frac{\pi d^2}{4} = \frac{\pi \times 73^2}{4 \times 1000^2} = 4.2 \times 10^{-3} m^2$.

Cross-sectional area=total area of die plate- total area of die holes.

Cross-sectional area $= 4.2 \times 10^{-3} - 1 \times 10^{-3} = 3.2 \times 10^{-3} m^2$.

Fa = intensive pressure x cross sectional area [1, 18].

$F_a = 3.2 \times 10^{-3} \times 15.4 \times 10^6 = 49,280N$.

Total resisting force $= \sigma \times \pi dT$. **(26)**

T= Thickness of the die (m), while σ = Design stress, N/m^2.

The permissible stress of the die material (mild steel) is $86Nmm^{-2}$ and the factor of safety for the material under steady load is 4.

$$\sigma = \frac{\max.stress}{factorofsafety} = \frac{86}{4} = 21.5Nmm^{-2}.$$

$$t = \frac{F_a}{\sigma \times \pi \times d} = \frac{49,280}{21.5 \times \pi \times 73} = 10mm.$$

The die thickness to withstand applied pressure is 10mm.

2.2.7 | The die holder design

The die holder is a stationary circular ring member for holding the die in place by bolting the die holder to the barrel head. The internal and external diameter of the ring is 75mm and 100mm respectively. The thickness of the die holder ring is 25mm.

2.2.8 | The screw shaft design

The screw is a rotating member consisting of the screw shaft and the screw flight used to convert rotary motion into translatory motion of the material in the screw channel. The screw shaft is used to transmit power to the screw flight, which convert the rotary motion of the screw shaft into translatory motion of any non-rotating material in the screw channel.

The screw shaft is designed to withstand the torsional load, the bending load and the axial compressive load due to the pressure of 15.4 MPa assumed to develop at the die end of the barrel in which it is subjected to. The torque required to rotate the screw is related to power and the speed in rpm by the following equation; [1, 18].

$$T = \frac{P \times 60}{2\pi}, \quad \textbf{(27)}$$

Where,

T = torque, Nm.

P = power transmitted, Watts.

N = speed, rpm.

As shown in *Fig. 3*, the total force at point A, Fav is the summation of tensions at the conditioner belt-drive (T3+T4).

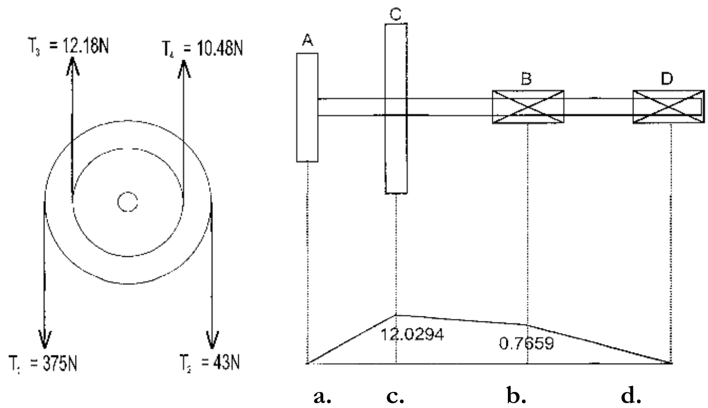

Fig. 3. Bending moment diagram of the screw shaft; a. small screw shaft pulley, c. extruder shaft pulley, b and d are bearing.

The total force at point C is the tension at the extruder's belt-drive,

$$F_{CV} = T_1 + T_2 = 375 + 43 = 418N.$$

The bending moment at point C, M_c,

$$M_c = F_{AV} \times 0.09 = 133.66 \times 0.09 = 12.0294N.$$

The bending moment at point B, M_b,

$$M_B = F_{CV} \times 0.045 - F_{AV} \times 0.135 = 418 \times 0.045 - 133.66 \times 0.135 = 0.7659Nm.$$

The axial compressive load developed at the die end due to pressure applied is given by the following equation [1, 18].

$$F_c = \frac{P_r \pi d^2}{4}, \quad (28)$$

Where,

F_c = compressive load, N,

P_r = pressure, Nm^{-1}

d = diameter of the screw, m.

Assuming a maximum pressure of $15.4MNm^{-1}$

$$F_c = 15.4 \times 10^6 \frac{\pi \times 0.07^2}{4} = 59,266.1454N.$$

The equivalent twisting moment (T_e) is given by the following equation [1].

$$T_e = \sqrt{\left[K_m \times M + \frac{F_c \times d}{8}\right] + (K_t \times T)} = \frac{\pi}{16} \times \tau \times d^3, \quad (29)$$

Where,

Te = equivalent twisting moment.

Km = combine shock and fatigue factor for bending.

Kt = combine shock and fatigue factor for torsion.

M = bending moment.

T = twisting moment.

F = axial load, N.

a = the allowable shear stress of the shaft material, N/m.

d = diameter of the screw shaft, m.

The allowable shear stress of the shaft material.

