Journal of Physics: Conference Series

PAPER • OPEN ACCESS

Fabrication and Evaluation of Screw-like Fish Pelletizer

Fabrication and Evaluation of Screw-like Fish Pelletizer

P.P. Ikubanni[1*], O. O. Agboola[1], A.A. Adeleke[2], B.T. Ogunsemi[1] and R. A. Ibikunle[1]

[1]Department of Mechanical Engineering, Landmark University, Omu-Aran, Kwara State, Nigeria.
[2]Department of Mechanical Engineering, University of Ilorin, Ilorin, Kwara State, Nigeria.
Corresponding Author; ikubanni.peter@lmu.edu.ng

Abstract-
Good and balanced meals are required for fish to stay healthy and the production of these meals requires some machines like pelletizer. This study therefore contributes to the improvement of existing models of this machine by designing, fabricating and evaluating the performance of a new pelletizer. After fabrication, 5 kg fish feed ingredients weight was processed for 2.5 minutes in the machine in quadruplicate. The average discharge efficiency, percentage loss due to residue ingredients and production rate for the machine are 92.25 %, 7.75 % and 110.7 kg/h, respectively. The results showed that an increase in drying days led to a corresponding increase in percentage moisture content removal with a similar reduction in the weight of the pelletized fish meal. This machine will be of great assistant to medium and small-scale aquaculture farmers, thereby reducing the need for foreign sources of fish feed in fish farming sector.

Key words: Development, fish meal, modeling, pelletize, aquaculture

1. Introduction

Just as human beings need balanced diet for healthy living and growth, fishes also need balanced diet in their meals for suitable growth. One of the appropriate ways for protein rich food availability to be increased is through fish farming and this depends on the feed given to the fish [1]. Pellets are considered highly desirable for feeding of animals due to the bonding of all the ingredients [2]. A degree of homogenization/gelatinization is achieved when moisture, heat and pressure are combined and energy contents increase when fish feeds are pelletized [3], [4]. In fish farming, pelletizing machine is considered a good development because healthy nutritious animal feeds are produced and also pelletizing fish feeds help to reduce wastage [5]. In Nigeria, numerous research works have been done on homogenization of fish feed through the design and fabrication of fish feed pelletizing machines. Burmanu et al. [5] developed a manually operated fish feed pelletizing machine. The efficiency achieved when the machine was evaluated was 88.3%. The effect of moisture content and speed of machine operation were the indices used during the performance evaluation of a fish feed pelletizing machine designed by Ojomo et al. [1]. It was reported that an increase in moisture content and operating speed caused an increase in the efficiency of the machine. Furthermore, a combined fish feed pelletizing machine with dryer incorporation was designed and fabricated by Ojediran et al. [4]. The machine was tested and its performance was evaluated. It was reported that at 18 and 10% moisture contents in the feed materials, the efficiencies of the machine were 72.35 ± 4.6 and 18.45 ± 1.70%, respectively. More so, the study gave useful information in designing pelletizer that will produce pellets optimally when the appropriate moisture conditions for feed materials are put into consideration. Several other researchers [2], [3], [6 – 11] have made further attempt to develop fish pelletizers. However, it is needful to develop another conceptualized design for the production of a fish feed pelletizer that would improve on the previous designed and fabricated models. Therefore, the present study highlighted the design, fabrication and performance evaluation of a new fish meal pelletizer.

2. Methodology

2.1 Description of machine and its working principle

The fish meal pelletizer consists of the feed-in unit (hopper); the pelletizing chamber, which consists of a shaft with a screw-like attachment which conveys the meal to the extrusion unit of the machine. The shaft has worm-like attachments which rotate as a result of the action of the rotation of a driven pulley that is connected to a driving pulley of an electric motor by means of a V-belt. As soon as the machine is switched on, the driving pulley rotates the driven pulley which set the machine ready to receive the already mixed fish feed. The mixed fish feed is loaded into the hopper to its full capacity. The screw-like attachment on the shaft conveys the feed from the point of entrance of the hopper to the extrusion plate. The cutter at the end of the worm shaft cut the feed into sizes as it extrudes. This process continues until there is no more feed to be fed into the machine and after this, the machine is switched off. The produced screw-like fish meals are collected for drying for moisture content reduction and for preservation.

