Development of A Revolving Die and Roller Fish Feed Pelletizer

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Abstract - **A revolving die and roller type pelletizing machine was designed and constructed to produce fish feed pellets for small scale fish farmers. The major components of the pelletizer were the hopper, rollers, a flat die, shaft, discharge tray, frame, V-belt, V-pulley and electric motor. These components were designed based on strength and rigidity. An electric motor drives the die by a shaft connected to its pulley. The rotation of the die initiates the rotation of the rollers which pick up the feed material and compress it into the die holes to form pellets. The pelletizing machine was tested at two speed levels of 507 and 761 rpm and at three moisture content (MC) levels (wet basis) of 20, 25 and 30%. At 30% MC, highest pellet output of 34.3 kg/hr and 40.4 kg/hr were obtained for die speeds of 507 and 761 rpm respectively. Higher pellet output obtained from die speed of 761 rpm could be as a result of the production of higher heat which resulted in proper gelatinization of the carbohydrate in the compounded feed. The gelatinized starch acts as a binding agent and this reduces crumbling during pelleting. The small and medium scale fish farmer can operate the machine because of its simplicity and this will alleviate the problem of sourcing for imported fish feed.**

Keywords – **Fish Feed Pellet, Pelletizing Machine, Revolving Die and Roller.**

I. INTRODUCTION

Fish farming has generated a lot of interest in Nigeria in the last two decades and equipment used in the processing of feed are quite sophisticated and are mostly imported from Asia and Europe. The small scale fish farmer is left with the option of waiting until he purchases fish feed since he cannot produce feed on his farm for his fish. 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 [1].

In Nigeria fish feed industry is poorly developed and few indigenous designs have been reported. A single screw fish pellet extruder which has a capacity of 64.07 kg/hr obtained at 25% (w.b) moisture content was developed [2]. A manually operated fish pelleting machine was developed and reported that the higher the moisture content the higher the pelleting efficiency [3]. A developed fish feed pelletizing machine which was operated at the speeds of 400, 600 and 900 rpm and moisture content range of 5 – 15%. From the performance analysis the highest throughput of 19.7 kg/hr was obtained for the machine [4].

Pelletized fish feeds have lower densities which enable them float on the surface of water for long periods or sink slowly to enable fish feed on them. They therefore remain available for consumption in ponds for a longer time than powdered fish feed and they are much easier to store for longer periods of time. Pelletized fish feeds compared with powered fish feeds are of greater nutritive value because the fish obtains total nutritive value of the feed in one bite. This has greatly improved the production quality of fish around the world. A research paper on the successful use of dry pellets for trout feeding was published [5].

Pelletizers are machines which produce dry, compressed pellets of fish feed when powdered or moist feed materials are fed into them. Variables resulting from mechanical parameters of the pelletizer which affects its operation and pellet produced are:

- Die thickness and diameter of holes are factors in pellet quality and quantity.
- Speed of rotation should also be considered for each die thickness/hole diameter combination.
- The input rate of feed introduced into the pelletizing chamber affects pellet quality.
- The amount of moisture added to a given volume of feed should be at a correct ratio such that the drive motor on the pellet mill is operating at its maximum amperage.

Other factors known to influence pellet quality include bulk density of the soft feed, its texture, chemical composition (fat, fibre, carbohydrate, protein and moisture) and prevailing ambient conditions of temperature and relative humidity. Increase in temperature increases gelatinization of raw starch. Starch gelatinization is the rupture of starch granules, thereby allowing the linear and cyclic molecules to hydrate and become sticky in the presence of water. Gelatinization occurs by mechanical means such as grinding and pressure. Functional heat due to passage of feed through a pellet mill adds 2–3 degrees of temperature. The moisture, temperature and time involved combine to impart a sticky surface to starch and condition ingredients which, when subsequently dried, improves pellet hardness and water stability [6].

Pellets are compressed; therefore loss of nutrient through leaching is minimized unlike the loosed powdered feed. The pelletized fish feed will go a long way to maximize profit from fish production and minimize wastage. For a roller and die type pelletizer, its operation involves forcing moist, soft feed through holes in a metal ring die. Feed is served through the die holes in increments so that the dissection of a finished pellet shows tight layers

of feed mixture. These holes may be round or square, tapered or non- tapered.

