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(Research Article)

Design and fabrication of a modified fish feed pelletizing machine

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Abstract

Fish feed pelletizing machine was designed and fabricated with the aim to improve on existing local pelletizers; encourage local technology and local fish farmers who may be faced with no power supply. It mainly consists of the hopper, pelletizing chamber, frame, bolts and nuts, screw conveyor, cutting mechanism, pelletizing die plate and power transmission unit with dual operation mode. Performance evaluations of the improved pelletizing machine as well as existing machine were carried out and the results showed that both machines were able to produce pellets with 8 mm average diameter and 10 mm average length. The overall mean values of pelleting capacity, specific energy consumption and efficiency of improved and the existing pelletizing machines were 1.20 kg/min, 0.010 kWh/kg and 97.09%; 0.89 kg/min, 0.014 kWh/kg and 75%, respectively. These imply that the improved pelletizing machine could produce a ton of feeds for a 14-hour daily operation and consume approximately 10 kWh of energy as compared to the existing pelletizing machine that would consume 14 kWh. The capacity of the improved pelletizing machine is quite better than the existing pelletizing machine. The improved pelletizing machine efficiency obtained is quite impressive as only about 2.91% of the feed mix might be lost as compared to 25% lost by the existing pelletizing machine. Therefore, the improved fish feed pelletizing machine is recommended for use by small-scale fish feed mill as the existing pelletizers have comparable higher losses couple with lower efficiency.

Keywords: Design; Fabrication; Fish; Cylindrical Pellets; Pelletizing

1. Introduction

Traditional method of processing fish feed is extremely strenuous; causes great discomfort to the operators and cannot predict grinding time. These result in the production of low quality feeds. The modern method is by the use of pelletizing machine. Pelletizing machine is a machine that can be used to create and extrude desired shapes of pellets from a mixture of components. In livestock, the components should have the required nutrient for their growth and development in order to meet the market requirements [1]. Also, the feed type and shape may depend on the type and age of the livestock. However, it has been observed that most livestock prefer solid and soft nutritious meals. Generally, soft capsules can easily be consumed by fish and poultry animal. Highly compressed/pelletized feed improves the nutritional value and growth of livestock, facilitates storage and transportation, saves space and extends shelf life. It also decreases feed wastage, reduces selective feeding, promotes better handling characteristics, destroys undesirable micro-organisms and increases bulk density. Other qualities added to livestock feed include complete pasteurization, improve pellet quality, increase feed utilization/ starch gelatinization and production of by-pass fat and by-pass protein [2, 3, 4, 5]. Thus, pelleting machine is essential for the production of livestock feed. The pelleting machine can be classified based on (i) the type of die such as disc die and ring die pelleters (ii) the product formed such as (a) balls and agglomerate pellets using balling disc machine (b) floating feed pellets using floating feed pelleting machine, etc. The quality and quantity of pellets produced from the machine are dependent on: (i) die thickness and holes diameter; (ii)

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speed of rotation for each die thickness/hole diameter combination; (iii) feed input rate; and (iv) amount of moisture in a given volume of feed. Other factors known to influence pellet quality include: (a) bulk density of the soft feed, (b) its texture, (c) proximate composition (d) prevailing ambient conditions of temperature and relative [6,7,8].

Pelletizing machines could be operated manually or electrically. In manually operated pelleting machine, the screw conveyor is moved or rotated using handle while in electrically operated machine, an electric motor (prime mover) is employed. Different pelletizing machine with different capacities and specific power consumption have been developed by many researchers in an effort to improve the efficiency of machines [9]. In spite of all these efforts, there are still limitations in terms of procurement and servicing of these machines. Others include (i) high cost of pelletizers (ii) poor design in terms of number of holes on the die and the clearance between the screw conveyor/auger and the cylinder wall (iii) high initial and maintenance costs (iv) high labour cost in securing skilled maintenance engineering staff and (v) dependency on expensive infrastructural facilities. Hence, there is need to develop a simple but modified fish pelletizing machine that could be electrically and manually operated; affordable by local farmers who may not have steady power supply, reduce drudgery and unhealthy practices in traditional method of fish feed production; and aid small scale fish farmers to produce their fish feeds and maximize profit.