The values of k_m and k_t is 3.0 for suddenly applied load with heavy shock rotating shaft.

$$\sqrt{\left[3\times 12.0294+\frac{59,266\times d}{8}\right]^2+(3\times 25.3)}=\frac{\pi}{16}\times 56\times 10^6 d^3.$$

Solving this express by hit and trial method,

d = 28.70mm say 30mm, and the equivalent bending moment (Me) is given by the following equation, [1]

$$M_e = \frac{1}{2}\left[K_m \times M + \frac{F\times d}{8}\right] + \sqrt{K_m \times M + \frac{F_c \times d^2}{8}} + (K_t \times T) = \frac{\pi}{32}\times \sigma \times d^3, \quad (30)$$

Where,

Me = equivalent bending moment.

a = maximum compressive stress of the shaft, Nm^{-2}.

The maximum compressive stress of the shaft is not to exceed, 12MPa.

$$\frac{1}{2}\left[3\times 12.0294+\frac{59,266d}{8}\right]+\sqrt{\left[3\times 12.0294+\frac{59,266d}{8}\right]^2+(3\times 25.3)^2}=\frac{\pi}{32}\times 112\times 10^6\times d^3.$$

Solving this expression by hit and trial method, 2 = 28.42mm.

The higher of the two is chosen, that is 28.70mm say 30mm.

2.2.9 | Design of the conditioner shaft

The torque required to rotate the conditioner shaft is given by the following formula [1, 18].

$$T = (T_3 - T_4)r. \quad (29)$$

$$T=(123.18-10.48)0.06=6.762\text{Nm}.$$

As shown in *Fig. (4)*, the highest bending moment is at the bearing point B.

$$M_B = F_{AV}\times L = 133.66\times 0.05 = 6.683\text{NM}.$$

The equivalent twisting moment, Te is given by the following formula,

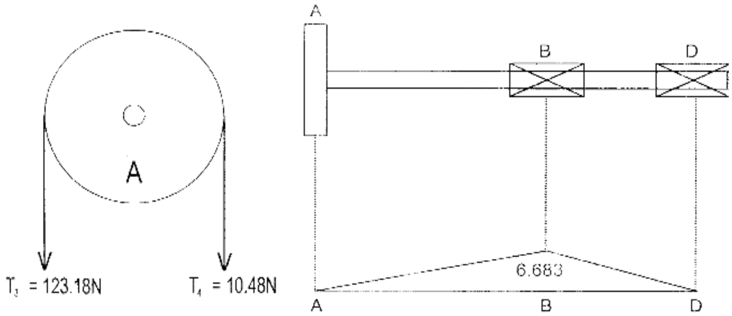

Fig. 4. Bending Moment Diagram of the Conditioner Shaft; a. pulley, b and c. bearings.

$$T_e = \sqrt{(K_m \times M)^2 + (K_t \times T)} = \frac{\pi}{16} \times \tau \times d^3. [1] \quad (30)$$

The allowable shear stress of the shaft material is 56MPa

$$\sqrt{(3\times 6.683)^2 + (k6.762T)} = \frac{\pi}{16} \times 56 \times 10^6 \times d^3.$$

d=13.74mm

The equivalent bending moment, M_e, is given as.

The maximum compressive stress of the shaft is not to exceed, 112MPa,

$$\frac{1}{2}\left[3\times 6.683 + \sqrt{(3\times 6.683)^2 + (3\times 6.762)^2}\right] = \frac{\pi}{32} \times 112 \times 10^6 \times d^3.$$

d=13mm.

But 20mm was chosen.

2.2.10 | The hopper

The hopper is designed to be mounted on the barrel at the feed section of the screw to facilitate the feeding of the wet feed material by force of gravity. The feed rate is at 65kg of material per hour. The hopper is a truncated frustum of dimension of 70mm X 70mm at the bottom, 400mm high and 400mm X 400mm on the top.

2.2.11 | Bearing selection

This is the member that facilitates free rotation of the assembled members. The load acts parallel to the axis of rotation of the bearings. Ball bearings are selected for the design based on the type and direction of loading required, speed suitability and independence of speed with the rolling friction.

The bearing is expected to bear equivalent load rating of 3 Tons, operating at a speed of 761r.p.m for an average life of 3years at 8 hours per day. Assuming, 25 days per month usage,

L_H = yrs x months x days x hrs.

Life of bearing, $L_H = 3x12x25x8 = 7{,}200hr.$

Rating life of bearing, $L_N = 60NL_H$.

N = operating speed, rpm.

$L_N = 60 \text{ X } 761 \text{ X } 7200 = 328.752 \text{ x } 10^6.$

Basic dynamic load rating of the bearing is calculated thus; [18], [21], [1].

$$C = P\left(\frac{L_N}{10^6}\right)^{1/k}, \quad (31)$$

Where,

C = basic dynamic load rating, N.

L_n = rating life of bearing, rev.

P = equivalent dynamic load rating, N.

K = service factor and K is 3 for all ball bearing.

$$C = 3{,}180\left(\frac{328.752\times10^6}{10^6}\right)^{1/3} = 21.9474KN.$$

From table, the bearing number 306 having basic dynamic load rating of 22KN was selected.

