DEVELOPMENT OF A SEMI - AUTOMATED FISH FEED PELLETIZING MACHINE

Kadafa, K.M.[1*], Tashiwa, Y.I.[1], Kabri, H.U.[1] and Bwade, E.K.[2]

[1]Department of Agricultural and Environmental Engineering, Faculty of Engineering, Modibbo Adama University, Yola

[2]Department of Agric. & Bio-Environmental Engineering Technology, Federal Polytechnic, Mubi

*Corresponding email: kkadafa@gmail.com

ABSTRCT

The high cost of imported fish feed and processing machines is a significant challenge for small scale and medium scale fish farmers in Nigeria, hindering the growth of the aquaculture industry. The aim of this project is to develop a semi - automated fish feed pelletizing machine using locally sourced materials to produce high-quality fish feed at an affordable cost. The pelletizer consists of hopper, screw conveyor, barrel, die, drive system and heater. The machine was fabricated using locally sourced mild steel materials. A heater element was attached to the barrel surface so as to ensure cooking of resin pellet and easy drying at the same time. The cylindrical pellets size produced was in the range 4 - 10mm diameter suitable for fish and poultry. The total cost of the machine is ₦130,800.00 and energy consumption of 2.98Kw-h. The developed machine is suitable for small-scale and medium-scale fish farmers, affordable and simple to maintain. It was recommended that there is need to further carry out the performance evaluation of the machine and explore the use of different feed ingredients.