2. Material and methods

2.1. Materials for Construction

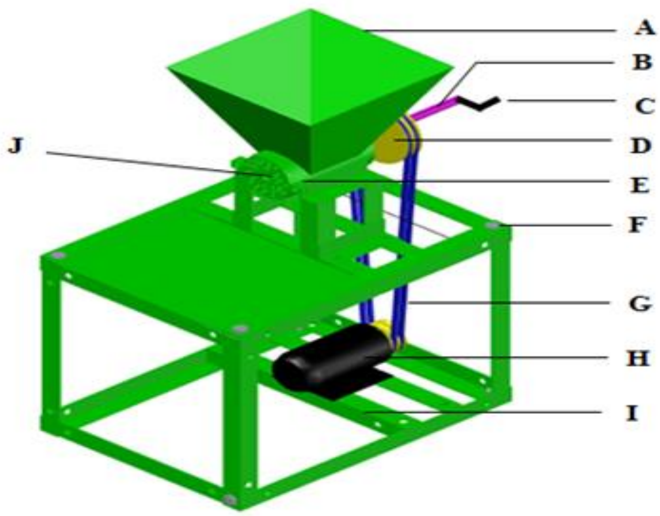
The materials used in this work were hacksaw, measuring tape, hammer, spanner, filing machine, bearing, v-belt, pulley, metals, electrodes, drilling machine, and nuts and bolts.

2.2. Materials Selection and Design Consideration

The selection of materials was based on: (i) availability of materials in the markets; (ii) strength; (iii) cost and (iv)possession of simple mode of the operation. The following were considered in the design: (i) safe operation; (ii) power requirement; (iii) ease of operation, maintenance and repair; (iv) economic; and (v) size and durability.

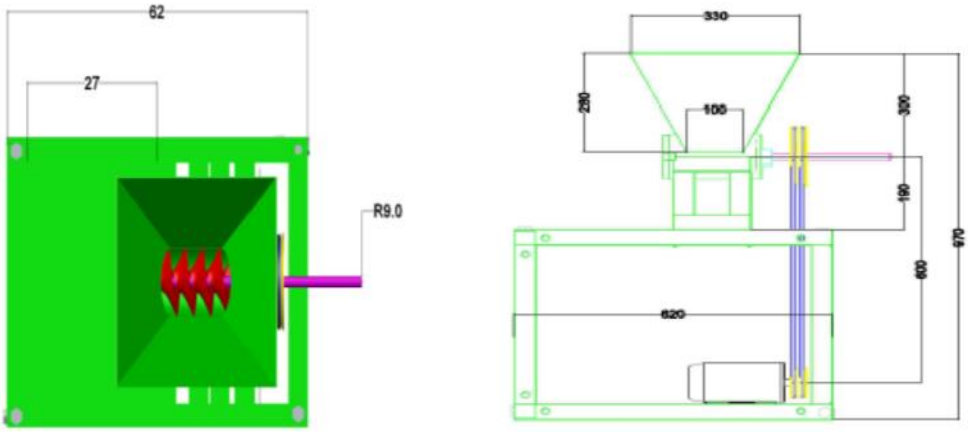
2.3. Components of the Pelletizing Machine

The major components of the fish feed pelleting machine designed are as follows: the hopper, pelletizing chamber, frame, bolts and nuts, shaft and screw conveyor, bearing, die plate and power transmission system. Some views of the machine are presented in Figure 1 and 2.



Key	Parts
A	Feed hopper
B	Shaft
C	Handle
D	Driven pulley
E	Pelletizing chamber
F	Bolt and nut
G	V-Belt
H	Electric motor
I	Frame
J	Die plate

Figure 1 Isometric view of the pelletizing machine and its parts



(b) Plan view **(c) Front view**

Figure 2 Plan and Front view of the pelletizing machine and its parts

2.4. Design Calculation

Machine components design analysis and calculations were carried out using Customized Machine M236 Design and Beam Version 2.95 Software Packages in order to determine and choose materials of appropriate strength, rigidity and sizes.

2.4.1. Hopper

The surface area (S_h) and volume of hopper (V_h) are given as [10]:

$$S_h = \left[2\,(a+b) \times \sqrt{\left(\frac{1}{2}\,[a+b]\right)^2 + h^2}\right] \qquad (1)$$

$$V_h = \frac{h}{3}\left[a^2 + (a \times b) + b^2\right] \qquad (2)$$

Where, a = length of the upper section, b = square base and h = height.