The bearing housing was machined from a mild steel rod of diameter 75mm using a lathe machine. The bearing housing is restrained to the frame of the machine to facilitate absolute rigidity of bearing housing. Standard bearings with specification number 6306 were used.

2.3 | Construction of the Machine Components.

The single screw extruding, machine components were constructed using instruments and machines at the mechanical fabrication workshop of Joseph Sarwuan Tarka University in Makurdi, Benue State.

2.3.1 | The Frame

The frame was constructed using angle iron of 50mm X 50mm. Tools such as tape, scriber, vice, hacksaw and electric arc welding machine were used to mark out and cut out the shapes before welding. A drill was used to drill holes where the electric motor will be mounted on the frame. The height is 495mm while the lower and upper width of the frame is 385mm and 230mm respectively.

2.3.2 | The Hopper

The shape of the hopper is a tapering trapezoid. The dimension of the hopper is height 320mm while bottom and top width is a perfect square of 70mm and 250mm respectively. The hopper was developed using a mild steel metal sheet of gauge 1.5mm which was marked out and cut into individual sheet then welded. A steel rule, scriber, electric arc welding machine and electric filling machine were used during the construction of the hopper.

2.3.3 | The Barrel

The barrel was developed from an existing steel pipe and cut out with hacksaw. Tape, scriber, hacksaw, electric filing machine, and electric arc welding machine were used during the construction of the barrel. The diameter of the pipe is 85mm and length is 490mm.The opening for the feeding of conditioned material is marked out and cut off with dimension is 90 X 70mm.

2.3.4 | The Die

A lathe machine was used to cut the die plate of diameter 70mm from a thick steel plate of 10mm thick and a drilling machine used to drill the die holes of 5mm. The following tools were used in the process; electric filling machine, veneer caliper, and vice and drill.

2.3.5 | The Die Holder

A lathe machine was used to cut both the outer and internal diameter of the die holder ring of 100mm and 60mm respectively from a mild steel plate of 5mm thick. The following machines and tools were used during the construction: Electric filing machine, veneer caliper and drilling machine to drill the holes where bolts and nuts can be used to secure the die.

2.3.6|The Screw Shaft

A lathe machine was used to machine the screw of 30mm, and this was fitted into the selected ball bearing of 30mm internal diameter; veneer caliper was used to take measurement.

2.3.7|The Bearing Housing

A lathe machine was used to machine the bearing housing of internal diameter 75mm from a solid mild steel rod of 100mm diameter. Tools such as power cutter, veneer caliper and a drilling machine were used in the process.

2.3.8|Assembly of the unit Parts into Single Screw Extruder

The frame is first assembled and welded and then the electric motor is mounted on it. The extrusion barrel with its shaft and pulley are mounted, and then the extruding die is attached to the end of the barrel and secured. The feeding channel is then welded and connected to the conditioning chamber with its shaft and pulley mounted. These parts are also joined by welding. The shutter is installed and the hopper is finally mounted over the conditioning chamber and welded to secure it. The belts are fitted on the pulleys and the electric motor is powered for powering and no load test. Final torque checks on bolts and nuts is done to reduce vibrations and noise while in no-load operation. *Fig. 5* shows the assembly process for the fish feed extruding machine.

Fig. 5 Assembly Process for the Fish Feed Extruding Machine ongoing in the Workshop.

2.4|Powering and No-Load test

The power cable of the electric motor is connected to a 15amp, 220V source of power and switched on. The machine was noticed to make very loud noises at first due to lack of tension in the belt drive. The no load test was allowed to run for 20 minutes while additional lubrication and adjustments were on-going. Water was poured in through the hopper to removed carbon particles in the system during construction. The extrudate will now be prepared for the Powering and Load testing of the Machine.

2.5|Fish Feed Material Preparation

The Fish feed material is prepared from maize, wheat meal and soya bean as earlier stated. The following processes are followed to obtain the extrudate.

2.5.1|Grinding

The materials were crushed separately to a particle size of less than 0.5mm using a dry engine grinder with a sieve of chosen diameter holes to determine the design size of the material before mixing.

2.5.2| Mixing

The grinded materials were mixed in the ratio of 30% of maize, 60% of soya bean and 10% of wheat flour. For the purpose of this project 10kg of total feed material was prepared. For industrial purposes a feed mixer is used to achieve more within a shorter time.

2.5.3 | Moisture Content Determination

The moisture content of the material is determined by drying a known mass of the wet material in an oven at a temperature of 100°C for 24 hours and weighing to determine weight reduction. The moisture content is determined using the equation,

$$MC_{wb} = \frac{\text{weight of wet sample} - \text{weight of dry sample} \times 100}{\text{weight of wet sample}}. \quad (32)$$

2.5.4 | Material Conditioning

It involves the addition and proper distribution of moisture in the bulk of the material in order to obtain the optimum moisture content of 20 to 24% for the extrusion process [11]. Conditioning the feed material properly either with steam or water is important and this is done before extruding. This is because moisture content below the optimum level will cause the pellets to crumble (turn back to powder) after leaving the machine and moisture content above the optimum level will results in soft pellets [22]. The quantity of water to be added was calculated using the equation,

$$\Delta G = G\frac{M_f - M_1}{100 - M_1}, \quad (23)$$

Where,

ΔG = mass of water to be added (g).