Most of the fish feed pelletizer type reported are the extrusion type which uses a barrel that houses a screw conveyor and a flat die. The objective of this study is to develop a fish feed pelletizer which pelletizes the feed by the use of a revolving die and two (2) rollers. The pelletizer is compact, cheap and portable enough to be used by small scale farmers to compound their custom feed.

II. MATERIALS AND METHODS

2.1 Material selection

A mild steel shaft having maximum permissible working stress in tension and compression of 112 MPa and a maximum permissible shear stress of 56 MPa was selected for the die shaft. Mild steel angle-iron bars of 4 mm were used to construct the frame. The die, rollers, discharge tray and hopper were constructed.

2.2 Design of the pelletizer

2.2.1 Power required by the pelletizer (Pp)

The power required to drive the pelletizer (Pp) shaft was estimated by considering the shear stress at the contact area between the die and the roller. The pelletizer power is a product of the roller speed (V_R), and the force (F_R), acting on the roller given by 1.

$$P_p = V_R \; X \; F_R \qquad (1)$$

The speed of the die and velocity ratio was calculated using 2 and 3 respectively;

$$V_d = \frac{\pi D_d N_d}{60} \qquad (2)$$

Where,
V_d = velocity of the die, m/s
D_d = diameter of the die, m
N_d = speed of the die, rpm

$$V.R. = \frac{D_d}{D_R} = \frac{N_R}{N_d} \qquad (3)$$

Where,
V.R = velocity ratio between roller and die
D_R = diameter of the roller, m
N_R = speed of the roller, rpm

$$V_R = \frac{\pi D_R N_R}{60} \qquad (4)$$

The force acting on the roller was calculated using 5,

$$F_R = \tau \; X \; A_R \qquad (5)$$

Where,
V_R = velocity of roller, m/s
F_R = Roller force, N
 = shear stress acting at the roller-die contact point, N-m^{-2}
A_R = area of the roller causing shear of the material and was taken as $\frac{1}{10}{}^{th}$ of the total area of the die, m^2

$$\tau = \mu \; X \; \gamma \qquad (6)$$

μ = viscosity of the feed material, Nsm^{-2}
 = shear rate of the feed material, s^{-1}

$$\gamma = \frac{V_R}{H} \qquad (7)$$

Where,
H = depth of the gear teeth on the roller, 0.002m
The viscosity of the feed material as given by 8 as [7],

$$\mu = \mu_o \left(\frac{\gamma}{\gamma_o} \right)^{n-1} \qquad (8)$$

Where,
μ_o = viscosity at a reference temperature (T_0) and shear rate (γ_0), Nsm^{-2}
 $_o$ = reference shear rate of the material, s^{-1}
n = the power law index number, and is assumed to be unity.

μ_0 at room temperature is extracted from a plot of viscosity against shear stress of a defatted soya flour, Nsm^{-2}.

From equation 5, force of the roller (F_R) was calculated as 188.2 N, since there are two rollers, the force applied will be multiplied by 2 to give 376.4 N. Therefore the power of the pelletizer, P_p as given by equation 1 when calculated is 2.286 kW

Plate 1 shows the 2 rollers on the die. The rollers roll on the die causing compressive and shear forces on the feed which forces the mixture out of the holes to form pellets.
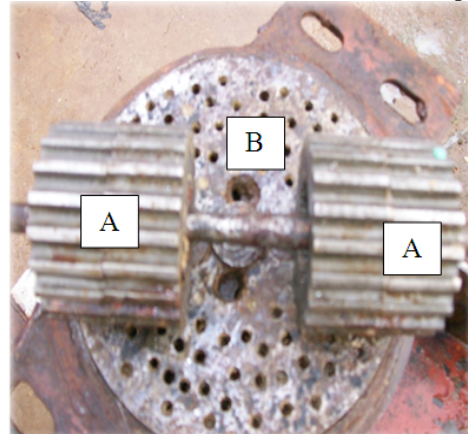
A - Roller and B - Die
Plate 1: The plan view of the rollers on top of the die