Keywords: Fish, Pelletizing, Machine, Design, Construction

1 INTRODUCTION

Fishes have always been an important species to man and an important source of animal proteins. It enjoys special consideration in Human civilization for its food, cooking, and nutritional value [1]. Earliest form of fish culture appears to be of the common carp (*Cyprinus carpio*), native to China, and the cultivation of *Tilapia mossamblaca* to Vietnam. Fish farming contributes about 50 percent of the fish consumed by humans globally. It produces about 35 percent of the world's animal protein. Fish contains 15-30 percent of protein; a higher percentage than the flesh of usual domestic animals reared for meat, egg, milk and beef Food and Agricultural Organization [FAO] [2]. The fishing sector is a significant source of income and livelihood for millions of people around the world as employment in fisheries and aquaculture has also grown at an average rate of 3.8 percent yearly since 1980. In 2007, more than forty-five million people were directly or indirectly engaged in fish production and about 12 percent of them were women. In 1980, only sixteen million seven hundred people were involved in fish production. Also, estimates from the FAO [2] shows that for every person involved in fish production, about three more jobs are created in post-harvest processing, sales, marketing and others. Nigeria consumes 1.5 million tons of fish annually (about 10 kilograms per capita). Global fish consumption per capita grew from 9.0 kilogram (live weight equivalent) in 1961 to 20.5 kilogram in 2018, by about 1.5 percent per year [3]. This Global food fish consumption increased at an average annual rate of 3.1 percent from 1961 to 2017, a rate almost twice that of annual world population growth (1.6 percent) for the same period, and higher than that of all other animal protein foods (meat, dairy, milk, etc.), which increased by 2.1 percent per year [3]. Mogaji *et al.* [4] Developed an improved fish feed pelletizing machine. The machine consists of three major parts namely; the pelletized chamber that accommodates the auger; the electrical chamber that hosts the electric power of 2h.p with 1400rpm and its throughput capacity of 18kg/hour and the table made up of angle iron. The improvement in this work is its ability to accommodate different pellet plate hole of diameter 2mm, 4mm, 6mm, 8mm and 10mm. The developed machine was tested and the results show high machine efficiency of 93 percent and pelletizing efficiency of 96.3 percent. The machine is limited to heating of feed and cutter for easy drying of the feed. According to Mogaji *et al.* [4] it is an established fact that protein from foods and animal origins is lacking in everyday diet of many Nigerian. This deficiency in protein is responsible for great deal of ill-health and many deaths in almost all the states of Nigeria. Farmers use cheap and locally sourced raw ingredients to produce feeds that are badly formulated, poorly made and misguidedly used due to a lack of technical expertise and inadequate manufacturing equipment in their on-farm feed manufacture despite the availability of the feed ingredients [5, 6]. Some small-scale farmers formulate low-cost feeds using locally available ingredients at farm level. The feeds fail to meet the needs of expanding semi-intensive aquaculture systems; they have inferior functional quality especially with regard to physico-chemical properties [7, 8]. Most quality feeds available in the market are imported and the locally made feeds are grappling with various challenges, ranging from inadequate formulation and poor blending of constituents [6]. Access to affordable high-quality feeds is a challenge to farmers [7, 9]. Fish feed technology is one of the least developed sectors of aquaculture particularly in Africa and other developing countries of the world [10]. It is one of the fundamental challenges facing the development and growth of aquaculture in the African continent. Therefore, to improve on this development of the automated fish feed pelletizer would be a positive development. Basically, the purpose of pelletizing is to take a finely divided, sometimes dusty, unpalatable and difficult-to-handle feed material and, by using heat, moisture and pressure, form it into larger particles. These larger particles are easier to handle, more palatable and usually result in improved feeding when compared to the un-pelleted feeds [11]. Pelletizing is one of the most commonly applied food processing technique in food industry. It is now a very popular processing technique used in the feed, cereal, and snack food industries and also one of the most versatile unit operations [12, 13]. It induces numerous chemical and structural transformations such as starch gelatinization, protein de-nitration, complex formation between amylase and lipids, and degradation of vitamins or pigments in starchy and proteinous food materials [14].Eugene [15] designed a pelletizer that consist of a screw pump similar to a screw press or screw conveyor in which feed is compressed and worked to form a semi-solid mass. The feed is forced through a restricted opening of the die at the discharge end of the screw with low efficiency. Ojomo *et al.* [16] carried out performance evaluation on a fish feed pelletizing machine. The machine consists of a hopper, barrel which houses the screw conveyor (auger), the cutting knife and the die orifice. Power supply to the machine is from 2 kW, 1420 rpm single phase electric motor. The machine showed higher throughput capacity of 19.7 kg/h with maximum pelletizing efficiency of 87.6 percent. Davies and Davies [17] developed and evaluate manually operated fish pelletizing machine. The operation of the machine does not require any highly technical expertise. The main features of the machine are: hopper, extrusion barrel, screw auger, bearing housing, crank arm, compression plate, flat die, pulley, sprout (gravity chute) knife cutter and the supporting frame. The performance of the machine was determined based on the following parameters namely: Pelleting efficiency, percentage mechanical damage, percentage feed loss, throughput capacity. The limitation of this machine is that it can only be operated manually. Olugboji *et al.* [18] worked on design, fabrication, development and testing of a cheap, electrically operated feed pellet machine with locally available materials. 2 h p electric motor was used to drive the machine, with a capacity of 5kg/hr. The area of weakness of this machine is its inability to produce 2mm and 4mm diameter pelletized feed. Ojediran *et al.* [19] developed and carried out performance evaluation on an indigenous fish feed pelletizing machine. The limitation of this machine is its ability to produce only 4mm diameter of pelletized fish feed. Nithin [20] develop a fish feeding mechanism for recirculation of aquaculture system. Okolie *et al.* [21] designed and produced a fish feed pelletizing machine. It consists of hopper, screw conveyor, barrel, dies, drives system and heater. The design was carried out using engineering principles with due consideration to cost, ease of operation, serviceability, durability, and performance. It is designed to be driven by a 1.5 h.p, three-phase electric motor with a heating element of 1500 W attached to the barrel surface to ensure adequate heating of the feed as they travel through the barrel. The machine is limited to production of 2-8mm diameter pellets. Coolaid *et al.* [22] developed manually operated two sprockets and chains system of fish feed pelletizer. The hand-driven, two chains and sprocket system fish feed pelletizing machine was fabricated with, three interchangeable die plates with hole diameter sizes of 4mm, 6mm and 8mm. The machine had an efficiency of 79 percent and a production rate of 12.6kg/hr. The machine is limited to manually operated, no heating and cutter for easy drying. All the deficiencies identified in the existing machines are improved upon in this work. Therefore, local production of fish feed is very important to the development and sustainability of aquaculture in Africa especially, in the rural areas of Nigeria and also for aquaculture to thrive and bridge the already existing wide gap between fish demand and supply especially in Africa. There is the need for simple, yet versatile machines at affordable prices which are capable of mixing and pelletizing a rich blend of the cereals such as rice, millet, maize and sorghum with high nutritional and tasty additives such as fruits, vegetables and others. It is against this background that a portable, low-cost, semi - automated fish feed pelletizer was developed. This work will contribute to improvement in the living conditions of the farmers in terms of income generation.