G = initial mass of formulated fish feed (g).

M_1 = initial moisture content of the formulated fish feed (% by weight).

M_f = desired moisture content of the fish feed to be extruded (% by weight).

The test was carried out at 15%, 20%, 25%, 30%, 35% and 40% moisture contents.

The quantity of water added in 10kg of the formulated fish feed (Prepared at 12% moisture content) was calculated for 15%, 20%, 25%, 30%, 35% and 40% moisture content of the product mix to be extruded as shown below,

$$\text{At } 15\% \ \Delta G = 10\frac{(15-12)}{(100-12)} = \frac{30}{88} = 0.34\text{kg}.$$
$$\text{At } 20\% \ \Delta G = 10\frac{(20-12)}{(100-12)} = \frac{80}{88} = 0.90\text{kg}.$$
$$\text{At } 25\% \ \Delta G = 10\frac{(25-12)}{(100-12)} = \frac{130}{88} = 1.48\text{kg}.$$
$$\text{At } 30\% \Delta G = 10\frac{(30-12)}{(100-12)} = \frac{180}{88} = 2.04\text{kg}.$$
$$\text{At } 35\% \ \Delta G = 10\frac{(35-12)}{(100-12)} = \frac{230}{88} = 2.61\text{kg}.$$
$$\text{At } 40\% \ \Delta G = 10\frac{(40-12)}{(100-12)} = \frac{280}{88} = 3.18\text{kg}.$$

2.6 | Performance Evaluation of the Extruder.

The effective testing and evaluation of an extruder takes into consideration such factors as moisture content, speed and output capacity [23]. In Akure an extruder was developed and tested, based on energy requirement, speed and moisture content [24]. Two machine speeds of 254rpm and 761rpm at six moisture contents levels of 15, 20, 25, 30, 35 and 40% are considered in testing the single screw extruder. The same electric motor is used but 2 difference pulley sizes are utilized to achieve the various speeds required for the testing [25]. Each moisture content level (15%, 20%, 25%, 30%, 35%, 40%) was tested in triplicate to ensure the reliability of results. A Complete Randomized Design (CRD) was employed to assess the effects of moisture content and speed, with statistical significance evaluated at the 5% level. The effects of the interaction of these parameters were also evaluated. Ten minutes was used for each test. After drying the output pellets in sunlight for 1 hour, the weight was recorded and converted to kg/hr to determine the extruder's output capacity. The picture of the final pellets obtained after drying is shown in *Fig 6*.

Fig. 6. The dried extruded fish feed using the fish feed extruding machine.

2.6.1 | Efficiency of the Extruder

Efficiency is the ratio of actual output capacity of the single screw extruder to the theoretical output capacity of the single screw extruder [18, 26].

The Theoretical Output Capacity of the Extruder

The output capacity of an extruder is related to the speed of the materials along the channel, the channel height and the channel width by the following formula [18]

$$Q_v = \frac{WHV}{3}, \tag{34}$$

Where,

W = width of the channel, m.

H = height of the channel, m.

Vz = velocity of the material along the channel, m/s.

The velocity of the material along the channel, Vz, is given by the formula [18].

$$V_z = \pi DNCos\emptyset. \tag{35}$$

N = the speed of the shaft, 761 rpm

The diameter of the screw is chosen as 50mm.

The pitch of the screw, 1mm is chosen to be equal to the diameter of the screw, therefore the angle, φ, is calculated as follows [18]:

$$\varphi = \tan^{-1}\left(\frac{1}{\pi D}\right) = \tan^{-1}\left(\frac{1}{\pi}\right) = 17.66^0.$$

$$v_z = \pi \times 0.05 \times \frac{761}{60} \cos 17.66^0 = 1.9ms^{-1}.$$

The width of the channel, W, is given by the formula [1, 21].

$$W = \pi DNSin\emptyset - \lambda, \quad (36)$$

Where ℓ = flight thickness and is chosen as 30mm.

Hence, W =*7Tx* 0.05 X sin 17.66" - 0.03 = 17.7mm

The height of the channel, H, is chosen as 10mm.

$$Q_v = \frac{0.0177 \times 0.01 \times 1.9}{3} = 1.121 \times 10^{-4} m^3 / s.$$

Assuming the density, p of the materials to be 600kgm^{-3} the mass flow rate, Q_m can be calculated from the volumetric flow rate Q_v, as follows; [1]

$$Q_m = Q_v \times \rho. \quad (37)$$

$$Q_m = 1.121 \times 10^{-4} \times 600 \times 3600 = 241.488 \frac{kg}{hr}.$$

The Actual Output Capacity

The actual output capacity is calculated from the overall average output capacity as 62.433 kg/hr as shown in *Table 4*, Actual output capacity = 62.433 $\frac{kg}{hr}$.