2.2.2 Analysis of forces acting between roller and die

The rollers and die surfaces were taken as frictional wheels and considered as toothed circular wheel (A) and plane circular wheel (B) respectively mounted on shafts. They were considered as having sufficient rough surfaces which press against each other as shown in figure 1.
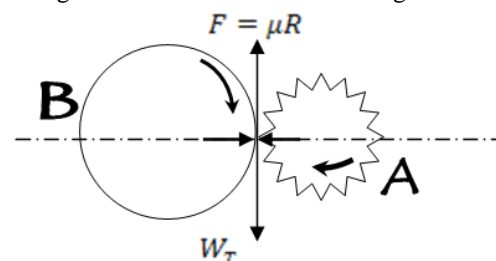

Fig.1. Friction wheels

The die (wheel B) is keyed to the rotating shaft and the roller (wheel A) to the shaft to be rotated. When the die (wheel B) is rotated by a rotating shaft, it rotates the roller (wheel A) in the opposite direction as shown in figure 1. The roller will be rotated by the die so long as the tangential force (W_T) exerted by wheel B does not exceed the maximum frictional resistance between the two wheels. But when the tangential force (W_T) exceeds the frictional resistance (F), there will be an occurrence of slip between the two wheels [8]. The teeth on wheel A act to pick up feed materials from the hopper and compress into the die holes and also to prevent slippage when in contact with wheel B. There are therefore internal reactions R_{NA} and R_{NB} acting on wheels A and B respectively. W_T is the tangential force developed as a result of the revolving die and F is the frictional force between the wheels.

$$W_T = \frac{2T_{max}}{D_G} \qquad (9)$$

Where,
T_{max} = Maximum torque developed by die shaft, N-m
D_G = Pitch circle diameter, m
The Frictional Force between the wheels is given by 10,

$$F = \mu R_N \qquad (10)$$

Where,
μ = Coefficient of friction of rubbing surfaces, 0.25.
R_N = Internal reaction of wheel, N
The pitch circle diameter of the roller is given as 60 mm and the mass of the rollers is 0.56 kg.
$R_N = W_T$ x acceleration due to gravity

The frictional force, if overcome by the die will result in slip of the roller on the die. In order to prevent slip, two tension housing, one on both sides of the pelleting chamber were incorporated to enable the adjustment of the rollers through its shaft. This increases the normal reaction (R_N) force on the roller and hence the frictional force between the revolving surfaces. Increase in the normal reaction (R_N) balances the tangential force (W_T) with the frictional force (F).

2.2.3 The pelletizer components
The basic machine parts (components) were designed on the basis of strength and rigidity.

A. Hopper design
The hopper is a truncated cone of gravity-flow type. The slant height is such that the content of the hopper empties unaided into the palletizing chamber. For dough like materials of moisture content higher than 20%, the hopper slant angle is preferably between 60-70° [9].

It is important to note that pressure is not distributed equally in all directions due to the development of arches and the frictional forces between the dough. Flow rate could be defined by 11 [9],

$$tB^{2.5}w = f\left(\frac{d}{B}\right) \qquad (11)$$

Where,
t = time in minutes for flow of 100g of solid
B = diameter of orifice in millimeters (mm)
W = Bulk density of materials in g/cm³.
d = average diameter of particle (mm)
f = coefficient of friction.

B. Die design
The die is made of mild steel whose density is 7850 kg/m³. The pelletizing chamber housing the die and rollers is a hollow cylinder originating below the hopper and terminating below the flat die. The diameter of the chamber is 165mm. The diameter of the die is taken to be 150mm to allow for free rotation in the chamber of 165 mm diameter. The die holes are of diameters of 5 mm and the arrangement considered to be a pressure vessel. The thickness of the die was calculated using 12 [8],

$$t = k.D_d \sqrt{\frac{p}{\sigma_t}} \qquad (12)$$

Where,
t = thickness of the die (mm)
k = coefficient of friction which depends on the material (mild steel)
D_d = diameter of the die, mm
P = compressive pressure of feed through the die holes. It is assumed that the maximum possible pressure developed by the rotating rollers will not exceed 2MPa.
σ_t = allowable design stress, MPa.