2 MATERIALS AND METHODS

In this work good material selection was undertaken to achieve the following purposes: convenient maintenance, to reduce the noise of the machinery, to produce the machinery at an economical cost, to improve and reduce dimensions, to achieve machine aesthetics, to improve the strength of the machinery, to improve its resistance to wear, corrosion and corrosive medium The materials that were used for the construction of the pelletizer are; mild steel, stainless steel, cast iron, and chemical paint. The following design considerations form the basis of this design: (i) The machine should be simple but rugged, and comparatively inexpensive. (ii) The fish feed must be fed constantly so that there is a consistent and uniform operation of the Pelleting machine. (iii) The speed of the shaft must be reduced by using a v-belt. (iv) Construction materials should be easily available. (v) The pitch of the screw conveyor is larger in the inlet compared throughout the screw so as to maximize transportation, in the barrel of the machine. (vi) There should be increase in pressure and temperature in the barrel of the pelletizing machine so as to push the pellet out of the die. (vii) The assembly of the machine is made simple for easier maintenance. (viii) The parts of the machine are locally, sourced and inexpensive as reported by [5, 6].

2.1 Volume of Hopper

The of the hopper is given by equation (1).

$$V = 13h\left(A_1 + A_2 + \sqrt{A_1A_2}\right) \tag{1}$$

Where, A_1= Bottom length × width =$L_1 \times w_1$, A_2= Top length × width =$L_2 \times w_2$.

2.2 Weight of pulley

The weight of the is given by equation (2).

$$Wp = m\rho g \tag{2}$$

Where, m = mass of pulley, ρ = density of steel, g = acceleration due gravity constant

2.3 Determination of shaft diameter

The shaft diameter of the machine was determined by the given expression below;

$$d3 = 16\pi ts\sqrt{(Kb \times Mb)^2} + \sqrt{(Kt + Mt)^2} \tag{3}$$

Where, ts = allowable stress for steel without keyway, N/M2(50MN/m2), Kb = combined shock and fatigue factor applied to bending, Mb= maximum, vertical bending moment, Mt= horizontal torsion moment Nm, Kt = combined shock and application to torsion bending moment = 1.0.

2.4 Pulley speed

The pulley speed is given by equation (4).

$$\frac{\omega_1}{\omega_2} = \frac{N_1}{N_2} = \frac{D_1}{D_2} \quad (4)$$

2.5 Length of belt

Length of belt (L_b) is given by equation (5) [23].

$$Lb = 1.57(D0 + D1) + \frac{(D_0 - D_1)^2}{4C} + 2C \text{ (Openbelt)} \quad (5)$$

Where, L_b = length of belt, mm, D_1 = Large pulley diameter, mm,$_0$ = Smaller pulley diameter, mm, C = Center distance between two pulleys, mm. The barrel is designed to withstand a higher temperature up to 400^{0}C and to be a very good source of heat conductor. The barrel is made up of steel which has a melting point of 1,515 ^{0}C. The volume of the barrel is determined by equation (6) [24].