2.2 Design Analysis

2.2.1 Design Analysis of Hopper

The hopper with four slanting sides formed a shape of the frustum of pyramid. Eq. (1) gives the appropriate volume for the frustum of a pyramid.

$$V = \frac{h}{3}\left[A_1 + A_2 + \sqrt{A_1 A_2}\,\right] \quad (1)$$

where V is the volume of the hopper (m^3), h is the height of the hopper (m), A_1 is area of the trapezium (m^2) and A_2 is Area of rectangle (m^2)

Eq. (2) can be used in determining the area of trapezium.

$$A_1 = \frac{1}{2}(a + b)h \quad (2)$$

where a and b are the short and long sides of the trapezium(m), respectively and h is the height (m)

Also, area of rectangle is given by Eq. (3)

$$A_2 = L \times B \quad (3)$$

where L and B are the length and breadth of the rectangle.

After appropriate substitution of Eqs. (2) and (3) into Eq. (1), the volume for the hopper was derived to be $0.009349\ m^3$.

Mild steel of 1.5 mm thickness was used in the construction of the hopper.

2.2.2 Design Analysis of Pelletizing Chamber

The pelletizing chamber is in form of a cylinder. The volume of the outer and inner cylinders as well as the screw-like attachment on the shaft was considered for the design. Eqs. (4) - (6) display the mathematical expressions used for the volume of outer cylinder, volume of the worm and volume of the inner cylinder, respectively.

$$Volume\ of\ outer\ cylinder\ (V_o) = \pi R^2 h \quad (4)$$

$$Volume\ of\ worm (V_w) = \pi a^2 h \quad (5)$$

$$Volume\ of\ inner\ cylinder (V_i) = \pi r^2 h \quad (6)$$

where R is the radius of the outer cylinder, a is the radius of the worm and r is the radius of the inner cylinder.
The volume of the outer cylinder (V_o), the volume of the worm (V_w) and the volume of the inner cylinder (V_i) were obtained to be 0.00458, 0.0012 and $0.0029m^3$, respectively.
The estimated volume of the pelletizing chamber (V_c) can be deduced using Eq. (7)

$$V_c = V_o - V_i - V_w \tag{7}$$
$$= (0.00458 - 0.00209 - 0.0012) = 0.00317m^3$$

2.2.3 Design Analysis for Length of Belt
The velocity of belt, the tension for which the belt is placed on the pulleys, the arc of contact between the belt and the smaller pulley, and belt condition usage were considered as stated by [12].

Velocity Ratio of the Belt Drive

The expression in Eq. (8) was obtained for velocity ratio of belt drive by Gupta and Khurmi [13] which later became Eq. (9).
Mathematically,

$$\pi d_1 N_1 = \pi d_2 N_2 \tag{8}$$

Therefore, $$\frac{d_1}{d_2} = \frac{N_2}{N_1} \tag{9}$$

where N_1 is speed of the driver (rpm), N_2 is speed of driven (rpm), d_1 is diameter of driver (m) and d_2 is diameter of driven (m).
When thickness of the belt is considered, the velocity ratio is given by Eq. (10)

$$V.R = \frac{N_2}{N_1} = \frac{(d_1+t)}{(d_2+t)} \tag{10}$$

The range of speed for the worm drives for extrusion is between 70and 300 rpm depending on the material texture and if the pulley of 1:5 is selected to have compact belt drive.
The length of the belt can be determined using Eq. (11) according to [13].

$$L = \pi(R + r) + 2x + \frac{(R-r)^2}{x} \quad \text{in terms of pulley radius} \tag{11}$$

where L is total length of the belt (m), x is distance between the centre of two pulleys (m), R is radius of the larger pulley (m) and r is radius of the smaller pulley.
Therefore by computation, the length of a belt is 1.1763 m. This is approximately 1.2 m.