C. Die shaft design
The shaft was designed to carry the weight of the die and roller. It is subjected to bending and twisting moment from the contact between the roller and the die. The shaft diameter was designed on the basis of strength using 13.

$$T_e = \frac{\pi}{16}\tau d^3 \qquad (13)$$

Where,
T_e = equivalent twisting moment, N-m
$$T_e = \sqrt{(K_m \times M)^2 + (K_t \times T)^2}$$
K_m = Shock and Fatigue factor for bending,
K_t = Shock and Fatigue factor for torsion,
M = Bending moment, N-m
T = Torque acting on the shaft, N-m
Therefore torque, T transmitted by the shaft is given by 14,

$$T = \frac{P \ X \ 60}{2\pi N} \qquad (14)$$

P = power of electric motor (kW)
N = Speed of electric motor (rpm)

D. Design of belt drive to drive the die
Power is transmitted from the electric motor to the die through a V-belt placed vertically. In order to ensure firm grip between the belt and pulley, the required length of the belt was determined by using 15,

$$L = 2x + \frac{\pi}{2}(D + d) + \frac{(D - d)^2}{4x} \qquad (15)$$

Where
L = Length of belt (mm)
d = diameter of electric motor pulley, mm
D = diameter of die pulley, mm
x = distance between centre of pulleys, mm

E. Bearing selection
The load acts perpendicular to the axis of rotation of the bearing. The bearings were selected for the design based

on the type and direction of loading, life requirements, speed suitability and independence of speed with rolling friction. Basic dynamic load rating for radial ball bearing was calculated for as,

$$C = W\left(\frac{L}{10^6}\right)^{\frac{1}{k}} \qquad (16)$$

Where,
C = Basic dynamic load rating, kN.
W = Equivalent dynamic load rating, kN
L = Rating life of bearing, (the maximum number of bearing revolutions before the first evidence of fatigue), revolutions
K = 3, for ball bearings.

F. Selection of pellet cutting knife

The cutting knife is located below the revolving flat die. It is a stationary knife which cuts the emerging strands of feed into pellets as they are discharged from the pelletizer. The pellets cutting knife is made of 2 mm mild steel having length of 30 mm and sharpened at the edges. The vertical position of the pellet cutting knife from the die determines the length of the cut pellets [10].
Pellet cutting knife variables.
- Blade speed – Pelletizer has a stationary blade.
- Blade angle – 90° to direction of rotation of flat die.
- Blade sharpness – 0.05-0.1mm range. The sharper the blade the less the energy required for cutting.
- Blade Clearance – Blade clearance between cutting edge and die was set between 10mm - 15mm for convenience.
- Moisture Content – Cutting force increased slightly with major decrease in moisture content. Moisture content of 20-30% wet basis is well suited for cutting without high deformation tendencies.

2.3 Working Principle of the Pelletizer

The conditioned fish feed was introduced into the hopper and this flows down into the pelleting chamber by gravity flow. The electric motor drives the die by a shaft connected to its pulley. The rotation of the die initiates the rotation of the rollers which pick up the feed material and compress it into the die holes to form pellets. The emerging pellets are cut by a pellet cutting knife and discharged through the pelleting chamber to the discharge tray by a tangential force of the rotating die. The pellets are collected into a bowl and sun-dried for 2 hours before storage. Plate 2 shows the constructed pelletizer. Table 1 gives the specifications of the developed die and roller pelletizer.

2.4 Performance tests of the Pelletizer

Fish feed was compounded and tested in the laboratory, the initial moisture content was determined as 12% (wet basis). The feed was divided into three (3) parts and predetermined amount of water used to increase the moisture content to 20%, 25% and 30% wet basis. The machine was first run empty for twenty minutes to stabilize the speed under no load condition. The machine speed was varied from 507 rpm to 761 rpm by using different pulley sizes. Each of the moisture content (20%,

25% and 30%) was replicated thrice for each speed used to test the performance of the machine.

A Complete Randomized Design (CRD) was used for the experimental design. The Analysis of Variance (ANOVA) and Fisher-Least Significant Difference (FLSD) was used to investigate the effect of the parameters on the pelletizer performance at p 0.05 level of significance.
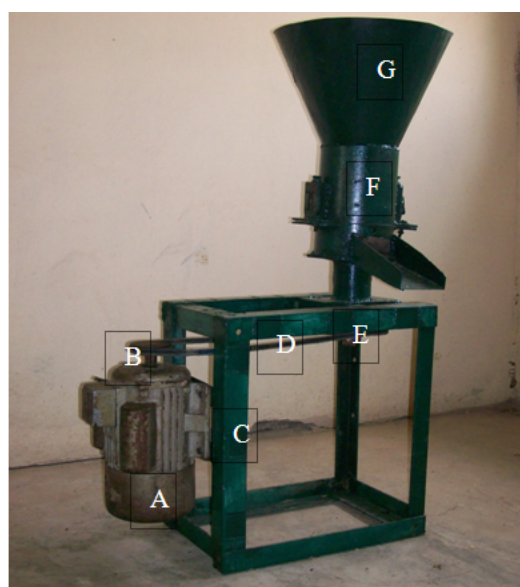