2.6 Volume of barrel

Volume of barrel = volume of cylinder. The volume of the barrel is given by expression (6).

$$V = \pi r2h \quad (6)$$

Where, r = radius of the barrel, mm, h = length of barrel, mm, π = constant.The capacity of the screw conveyor can be calculated using equation (7) [24].

$$Q = 15\pi D2sv\phi\wr c \quad (7)$$

Where,Q = Capacity of the conveyor, tones/hr, D = Screw diameter, m, s = Pitch of the screw, m, v = Speed of the machine, rpm, ϕ = Loading efficiency, ¼ or 0.25% [24], c = Factor of inclination of screw shaft to horizontal at angle, C = 1.0, Bulk density of conveying materials ˥ = 1.2tons/m^3 [24]. Since the heating element is to be applied on the exterior part of the barrel, heat will be transferred from the external surface to the internal surface of the barrel Let R_1, R_2, T_1, T_2, be internal diameter, external diameter, internal temperature and external temperature, respectively. Rate of heat transfer in cylinder is determined by equation (8) [25, 26].

$$Qh = \frac{2\pi K \times (T_1 - T_2)}{In(\frac{R_2}{R_1})} \quad (8)$$

Where, Q_h = Amount of heat transfer, W, R_1 = inner cylinder diameter, m, R_2 = outer cylinder diameter, m, ($T_1 - T_2$) = temperature difference ^{0}C, b = thickness of cylinder wall, m, K is proportionality constant known as Thermal conductivity (W/m ^{0}C) [25], K = 43 W/m ^{0}C [27]. The electrical energy consumption of the machine was determined by equation (9) [23].

$$E_c = P_c \times T \quad (9)$$

Where: E_c = the electric energy consumption, Kw-h, P_c = the amount of power consumed, Kw, T is the total operating time, hr.

Plate 1. Pictorial of the Machine

Table 1. Machine Construction parameters

Component Part	Dimension	Material Used	Quantity
Hopper	ø 300 x 435 mm	Mild steel plate	1
Barrel	ø 133 x 800 mm	Mild steel (aco pipe)	1
Screw conveyor	ø 50 x 1000 mm (inner shaft), ø 125 x 800 mm (sleeve pipe)	High carbon steel Mild steel	1
Die head plate	ø 135 x 10 mm	Mild steel plate	1
Frame	2mm x 2mm	Angle iron	5
Pulley	ø 250 mm	Mild steel	1
Fasteners (bolts and nuts)	ø 15 x 50mm (for tightening), ø 10 x 50mm (for barrel casing)	Mild steel bold and nuts	8 20
Finishing and coating	-	Chemical (paint)	-
Pillow bearing	ø 50 mm	-	2
Flat bar	ø 40 mm x 800mm	Mild steel	1
Mild steel welding electrode	Gauge 10 and 12	-	2 packets
Grinding disk	-	-	2
Electric motor	5 horse power	-	1
V- belt	12 mm thickness	Rubber	2

The machine was fabricated based on the design specification. The construction was carried out with locally sourced materials to reduce the cost of production to meet the design objective. Each of the components was designed and fabricated following the due fabrication process. This entails marking and cutting out the required shape and dimension, welding of the parts to form the components, and surface finishing improving on the aesthetics. The fabricated components were then assembled to give the desired machine. The frame was constructed with mild steel angle iron. Two lengths of the material were procured and cut into appropriate dimensions using power saw. The frame measures as in table 1. The hopper was constructed with sheet metal. These dimensions were cut out and joined together by arc - welding, bolts and nuts of M8 x 30 size. The frame was braced across the length and width to provide required strength for the frame. 2mm mild steel metal sheet was fastened to the base of the frame for mounting of the electric motor. Figure 1, 2 and 3 shows the isometric, exploded and 0rthographic views of the pelletizing machine. The important components of the pelletizing machine (figure 1) are; the hopper (1) where the fish feed is fed into the machine and the pelletizing barrel (2) which enclosed screw conveyor. The shaft (3) is operated by pulley (7) and belt (8) system that is powered by an electric motor (6). The drive shaft and driven here was however connected in linked by a v-belt through drive and driven pulleys. A spherical plate with little openings in it called the die (4) or extrusion plate is synchronizing on the end part of the barrel. The shaft with the screw conveyor is mounted on the machines frame with a roller bearing (12) at the end and self-aligning similar bearings at the beginning of the shaft for better support. The barrel (2) is a cylindrical vessel with opening where the hopper was welded upon, it is from this opening that the feedstock enters the barrel of the machine. The pitch of the screw conveyor at the inlet (i.e. directly below the opening where the hopper was mounted) is larger to maximize transportation of feedstock as it enters the barrel. The barrel housed the screw conveyor (auger), the conveyor consists of two parts. The first part of the screw conveyor feeds in the material in granular form and the second part of the conveyor compressed the material into a semi-solid plasticized mass. The pitch of the conveyor at the middle and end is decrease and the pressure is also increased for uniform pellets in the die. The pelletized feed is forced out through the die. [5, 6].