Design Analysis of V-Belt Driver

Using Eq. (12), the tight and slack tension can be determined

$$2.3\log\left(\frac{T_1}{T_2}\right) = \mu\theta\operatorname{cosec}\beta \tag{12}$$

where T_1 is tension on tight side of the belt, T_2 is tension on slack side of the belt, μ= coefficient of friction and β is half of the groove angle.
The tension determinant formula was obtained using Eq. (13)

$$T_1 = T - T_C \tag{13}$$

where T is maximum belt tension and T_c is centrifugal belt tension

$$\text{But} \quad T = \delta a \; and \; T_c = Mv^2 \tag{14}$$

where δ = Allowable stress in belt material = 2.5MPa

a= Cross-sectional area of the belt material= $L \times B - 2\left(\frac{1}{2}BH\right)$ (15)

where L = Length (m), B = Breadth (m) and H = Height (m)

Also $T_c = Mv^2$
where M is Mass per unit length of the belt material (kg/m)
v is Belt velocity (m/s) = ωr =$2\pi N_p R_p$ (16)
Eq. (12) can be transformed into Eq. (17) to determine T_2. Equation (18) was used to determine the wrap angle which was substituted into Eq. (17).

$$T_2 = \frac{T_1}{e^{\mu\theta} \sin\beta} \quad (17)$$

To obtain θ, $\theta = 180 - 2\alpha$ (18)
By computation, the tension on the tight and slack sides of the belt, respectively are 178.8 and 12.93 N.
From this, it can be deduced that the ratio of tight to the slack tension is dependent on the value of the wrap angle, that is,

$$\frac{T_1}{T_2} = \frac{178.8N}{12.98N} = 13.83 = 14$$

2.3 Design Analysis of Power Transmitted Belt

Power transmitted by the belt is obtained using Eq. (19)

$$P = (T_1 - T_2)V \quad (19)$$

where P is Power transmitted and V is velocity of the belt. This is given by Eq. (20)

$$V_1 = \frac{\pi D N_1}{60} \ and \ V_2 = \frac{\pi D N_2}{60} \quad (20)$$

Where there is no slip, $V_1 = V_2 = V$
where D is Diameter of the driver (m), d is diameter of the driven (m), N_1 is speed of the driver (Motor speed) (rpm), N_2= speed of the driven (Worm speed) (rpm).
By computation, the power transmitted by the belt was obtained to be 2.5 kW.

2.4 Design of Shaft

The shaft was designed based on maximum shear theory of failure [13].

$$\tau_{max} = \frac{16}{\pi d^3}\sqrt{(K_b M)^2 + (K_t T)^2} \quad (21)$$

From Eq. (21), the diameter of the shaft can be obtained using Eq. (22)

$$d^3 = \frac{16}{\pi \tau_{max}}\sqrt{(K_b M)^2 + (K_t T)^2} \quad (22)$$

Where d is shaft diameter (m), τ_{max} is maximum shear stress (N/m^2), M is maximum bending moment (N/m), T is maximum torsional moment (N/m), K_b is combined shock and fatique factor applied to bending moment (K_b= 1.5), K_t is combined shock and fatique factor applied to torsional moment (K_t = 1.5).

2.5 Shaft Design for Torsional Rigidity

Equation (23) was utilized to determine the torsional rigidity of the shaft [13].

$$\frac{\tau}{J} = \frac{G\theta}{L} \quad (23)$$

But $J = \frac{\pi d^4}{32}$ for solid shaft (24)

Therefore $\theta = \frac{32\tau L}{\pi G d^4}$ (25)

where θ is Angle of twist (rad), d is shaft diameter (m), L = shaft length (m), τ = Torsional moment (N/m), G = Torsional modulus of rigidity (N/m^2), J = Polar moment of inertia (m)
From Eq. (22),

$$d^3 = \frac{16}{\pi\tau_{max}}\sqrt{(K_b M)^2 + (K_t T)^2}$$

Torque with the value 104.22 Nm was be derived using Eq. (26)

Power, P = Torque, T × Angular velocity, ω (26)

Therefore, the maximum torsional moment was obtained to be 52.18 MN/m^2.

2.6 Fabrication Processes

Sheet metal plate (mild steel) of 1.5 mm thickness was cut to dimension for the fabrication of the hopper and the cylindrical pelletizing chamber. The hopper and the pelletizing chamber were welded together after a passage for feed entrance into the chamber from the hopper has been created. The discharge plate was made from 3 mm thick mild steel and holes were drilled to allow the passage of the pelletized fish feed. The shaft was machined to dimension using the lathe machine before the worm-like attachment was welded on the shaft. This was introduced into the pelletizing chamber with one end of the shaft connected to the discharge plate and bearing holding the other end for easy rotation. The discharge plate was connected to the pelletizing chamber temporarily with bolts and nuts for easy removal for maintenance after use. The frame was fabricated to dimension using 2 mm thick angle iron with the motor drive section incorporated on the frame. The driving and driven pulleys were connected with a V-belt for power transmission. The orthographic views of the machine are displayed in Figure 1 while the isometric drawing is shown in Figure 2.