2.4.2. Pelletizing Chamber (Barrel)

The surface area (S_b) and volume (V_b) are given as [11]:

$$S_h = \pi\, D_o \left[\frac{D_o}{2} + L\right] \qquad (3)$$

$$V_b = \pi\, \frac{{D_i}^2}{4}\, L \qquad (4)$$

Where, D_o = outer diameter, D_i = inner diameter and L = length.

2.4.3. Total Power Required for Pelletizing Process (P_t)

The total power required for the pelletizing process is given as [12, 13]:

$$P_t = \frac{(W_c + F_{at} + W_p)\, V_p}{1000} \qquad (5)$$

Where, W_c = weight of shaft, screw conveyor and cutting mechanism, F_{at} = axial thrust by the screw conveyor, W_p = weight of pulley and v_p = peripheral velocity of the rotating mechanisms.

2.4.4. The Torque (T_m) at Motor Pulley

The torque at motor pulley is given as [14]:

$$T_m = \frac{[P_s \times 60]}{[2\pi \times N_1]} \tag{6}$$

Where, P_s = power of the electric motor and N_1 = speed of the electric motor.

2.4.5. The Power Transmission System

The belt velocity (V_1), velocity ratio (VR), nominal length of the belt (L), minimum (C_{min}) and maximum (C_{max}) centre distances of the pulleys were obtained as [14] :

$$V_1 = \frac{[\pi \times D_1 \times N_1]}{60} \tag{7}$$

$$\text{Velocity ratio} = \frac{N_2}{N_1} = \frac{D_1}{D_2} \tag{8}$$

Where, N_2 = shaft speed, D_2 = shaft pulley diameter and D_1 = motor pulley diameter.

$$C_{min} = [0.5\,(D_2 + D_1)] + D_1] \tag{9}$$

$$C_{max} = 2\,(D_2+D_1) \tag{10}$$

$$L = 2C + \left(\frac{[\pi(D_2 + D_1)]}{2}\right) + \left(\frac{[D_2 - D_1]^2}{4C}\right) \tag{11}$$

Where, C = maximum center distance

2.4.6. Angle of Inclination (α), Contact Angle of the Belt (Θ) and Coefficient of Friction (μ)

The angle of inclination (α), contact angle of the belt (Θ) and coefficient of friction (μ) are expressed as [14]:

$$\alpha^o = \arc\sin\left[\frac{D_2 - D_1}{2C}\right] \tag{12}$$

$$\Theta = [180° - (2 \times \alpha°)]\frac{\pi}{180} \tag{13}$$

$$\mu = \left(0.54 - \left[\frac{42.5}{152.6 + V_1}\right]\right) \tag{14}$$

Belt Tensions (T_1 and T_2) and Power Transmitted by the Belt (P_b)

The belt tensions (T_1 and T_2) and power transmitted by the belt (P_b) were calculated as [14]:

$$T_2 = \left(\frac{T_m}{0.5\,D_1}\right) \times \frac{1}{(e^{[\mu.\Theta\,\text{cosec}\,\beta°]}) - 1} \tag{15}$$

$$T_1 = \left(\frac{T_m}{0.5\,D_1}\right) - T_2 \tag{16}$$

$$P_b = (T_1 - T_2) \times V_1 \tag{17}$$

Where, T_m = torque at motor pulley, T_2 = tension on the slack side of the belt, T_1 = tension on the tight side of the belt and P_b = power transmitted by the belt.

2.4.7. Shaft Design

The shaft was designed based on what it would be subjected to, i.e., the combined twisting and bending moments. Distances from the point where moment was taken, vertical and horizontal loads were manipulated into Beam Version Software 2.95 to obtain vertical and horizontal loading diagrams.

The resultant bending moment (M_R), equivalent twisting moment (T_e) and shaft diameter (d_s) were calculated as [14]:

$$M_R = \sqrt{(MBM_V)^2 + (MBM_H)^2} \quad (18)$$

where, MBM_V = vertical bending moment and MBM_H = horizontal bending moment.

$$T_e = \sqrt{(M_R)^2 + (T_m)^2} \quad (19)$$

$$d_s = \left[\frac{16T_e}{\tau\pi}\right]^{1/3} \quad (20)$$

2.4.8. Key and Keyway Design

Key width (W_k), key length (L_k) and key thickness (t_k) were obtained as [14]:

$$W_k = \frac{d_s}{4} \quad (21)$$

$$L_k = \frac{2\times T\times 1000}{W_k\ \tau\, d_s} \quad (22)$$

$$t_k = \frac{4\times T\times 1000}{L_k\, d_s\, \sigma_c} \quad (23)$$

Where, σ_c = key crushing stress and T= torque transmitted by the shaft.