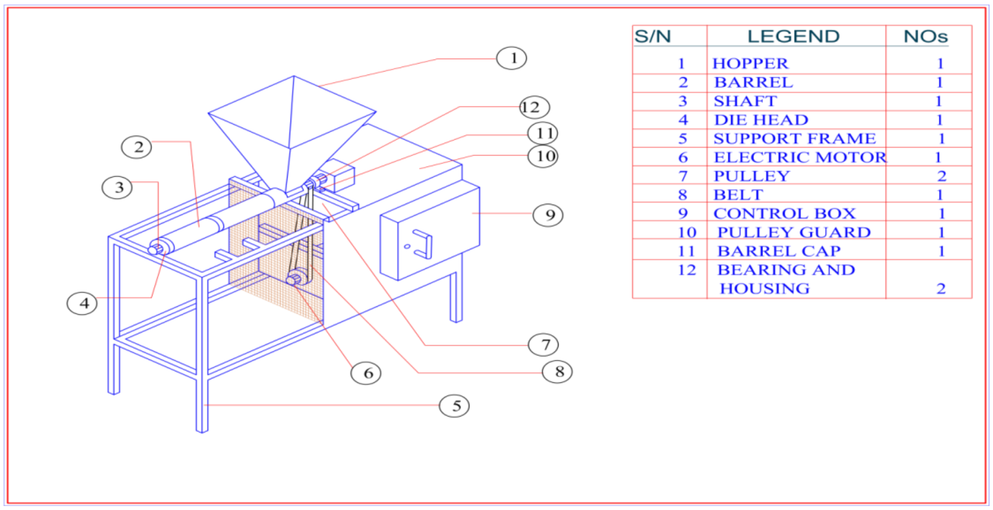

Figure 1. shows the isometric view of the pelletizing machine

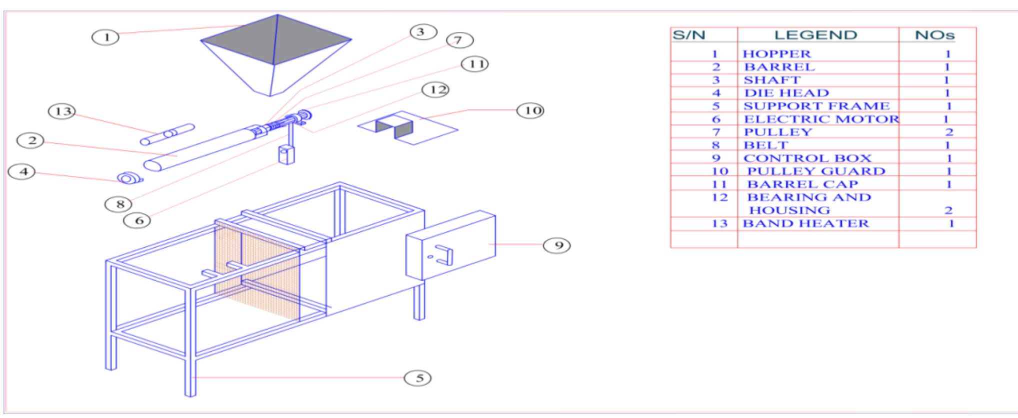

Figure 2. Operating principles of the machine

The feed mixes are loaded into the hopper of the pelletizing machine and the feed falls into the barrel by gravity. The motor provides power that rotates the auger in the cylinder in which the feed experiences circular motion in a horizontal plane about the axis. The feed is pressed against the die and it comes out through the openings in spiral forms. Then cutter cuts the feed at the outlet of the die at a desired length.