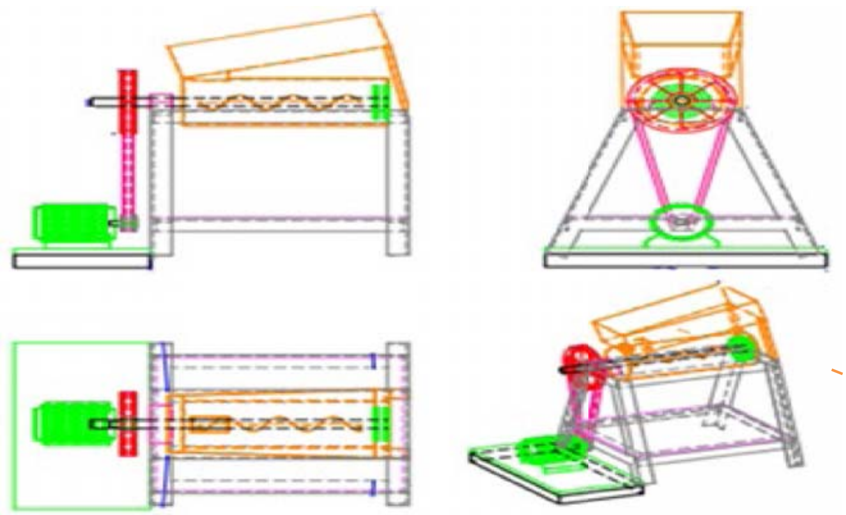

Figure 1: Orthographic view of the fish meal pelletizing machine

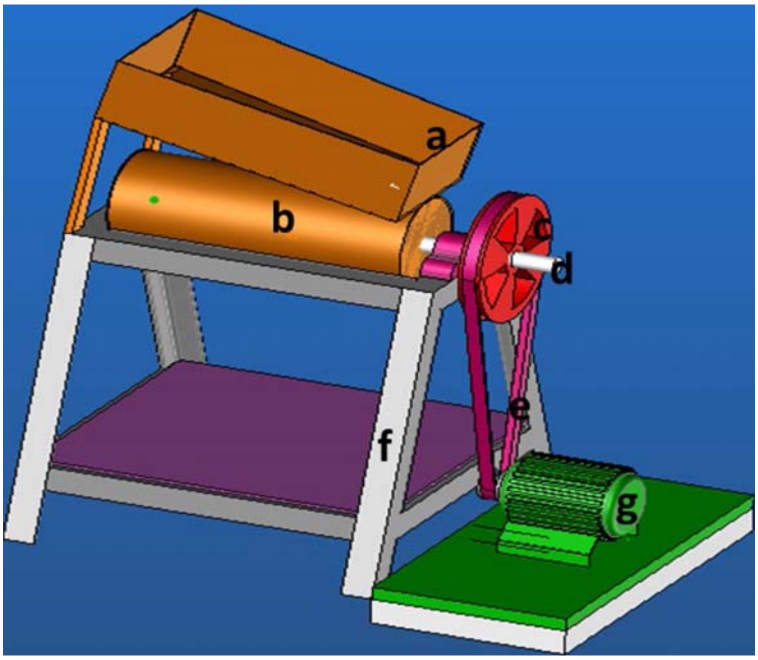

Figure 2: Isometric view of the fish meal pelletizing machine; a: hopper, b: pelletizing chamber, c: pulley, d: shaft, e: v-belt, f: frame and g: prime mover

2.7 Machine Testing and Performance Evaluation

The machine was tested after construction. The fish feed ingredients as stated by Olusegun et al. [8] studies were properly mixed. The total weight of the mixed ingredients was 5 kg. After the machine had been switched on, the mixture was fed into the machine via the hopper. A container was placed to collect the fish feed pellets compacted through the discharging die. The testing process was repeated at the same ingredients' weight of 5 kg for 4 times in which the averages of the needed terms were obtained.