The theoretical output capacity = 241 Kg/hr.

Therefore the efficiency is calculated as follows; $\%E = \frac{62.433}{241} \times 100 = 26\%.$

2.7 | Design and Production Work plan of The Extruder

The total construction time was 10 days.

2.8 | The Operation of the Machine

The feed materials are introduced manually into the hopper. The feed materials flow under gravity into the conditioning chamber where they are mixed with hot water into dough mass. There is a shutter to close the conditioning chamber until the feed material and hot water are thoroughly mixed satisfactorily. Shearing forces aid in the proper mixing of the mixture into a dough or pasty material. The shutter is removed and the material flows into the feeding section of the screw inside the barrel through the feeding channel. During operation the screw conveys the feed materials, subjecting it to shear stresses, and forces it out through the die plate holes. The drive from the electric motor powers the shaft of the screw. *Fig. 7* is the assembly diagram of the machine. The assembly diagram shows some of the parts like the hopper, the conditioning chamber, the extrusion channel, the die holder, the extruder, the frame, electric motor, the belt, pulley and others.

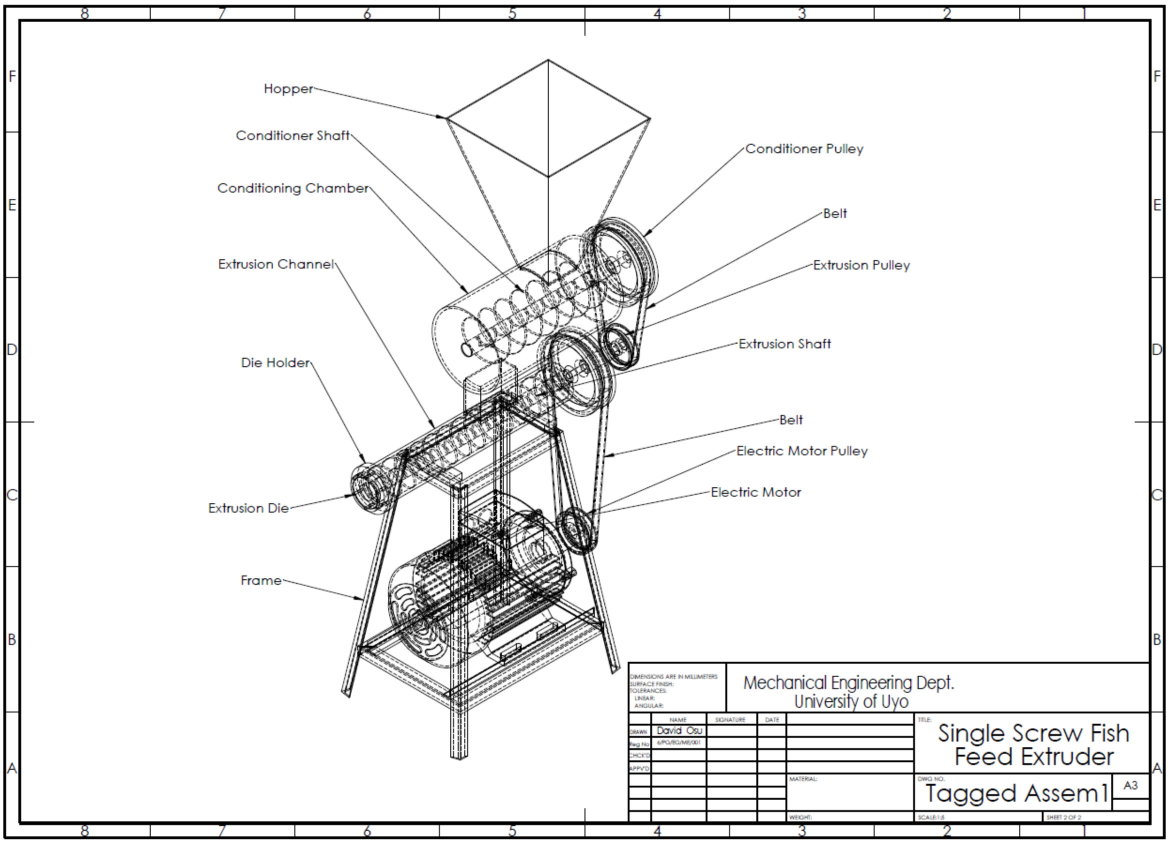

Fig. 7. The assembly diagram of the machine.

3 | Results

The results of the performance tests carried out on the single screw extruder are presented in *Table 4* while the Analysis of Variance (ANOVA) of the results presented in *Table 5*. The relationship between output and moisture content at the two speeds is presented in *Fig. 9* while the relationship between output and speed at the three moisture content levels is presented in *Fig. 10*. The final extrudate obtained from the machine was dried and crumbled into utility sizes of not more than 3-4mm. The extrudate can be stored for 1 month at room temperature with low humidity. *Fig. 6* shows the pellets before crumbling to utility sizes.