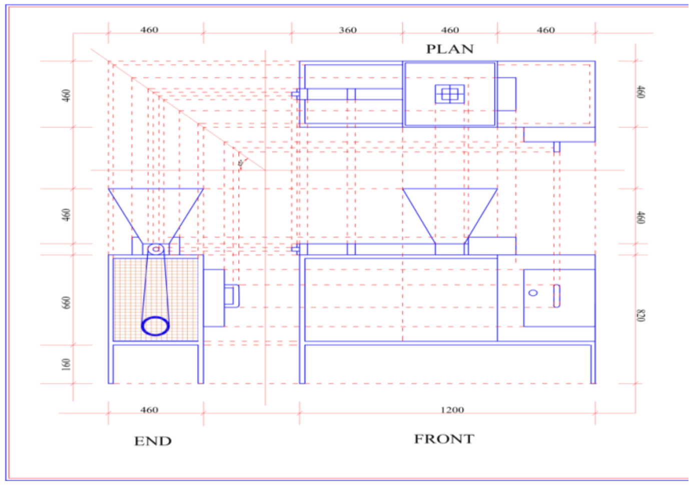

Figure 3. orthographic projection

3 RESULTS AND DISCUSSIONS

The results of design calculations are presented in table 2 below.

Table 2. The results of design of the major parts of the machine

S/N	Component unit	Specification	Parameter
1	Hopper volume, V	a = 350 mm, b = 850mm	21,263,328 mm^3
2	Barrel volume	r = 31 mm, h = 450 mm	1,358,757.9 mm^3
3	Screw conveyor capacity, Q	D = 0.054 m, s =0.05 m,	2.44 tons/hr
4	Screw conveyor volume	L= 0.45 m, b = 0.031 m, D = 0.054 m	0.0007533 m^3
5	Screw conveyor weight	m =2.76Kg,	27.12 N
6	Shaft diameter	$M_b = 49.61_{Nm}$, M_t = 23.49 Nm, K_b = 1.5, K_t = 1.0, t_s = 50 MN/m^2	25 mm
7	V- belt length, L_b	D = 0.127m, D_1 = 0.15 m, C = 0.61 m	1.65 m
8	Electric motor power required, TP	P_{L} = 0.00813 Kw, P_N = 2.08 Kw	2.25 Kw

From Table 2 above the results shows the calculated parameters of the machine when compared with other designs by [4, 6, 22, 28, 29]. It shows that the hopper volume for this machine smaller than all those cited above. The machine is simple, and portable not cumbersome. The investment cost of the machine is presented in table 3. Table 3 shows the results of investment cost of the machine. It indicates that the machine is cost effective.

Table 3. Cost of Production of the Machine

S/N	Description	Total Price (₦)
1	Angle iron	14,000.00
2	Bolts and nuts	2,000.00
3	Metal plate	4,500.00
4	Bearing	5,000.00
5	Shaft with screw conveyor	5,000.00
6	Electric motor	57,500.00
7	Belt	1,000.00
8	Pulley	3,000.00
9	Cable and wire	1,500.00
10	Heating element	1,500.00
11	Switches	4,000.00
12	Wire mesh	1,000.00
13	Mild steel welding electrode	4,000.00
14	Flat bar	1,000.00
15	Labour/Painting	25,000.00
Total		130,000.00

4 CONCLUSIONS

A semi-automated fish feed Pelleting machine was designed and constructed in the department of Agricultural and Environmental Engineering to enable efficient fish feed production. It is recommended to carry out the performance evaluation of the machine and to develop similar machine for Pelleting feed for poultry and other animals. This study contributes to knowledge by development of a machine that is simple, easy and affordable semi-automated fish feed Pelleting machine.

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