2.4.9. Bearing Selection for Shaft

The equivalent dynamic load (P), on the system, the nominal rating life of the bearing (L), the full bearing life in working hours (L_h) and reliability (R) were calculated as [15, 14]:

$$P = [X .V. F_r] + [Y. F_a] \quad (24)$$

$$L = \left[\frac{C}{P}\right]^k \times 10^6 \text{ revolutions} \quad (25)$$

$$L_{(h)} = \frac{5\times L}{60\ N_2} \quad [\text{hours}] \quad (26)$$

[Note: If L_h > 4000 hours, the bearing is selected]

$$\text{Log}_e\left[\frac{1}{R}\right] = \left[\frac{L}{a^*}\right]^{b^*} \quad (27)$$

Where, F_r = radial load, F_a = axial load, C= basic dynamic load rating, k = life exponent for ball bearing, N_2 = shaft speed, Y= axial load factor, X= radial load factor, V= bearing type, a^* and b^* are constants.

2.4.10. Design of the Frames and Bolts

The frame and bolts designs were obtained based on the consideration to the shear stress on the machine [16, 17, 18] as:

$$d_b = \sqrt{\frac{4\times W_{t.max}}{\pi\, S_e}} \quad (28)$$

Where, d_b = bolt diameter, $W_{t.max}$ = assumed maximum total weight of the machine/loads and S_e = allowable endurance stress of mild steel.

2.4.11. Die Design

The effective die area (A_c), die output area (A_o) and axial thrust (F_{at}) required to extrude the feed mix were given as [14]:

$$A_c = \frac{\pi}{4}\left(d_d^2 - d_s^2\right) \quad (29)$$

$$A_o = \frac{\pi}{4} \times d_h^2 \times N_h \quad (30)$$

$$F_{at} = P_e \times (A_c - A_o) \quad (31)$$

Where, N_h = number of die holes, d_h = each die diameter, d_d = pellet diameter and P_e = extruding pressure.

2.5. Cost of Materials for Machine Fabrication

The bill of engineering materials is presented in Table1.

Table 1 Bill of Engineering Materials

S/N	Description	Total Price (₦)
1	Angle bars	15,000.00
2	Bolts and nuts	1,000.00
3	Metal plate	7,000.00
4	Ball bearing	1,500.00
5	Shaft with screw conveyor	1,500.00
6	Electric motor	35,000.00
7	Belt	800.00
8	Pulley	700.00
9	Labour/Painting	18,000.00
	Total	80,500.00

2.6. Mode of Operation of Pelletizing Machine

The dough (feed mix) is introduced into the hopper. The gate allows the feed mix to get down by gravity into a 0.005 m thick cylindrical steel pelletizing chamber (barrel) for caking of the feed. The feed pelletizing machine is powered by an electric motor which rotates the shaft carrying the screw conveyor by the aid of pulley and belt system. The rotation of the shaft is such that the screw conveyor moves the dough towards the die where a three- metal blade (cutting mechanism) fitted on the shaft moves at the speed of the shaft and cuts the feed as it passes through the die where the pellets are formed.

2.7. Performance Evaluation of the Improved Pelletizing Machine

2 kg feed mix was weighed and introduced into the pelletizing machine. The time for the feed mix to completely form the products (pellets) when it was operated, was noted. The length and mass of pellets produced were also measured using vernier calipers and electronic weighing balance. The test was replicated and the average values calculated. The procedure was repeated for 2.5, 3.0, 3.5, 4.0, 4.5 and 5.0 kg feed mixes. The following parameters: pelleting capacity, specific energy consumption and machine efficiency were used to assess the performance of the pelletizing machine as given in equations (32) to (34).

$$PC = \frac{\text{Mass of pellets produced (Kg)}}{\text{Time taken (min)}} \quad (32)$$

$$SEC = \frac{\text{Power of electric motor (kW)} \times \text{time taken (h)}}{\text{Mass of pellets produced (kg)}} \quad (33)$$

$$\eta = \frac{\text{Mass of pellets produced (kg)}}{\text{Mass of feed mix (kg)}} \times 100 \quad (34)$$

Where, PC = pelleting capacity (kg/min), SEC =specific energy consumption (kWh/kg) and η= machine efficiency (%).