Table 4. Output of the single screw extruder in kg/hr.

Speed(rpm)	M.C	Output(Kg/hr) (Rep.1)	(Rep.2)	(Rep.3)	Total(kg/hr)	Mean(kg/hr)
254	15	63.5	58.7	61.1	183.3	61.1
	20	61.2	61.1	64.7	187	62.3
	25	63.7	61.3	65.9	190.9	63.6
	30	58.8	62.6	62.9	184.3	61.4
	35	63.6	64.8	54.7	183.1	61.0
	40	66.1	52.4	63	181.5	61.6
505	15	58.4	64.2	61	184.9	61.2
	20	62.0	62.0	65.0	188.5	63.0
	25	65.6	60.0	64.0	192.2	63.2
	30	62.0	64.0	62.0	189.7	62.7
	35	63.6	62	62.2	184.3	62.6
	40	64.0	61.1	59.6	184.7	61.6

Table 4. Continued.

Speed(rpm)	M.C	Output(Kg/hr) (Rep.1)	(Rep.2)	Total(kg/hr) (Rep.3)		Mean(kg/hr)
761	15	58.8	64.9	61.2	184.9	61.6
	20	63.6	66.0	58.9	188.5	62.8
	25	66.1	61.3	64.8	192.2	64.1
	30	62.3	65.0	62.4	189.7	63.2
	35	64.0	60.8	59.5	184.3	61.4
	40	64.0	61.1	62.0	184.7	61.6

Analysis of Variance (ANOVA)

Table 5. Analysis of Variance of the result (tests between-subjects effects).

Dependent Variable: OUTPUT

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	42.513[a]	11	3.865	.322	.973
Intercept	138681.760	1	138681.760	11565.380	.000
Moisture Content	34.623	5	6.925	.577	.717
Speed	5.601	1	5.601	.467	.501
Moisture Content * Speed	2.289	5	.458	.038	.999
Error	287.787	24	11.991		
Total	139012.060	36			
Corrected Total	330.300	35			

a. R Squared=0.129 (Adjusted R Squared=-0.271)

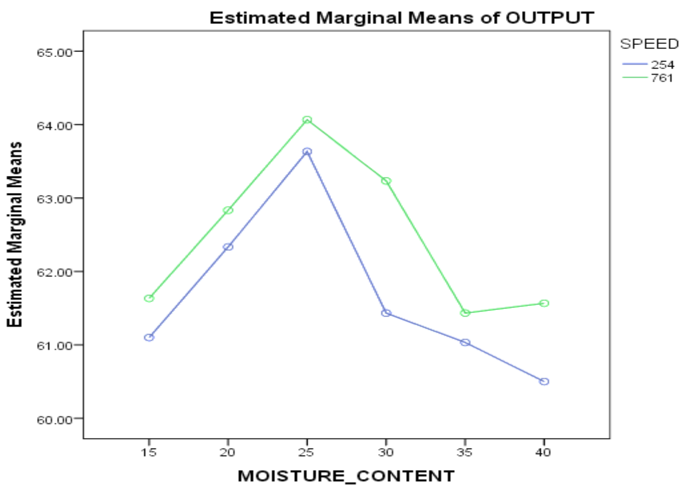

Fig. 8 Output and Moisture content plotted at two reference speeds.

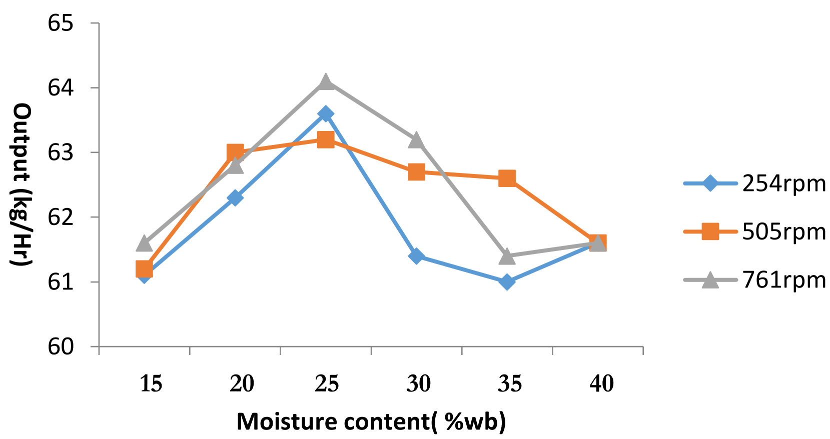

Fig. 9. Relationship between Output and Moisture content at different speeds.