The discharged pellets were weighed with a weighing balance so as to determine the discharge rate (efficiency of the machine) and the loss due to non-pelletized ingredients. The percentage moisture content removed after drying between 1 and 7 days were also determined by measuring the weight of the pelletized fish feed before and after drying for 7 days. Equations (27) – (29) was used to obtain the discharge rate (efficiency), percentage loss due to non-pelletized ingredients and the percentage moisture content loss after drying.

$$Discharge\ Rate(Efficiency) = \frac{Pelletized\ feed\ weight}{Weight\ of\ Ingredient} \tag{27}$$

$$\%\ loss\ due\ to\ non-pelletized\ ingredients = \frac{Residue\ Ingredient\ weight}{Weight\ of\ Ingredient} \tag{28}$$

$$\%\ moisture\ content\ removal\ = \frac{Wt.\ of\ pellet\ fish\ feed - Wt.\ of\ pellets\ after\ drying}{Wt.\ of\ pellet\ fish\ feed} \tag{29}$$

3. Result and discussions

3.1 Performance Evaluation of the Pelletizing Machine

Table 1 shows the production rate, efficiency and percentage loss due to non-pelletized ingredients of the machine. The average values of the weight of the ingredients, discharge time, weight of the pelletized feed, weight of the residue ingredients, production rate, efficiency and the loss due to non-pelletized ingredient are 5 kg, 2.5 min, 4.61 kg, 0.39 kg, 110.7 kg/h, 92.25% and 7.75%, respectively. This implied that when 5 kg of the prepared fish feed ingredients is processed for 2.5 minutes, the production rate is 110.7 kg/h, the efficiency of the machine is 92.25% and the percentage residue loss is 7.75%. The efficiency of the machine fabricated in this study is 4 - 6% higher than the pelletizer machine designed and fabricated by Ojomo et al. [1]. However, the efficiency obtained for this work was 1.95% lower to that of Olusegun et al. [8].

Table 1: Production rate, discharge rate (efficiency), and percentage loss due to non-pelletized ingredients

No. of runs	Wi (kg)	Dt (min)	Wpf (kg)	Wri (kg)	Pr (kg/h)	Dr (%)	Plp (%)
1	5	2.50	4.60	0.40	110.40	92.00	8.00
2	5	2.50	4.62	0.38	110.88	92.40	7.60
3	5	2.50	4.58	0.42	109.92	91.60	8.40
4	5	2.50	4.65	0.35	111.60	93.00	7.00
Average	5	2.50	4.61	0.39	110.7	92.25	7.75

* Wi- Weight of Ingredients, Dt-Discharge Time, Wpf-Weight of Pelletized feed, Wri-Weight of residue ingredients, Pr-Production rate, Dr-Discharge rate (efficiency) Plp-loss due to non-pelletized ingredients (%).

3.2 Percentage Moisture Content Removal (Percentage Dryness Value) and Drying Days

For easy storage of the pelletized feed so as to have longer shelf life compared to when moist and to be able to float on water for longer time, the pelletized feed was dried for 7 days. The percentage moisture content removal can be termed the percentage dryness of the pelletized fish feed. The percentage moisture removal at 4.6 and 4.65 kg pelletized feed weight are displayed in Tables 2 and 3. It was observed that as the drying day increases, there was a decrease in the weight of the pelletized feed due to the rate of moisture removal through drying. However, there was increment in the percentage moisture content removal with respect to the initial weight of the pelletized feed before drying. Therefore, it can be said that moisture content loss reduces as the day or time increases with respect to the previous day. This is in agreement with the studies of Siddique and Wright [14] on the effects of different drying time and temperature on moisture percentage of Pea seeds and Modibbo et al. [15] on the effect of moisture content on drying rate. It was observed that the percentage moisture removal remains constant on the sixth and seventh days of the experiment. This might be due to an appreciable removal of the moist in the feed. The percentage moisture content removal at 4.6 and 4.65 kg pelletized feed weights on the last day was 18.0 and 18.1%, respectively.