The procedure was repeated using the existing pelletizing machine.

3. Results and discussion

The pelletizing machine specifications based on design calculation are presented as follows:

3.1. Hopper

- Length of upper section (a) = 0.33 m
- Square base (b) = 0.10 m
- Height (h) = 0.28 m
- Surface area (S_h) = 0.26 m^2
- Volume (V_h) = 0.014 m^3

3.2. Pelletizing chamber

- Outer diameter (D_o) = 0.110 m
- Inner diameter (D_i) = 0.100 m
- Length (L) = 0.180 m
- Surface area (S_b) = 0.081 m^2
- Volume (V_b) = 0.0014 m^3

3.3. Total power required for pelleting process

- Axial thrust by the screw conveyor (F_{at}) = 65 N
- Weight of shaft, screw conveyor and cutting mechanism (W_c) = 25 N
- Peripheral velocity of the rotating mechanisms (V_p) = 6 m/s
- Dimension of each blade from the centre of the shaft = 4 mm by 5 mm by 50 mm
- The total power required for pelletizing process (P_t) = 0.624 kW
- Electric motor: Viking single-phase, 1.0 Hp (0.745 kW), 1400 rpm

3.4. Torque (T_m) at motor pulley

- Torque (T_m) = 5.08 Nm

3.5. Power transmission system

- Belt type = "*A*"
- Motor pulley diameter (D_1) = 0.065 m
- Shaft pulley diameter (D_2) = 0.140 m
- Belt velocity (V_1) = 4.77 m/s
- Shaft speed (N_2) = 650 rpm
- Velocity ratio (VR) = 0.03
- Minimum centre distance (C_{min}) = 0.168 m
- Maximum centre distance (C_{max}) = 0.410 m
- The nominal length of the belt (L) = 1.143 m
- Angle of contact or wrap (Θ) = 2.96 rad
- Angle of inclination (α) **=** 5.25 ^{0}
- Coefficient of friction (μ) = 0.44 (for leather belt on cast iron pulley)

3.6. Belt tension and power transmitted by the belt

- Tension on the tight side of the belt (T_1) = 154.6 N
- Tension on the slack side of the belt (T_2) = 1.79 N
- Angle of groove (β) for "A"-type V-belt = 17^0
- The power transmitted by the belt (P_b) = 0.728 kW

3.7. Shaft design

The shaft loading diagram obtained is presented in Figures 3 – 5 with other parameters as:

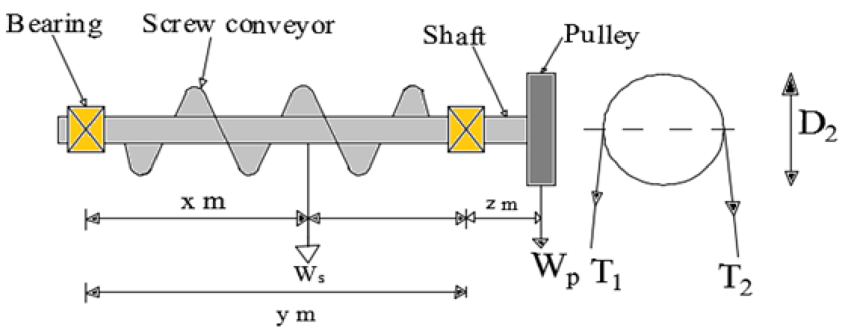


Figure 3 2-D view of shaft with double groove pulley, screw conveyor and supported by 2 bearings