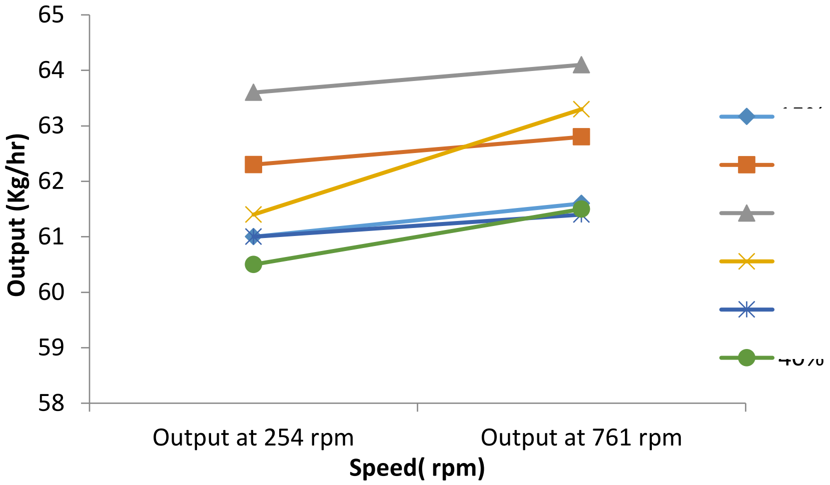

Fig. 10. Relationship between Output and Speed at different moisture content.

Moisture_Content

Table 6. Analysis of moisture content and output (Dependent variable: output).

Moisture Content	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
15	61.367	1.414	58.449	64.284
20	62.583	1.414	59.666	65.501
25	63.850	1.414	60.932	66.768
30	62.333	1.414	59.416	65.251
35	61.233	1.414	58.316	64.151
40	61.033	1.414	58.116	63.951

Table 7. Analysis of speed and output (Dependent variable: output).

Speed	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
254	61.672	.816	59.988	63.357
761	62.461	.816	60.777	64.146

Moisture Content * Speed

Table 8. Analysis of moisture content and speed combined with output (Dependent variable: output).

Moisture Content	Speed	Mean	Std. Error	95% Confidence Interval	
				Lower Bound	Upper Bound
15	254	61.100	1.999	56.974	65.226
	761	61.633	1.999	57.507	65.760
20	254	62.333	1.999	58.207	66.460
	761	62.833	1.999	58.707	66.960
25	254	63.633	1.999	59.507	67.760
	761	64.067	1.999	59.940	68.193
30	254	61.433	1.999	57.307	65.560
	761	63.233	1.999	59.107	67.360
35	254	61.033	1.999	56.907	65.160
	761	61.433	1.999	57.307	65.560
40	254	60.500	1.999	56.374	64.626
	761	61.567	1.999	57.440	65.693

4 | Discussion

From this Two-way ANOVA table in *Table 5*, it is seen that even when we screen out the effect of speed, there is no significant effect of moisture content on the output till we reach 25% because the significant value

0.717 is greater than our p-value 0.05 (95% confidence level) and the F value of 0.577 shows that the moisture content does not affect the output before 25% [1]. 25% moisture content is the best for conditioning mixtures to be extruded using the single screw extruder. *Table 4* above confirms this.

In summary, neither speed or Moisture content nor the interaction between speed and moisture content affects the output differently. The downward turn of output is in the higher moisture content levels which give lower yields. As water content of the feed mixture increases above 25%, it affects the bonding ability of the particles as well as gelatinization and agglomeration [1].

From *Table 4*, a mean maximum output capacity of 64.067 kg/hr was obtained at the speed of 761rpm and moisture content of 25%. A mean maximum output of 63.2kg/hr was obtained at 505rpm and a moisture content of 25%. The mean minimum capacity of 61.1 Kg/hr at a moisture content of 15%. The output drops to 61Kg/hr as moisture content is increased to 40%. A mean maximum output of 63.633 Kg/hr at 25% moisture content was recorded for the machine when it was operated at a speed 254 rpm, at the same speed the mean minimum output capacity was 61.1 kg/hr at the moisture content of 15%. This gave an average output capacity of 62.433 kg/hr. The output capacity of the extruder is fair because, if the operator is to work for 8hours in a day, it means he/she will spend two days to produced one ton of fish feed. The result shows a linear relationship between output and both speed and moisture content as shown in *Fig. 8* and *Fig. 7*. As the speed increases the output increases. Also the output increased with an increase in moisture content but drops sharply when the material becomes too wet. The extrudate quality drops within the considered screw speeds and moisture contents of the fish feed material, these two factors are not significantly different on the output capacity as shown above using the ANOVA [1].

The required F-values for statistical significance for degrees of freedom 1 (numerator) and 12 (denominator) for speed are found in F-distribution Table at 5% (0.05) and 1% (0.01) significance as 4.74 and 9.33 respectively. Also, the F-values for both moisture content and interaction (speed x M.C) are 3.89 and 6.93 for the 5% and 1% significant levels respectively. Each is based on 2 (numerator) and 12 (denominator) degrees of freedom from the F-distribution table. Since the observed values of F (M.C), F(S) and F (interaction S X M.C) are less than the required values for significance at the 5% and 1% levels, we can say that, there is no significant difference [1].