Table 2: Percentage moisture content removal at 4.6 kg pelletized feed weight

No. of drying Days	Weight of Pelletized feed (kg)	Weight of Pelletized feed after drying (kg)	Percentage moisture content removal (%)
1	4.6	3.85	16.3
2	4.6	3.82	17.0
3	4.6	3.80	17.4
4	4.6	3.79	17.6
5	4.6	3.78	17.8
6	4.6	3.77	18.0
7	4.6	3.77	18.0

Table 3: Percentage moisture content removal at 4.65 kg pelletized feed weight

No. of Drying Days	Weight of Pelletized feed (kg)	Weight of Pelletized feed after drying (kg)	Percentage moisture content removal (%)
1	4.65	3.9	16.1
2	4.65	3.87	16.8
3	4.65	3.85	17.2
4	4.65	3.83	17.6
5	4.65	3.82	17.8
6	4.65	3.81	18.1
7	4.65	3.81	18.1

Figures 3 and 4 showed the linear relationship between percentage moisture content removal and weight of pelletized feed after drying at both 4.6 and 4.65 kg, respectively. As moisture content removal increases, the weight of the pelletized feed decreases as well as the day increases. This implied that the moisture present in the fish feed reduces as drying days increase.

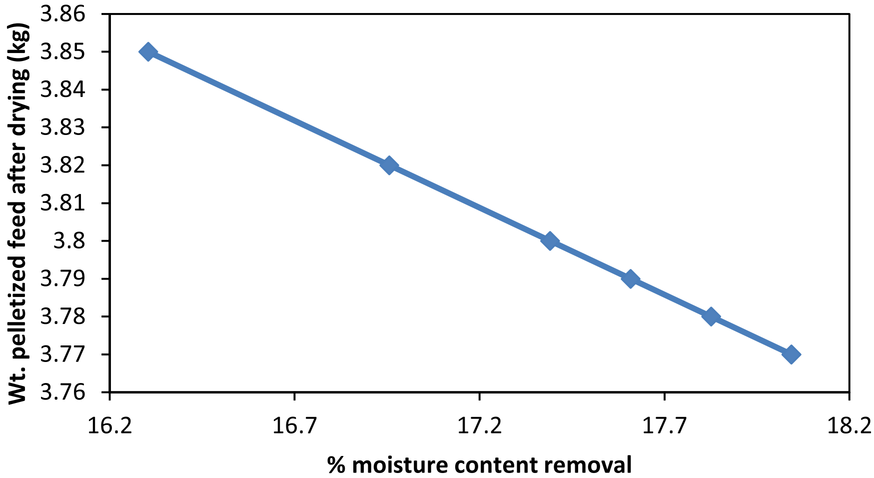

Figure 3: Weight of pelletized feed after drying against percentage moisture content removal at 4.6 kg

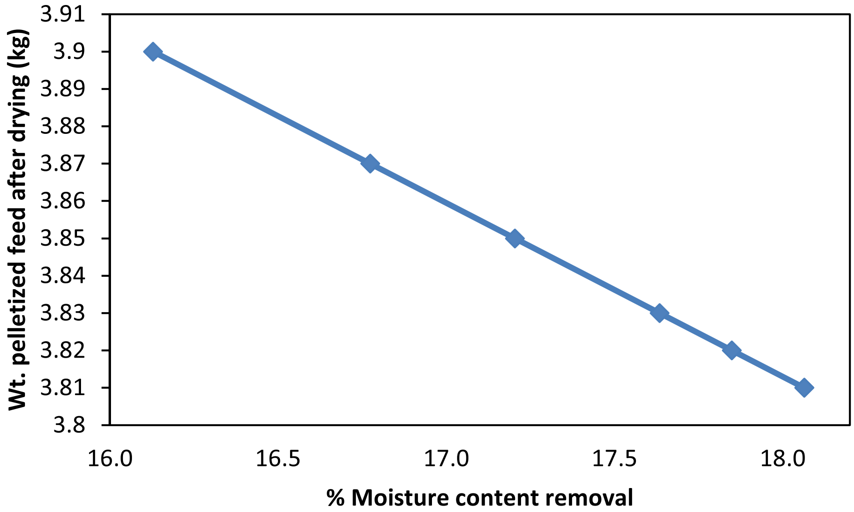

Figure 4: Weight of pelletized feed after drying against percentage moisture content removal at 4.65 kg

4. Conclusion

In the screw-like fish feed pelletizer fabricated and tested, the average production rate of the machine was 110.7 kg/h at an average discharge efficiency of 92.25%. Increasing the discharge time will increase the discharge efficiency of the machine thereby reducing weight of residue. Moisture content reduction percentage increases as the drying days increase whereas the weight of the pellets reduces as the drying days increase. The linear relationship between the weight of pelletized feed after drying and percentage moisture content removal depicts good trend for which moisture loss in the feed is a function of the number of drying days and invariably reduces the weight of the feed.