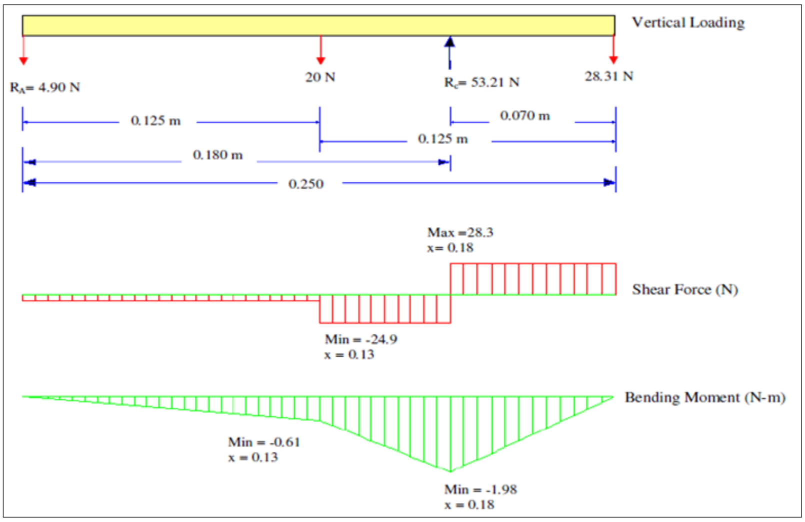


Figure 4 Vertical loading on the shaft

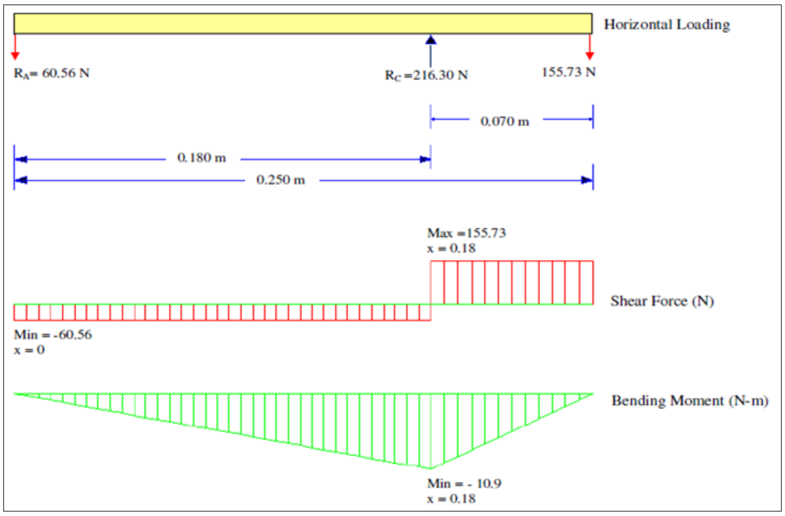


Figure 5 Horizontal loading on the shaft

3.8. Note

- For vertical loading, the reaction at R_A= 53.21 N and R_c = - 4.90 N
- For horizontal loading, the reaction at R_A = 216.30 N and R_c = - 60.56 N
- Maximum vertical bending moment (MBM_V) = -1.98 N-m
- Maximum horizontal bending moment MBM_H = -10.90 N-m
- (v) Resultant bending moment (M_R) = 11.08 N-m
- (vi) Equivalent twisting moment (T_e) = 12.19 N-m

Shaft diameter (d_s) = 11.1 mm [12 mm selected based on the strength, rigidity, stiffness and allowable shear stress (τ) of 42 N/mm2]

3.9. Key and keyway Design

- Key width (W_k) = 3.0 mm
- Key length (L_k) = 7.3 mm
- (iii)Key thickness (t_k) = 2.8 mm

Note that the values were obtained based on key crushing stress (σ_c) = 84 N/mm^2) and torque transmitted by the shaft (T) = 5.08 N-m.

3.10. Bearing selection for shaft

- The equivalent dynamic load (P) = 0.297 kN (using radial load factor, X = 0.56, bearing type (V = 1, for all types of bearing when the inner race is rotating), radial load, F_r = 0.04831 kN, axial load factor, Y = 1.73 and axial load, F_a= 0.15573 kN
- The nominal rating life of the bearing (L) = 6.03 × 10^9 revs (using basic dynamic load rating, C = 5.4 kN and life exponent, k = 3, for ball bearings)
- The full bearing life in working hours (L_h) = 772549 hours [Hence,bearing as L_h > 4000 hours, and so double row deep groove ball bearing with the code S6204 W303B was selected to support the loads on the shaft].
- The reliability (R) of 100% (Using the constants [a^* = 6.84 and b^*=1.17])

3.11. Design of frames and bolts

- Maximum total weight of the machine/loads ($W_{t.max}$) = 0.4 kN
- Bolt diameter (d_b) = 2.17 mm [Using allowable endurance stress of mild steel (S_e) as 107.696 × 10^3 kN/m^2].