The presence of water promotes gelatinization of starch components and stretching of expandable components. When the moisture content level of the feed material was low the agglomeration of the material was reduced and unstable pellets were formed. However, with optimum water content level, water stable pellets were formed which sank slowly into the pond and remain intact without dissolving for two or more hours to allow the fish eat. Pellet yield and formation was highest for all three speeds used, this may be as a result of the high rate of agglomeration of particles during compression. When the dough is too viscous, it requires greater power to compress and where that power is not available, belt slip occurs. The water stability of pellets formed depends on the level of gelatinization of starch. The higher the gelatinization of starch the more stable the pellets formed will be [1, 21].

The pellets obtained have a long shelf life so they can be stored for long periods of time, facilitating their handling by occupying small volumes of space. In fact, in this study, the water activity of the different samples after extrusion did not show significant differences and was on average ~0.67, providing an appropriate shelf life. Accordingly, evaluation of the resistance of pellets to breakage over time is important. In this work, this was measured as hardness, which was expressed as the maximum breaking force (N) obtained from the force–deformation curve [1].

The variation in hardness of the pellets over time, 1, 7, and 30 days after extrusion for all the studied conditions. Overall, the mean values of hardness of pellets after 1-day extrusion had the lowest hardness compared to those stored for 7 or 30 days after extrusion. After 1-day storage, no significant differences were observed in hardness between samples prepared using different feed moisture contents processed at an extrusion temperature of 80 °C. Regarding samples processed at higher extrusion temperatures, a decrease in hardness was observed when the feed moisture content was 40%, which was significantly lower ($p<0.05$) than those obtained in samples prepared with a 20% or 25% feed moisture content. Although the hardness mean values of samples with 25% feed moisture content were lower than those obtained in samples with a 30% feed moisture content, a significant difference between these two moisture contents was observed only at 80°C, after 1-day storage. Furthermore, no significant differences (p>0.05) were observed in hardness when comparing samples processed at extrusion temperatures above 80°C after 1 day. Thus, when processing mixes at temperatures higher than 80°C, the resistance to breakage after 1-day extrusion depended mainly on the feed moisture content [1]. However, in this work no much attention was given to extrusion temperature variation, since it was not the core objective of the research work.

The performance analysis results of the designed and produced single screw fish feed extruder show that, the best moisture content for high output or performance of the machine is 25% moisture. The machine output was also found to increase with the operational speed of the single screw fish extruder machine [1].

4 | Conclusion

The research work "the Design and Production of a Single Screw Fish Feed Extruder" has been undertaken and critical analysis painstakingly taken and the following conclusions have been drawn from this work:

I. The total power required to operate the machine is 1014 W. The extruding section requires 1475 W while the conditioning section requires 539 W. The theoretical output capacity of the machine is 241,488 kg/hr and the actual output capacity is 62.433 kg/hr which gives an efficiency of 26%. The low efficiency did not stop the machine from being useful. It is still better than some imported machines that it was compared with.

II. The mean output capacity of the extruder is 63.266 kg/hr which is equivalent to 500kg/day for 8hrs. Belt slip affects the machine at 15% moisture content of the mixed dough. Also, the performance test was affected by the slow feeding of the mixed dough from the conditioner to the extruder barrel. Subsequent work will require improvement on this.

III. The produced feed has very low floating capacity. It is produced with high bulk density materials so floating rate is low. Compared to industrially extruded feeds, the buoyancy ratio is 1:5 which means when placed in water, the produced feed will sink five times faster than the floating feed. The main difference is the injection of high pressure while extruding and the addition of lysine and floating catalyst. This problem calls for further work.

IV. The conditioner which is a composite design has reduced labour rates such that one person can safely operate the machine.

V. The output of the machine at all moisture contents of the extruded material increases as the operational speed increases. The optimum moisture content for all operational speeds of the produced machine was found to be 25% moisture content in the extruded material.

Author Contribution

This is to publicly declare that the four authors of this publication (names listed above) were involved in the conceptualization of this research topic. Mr. David Osu the first author was saddled with the responsibility of data curation and assisted by the other three authors with formal analysis. No outside funding was received for this project. The major financial contributor to this project was the first author. The four authors were jointly involved in the research project; playing various roles as supervisors, investigators and resource providers to enable the project go through the various stages of conceptualization, data curation, formal analysis, funding, investigation, methodology, project administration, resource provision, software provision, supervision, validation, writing original draft and final report, and final paper for publication. This was adopted by all the four members of the research team.

Funding

The members of this research team wish to publicly declare that this project was self-funded by team members.

Data Availability

The data used for this work is available in the University of Uyo, Uyo-Nigeria library, in the M.Eng.degree report submitted to the University. It is also available in journal publication made from the work. The references included in our journal publication are duly referenced. Every second party data used in the publication is duly referenced and credit given to source.

Conflict of Interests

The authors wish to publicly declare that there is no conflict of interest in this publication all the four authors have agreed to submit their work for journal publication.

Financial Interests

We wish to publicly declare that this is a self-sponsored research work contributed to by the research team members.

Non-Financial Interests

This work is free of all encumbrances, whether financial or non-financial interests

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