Acknowledgements

The financial support offered by Landmark University in sponsoring this research work for publication is highly appreciated.

Reference

[1] Ojomo, A. O., Agbetoye, L. A. S., & Ologunagba, F. O. (2010). Performance Evaluation of a Fish Feed Pelletizing Machine, ARPN Journal of Engineering and Applied Sciences, 5(9), 88 – 97.

[2] Odesola, I. F., Kazeem, R. A., & Ehumad, N. C. (2016). Design and Construction of a Fish Feed Extruder. International Journal of Scientific & Engineering Research, 7(8), 1378 – 1386.

[3] Olugboji, O. A., Abolarin, M. S., Owolewa, M. O., & Ajani, K. C. (2015). Design, Construction and Testing of a Poultry Feed Pellet Machine. International Journal of Engineering Trends and Technology, 22(4), 168 – 172.

[4] Ojediran, J. O., Fasinmirin, J. T., & Owa, O. P. (2017). Development and Performance Evaluation of an Indigenous Fish Feed Palletizing Machine. Journal of Engineering and Engineering Technology, 11(2), 139 – 148.

[5] Burmamu, B. R., Aliyu, B., & Tya, T. S. K. (2015). Development Of A Manually Operated Fish Feed Pelleting Machine. International Journal of Research in Engineering & Advanced Technology, 2(6), 23 – 32.
[6] Nwaokocha, C. N., & Akinyemi, O. O., (2008). Development of a Dual-mode Laboratory Sized Pelletizing Machine. Leonardo Journal of Sciences, 7(13), 22 – 29.
[7] Olusegun, H. D., Adekunle, A. S. (2009). Design, Construction and Testing of a Wormlike Pellet Fish Feed Processing Machine. International Journal of Engineering, 3 (1), 31 – 44.
[8] Olusegun, H. D., Adekunle, A. S., Ohijeagbon, I. O., Akande, K. A., & Mohammad, B. G. (2017). Design, Fabrication and Evaluation of Fish Feed Pelletizing Machine, Journal of Science and Technology, 37(1), 51 – 65.
[9] Kaankuka, T. K., & Osu, D. T. (2013). Development of a Revolving Die and Roller Fish Feed Pelletizer. International Journal of Engineering Innovations and Research, 2(1), 105 – 110.
[10] Ojo, S. T., Olukunle, O. J., Aduewa, T. O., & Ukwenya, A. G. (2014). Performance Evaluation of Floating Fish Feed Extruder. IOSR Journal of Agriculture and Veterinary Science, 7(12), 103 – 113.
[11] Ikubanni, P. P., Agboola, O. O., & Ogunsemi, B. T (2019). Development and Performance Evaluation of Screw-like Fish Meal Pelletizer. CIGR - Agricultural Engineering International (In-Press)
[12] Jones, M. G., (2002). Mechanics of Materials. 2th Edition, Nelson Thornes, Cheltenham, United Kingdom, pp. 1 – 43.
[13] Gupta, J. K., & Khurmi, R. S. (2006). Machine Design. 14th Edition, Rajendra Ravindra Printers (Pvt) Ltd., India.
[14] Siddique, A. B., & Wright, D. (2003). Effect of Different Drying Time and Temperature on Moisture Percentage and Seed Quality (Viability and Vigour) of Pea Seeds (Pisum sativum L.). Asian Journal of Plant Sciences, 2, 978 – 982.
[15] Modibbo, U. U., Osemeahon, S. A., Shagal, M. H., & Halilu, M. (2014). Effect of Moisture Content on the Drying Rate using Traditional Open Sun and Shade Drying of Fish from Njuwa Lake in North-Eastern Nigeria. IOSR Journal of Applied Chemistry, 7(1), 41 – 45.