3.12. Die design

- Pellet diameter (d_d) = 130 mm
- Pellet thickness (t) = 5 mm
- Number of die holes (N_h) = 25
- Die hole diameter (d_h) = 8 mm
- Effective die area (A_c)= 52647.35 mm^2
- Die output area (A_o)=5027.20 mm^2
- Axial thrust (F_{at}) = 65 N
- Extruding pressure (P_e) = 1.36 × 10^{-3} N/mm^2

The fabricated pelletizing machine performance evaluation is presented in Table 2.

Table 2 Mean mass of feed mix, pellets produced, pelleting time and capacity, specific energy consumption and efficiency of improved machine

S/N	**Mass of Feed Mix [M_f] (kg)**	**Mass of Pellets Produced [M_p] (kg)**	**Length of Pellets Produced [L] (mm)**	**Pelleting Time [t] (min)**	**Pelleting Capacity [PC] (kg/min)**	**SEC**	**Machine Efficiency [η] (%)**
1	2.00	1.93	10.2	1.5	1.29	0.0097	96.5
2	2.50	2.43	10.3	2.0	1.22	0.0102	97.2
3	3.00	2.96	9.8	2.4	1.23	0.0101	98.7
4	3.50	3.34	10.2	3.0	1.11	0.0112	95.4
5	4.00	3.83	9.9	3.3	1.16	0.0107	95.8
6	4.50	4.45	10.1	3.7	1.20	0.0103	98.9
7	5.00	4.86	9.9	4.0	1.22	0.0102	97.2
		Overall Mean	10.03		1.20	0.0103	97.09

The existing machine performance evaluation was also carried and is presented in Table 3.

Table 3 Mean mass of feed mix, pellets produced, pelleting time and capacity, specific energy consumption and efficiency of the existing machine

S/N	Mass of Feed Mix [M_f] (kg)	Mass of Pellets Produced [M_p] (kg)	Length of Pellets Produced [L] (mm)	Pelleting Time [t] (min)	Pelleting Capacity [PC] (kg/min)	SEC	Machine Efficiency [η] (%)
1	0.50	0.38	8.6	0.36	1.04	0.012	75
2	1.00	0.84	7.9	0.85	0.99	0.013	84
3	2.50	1.62	9.0	2.50	0.65	0.019	65
4	4.00	3.25	11.2	3.50	0.93	0.013	81
5	4.67	3.31	8.3	4.00	0.83	0.015	71
		Overall Mean	9.0	-	0.89	0.014	75

A comparative analysis of the existing and improved pelleting machine was based on the fact that the same feed mix, diameter of die hole and power supplied. Both pelletizing machines were able to produce pellets of 8 mm average diameter. The improved pelletizing machine produced pellets of 10 mm average length as compared to 9 mm length produced by the existing machine. The overall mean values of pelleting capacity, specific energy consumption and efficiency of improved and the existing pelletizing machines were 1.20 kg/min, 0.010 kWh/kg and 97.09%; 0.89 kg/min, 0.014 kWh/kg and 75%, respectively. These imply that the improved pelletizing machine could produce a ton of feeds for a 14-hour daily operation and consume approximately 10 kWh of energy as compared to the existing pelletizing machine that would consume 14 kWh. The capacity of the improved pelletizing machine is quite better than the existing pelletizing machine. The improved pelletizing machine efficiency obtained is quite impressive as only about 2.91% of the feed mix might be lost as compared to 25% lost by the existing pelletizing machine. Therefore, the improved fish feed pelletizing machine is recommended for use by small-scale fish feed mill.

4. Conclusion

The improved fish feed pelletizing machine developed was able to convert formulated fish feed dough into pellets with efficiency of 97.09% as compared to the existing pelletizing machine of 75%. With the improved fish feed pelletizing machine capacity of 1.20 kg/min, the machine can produce a ton of feeds for a 14-hour daily operation making it more efficient for small-scale fish feed mill.

Compliance with ethical standards

Disclosure of conflict of interest

There is no conflict of interest for this manuscript.

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