Plate 2: Pictorial view of the pelletizer
(A - Electric motor, B – Electric motor shaft and pulley, C – Frame, D - Electric motor/Die belt, E – Die pulley, F – Die and roller chamber, G – Hopper)

Table 1: The specifications of the developed die and roller pelletizer

1.	Type	Electric motor driven
2.	**Overall dimension**	
	Height	550 mm
	Length	480 mm
	Width	315 mm
3.	**Pelleting chamber**	
	Chamber	Dia. 165 mm
	Flat die	Dia. 152 mm
		Thickness 10mm
		Hole sizes 5 mm
	Rollers (2)	Dia. 60 mm
	Knife	2 mm x 30 mm

III. RESULTS AND DISCUSSION

Table 2 is the output of the pelletizer when tested at two speeds of 507 rpm and 761 rpm and three moisture content levels of 20%, 25% and 30%.

Table 2: Output of the Pelletizer at different speeds and moisture content levels

Speed(rpm)	M.C (%w.b)	Output (kg/hr)			Total	Mean
		Rep. 1	Rep. 2	Rep. 3		
507	20	21.6	25.9	28.8	76.3	25.4
	25	24.0	36.0	38.4	98.4	32.8
	30	31.2	38.2	33.6	103.0	34.3
761	20	30.0	30.0	27.6	87.6	29.2
	25	33.6	32.4	36.0	102.0	34.0
	30	40.8	40.8	39.6	121.2	40.4
Total					**588.5**	**32.68**

A. Effect of moisture content on pellet produced

Pellet forming rate was low for both speeds at moisture content of 20% relative to 25% and 30%. This may be because a reasonable amount of moisture is required to effect pellet formation by compression unlike extrusion. At the initial speed of 507 rpm, the pelletizer showed an increase in pellet output, from 25.4 to 34.3 kg/hr with a corresponding increase in moisture content from 20 to 30%. At the speed of 761 rpm, pellet yield of 40.4 kg/hr was highest at 30% moisture content, which is the most favourable moisture content for pelleting by compression when feed material is mixed with water at room temperature [11].

Table 3 is the ANOVA table for the effect of different die speeds, moisture content levels and their interaction on pellet output (kg/hr). From Table 3 only moisture content had significant effect on the pellet output. Table 4 is the mean effect of different die speeds and moisture content levels on the developed fish feed pelletizer performance at $p < 0.05$ level of significance. At the speed of 507 rpm there was a significant difference at moisture content levels of 20% and 25%, beyond these, there was no significant difference. At the speed of 761rpm there was significant difference at the three moisture content levels.

Table 3: A two-factor ANOVA of pelletizer feed output (kg/hr) for different die speeds and moisture content levels

Source of Variation	SS	Df	MS	F	P-value	F crit
Speed (S)	60.86722	1	60.86722	4.010726^{ns}	0.068333	4.747225
Moisture Content (MC)	307.4878	2	153.7439	10.13065^{*}	0.002648	3.885294
Interaction (S x MC)	17.78111	2	8.890556	0.585826^{ns}	0.571803	3.885294
Error	182.1133	12	15.17611			
Total	568.2494	17				

* = significant at p 0.05 level, ^{ns} = not significant at p 0.05

Table 4: Mean pelletizer feed output (kg/hr) as affected by different die speeds and moisture content levels.

Die speed (rpm)	Moisture content (%))		
	20	25	30
507	25.4^{a}	32.8^{bc}	34.3^{c}
761	29.2^{d}	34.0^{e}	40.4^{f}

Means having the same letter in the same row are not statistically different from each other at p 0.05 using t-Test.

The presence of water promotes gelatinization of starch components and stretching of expandable components [3]. If the moisture content level of the feed material is low the agglomeration of the material is reduced and unstable pellets are formed. However with optimum water content level, water stable pellets are formed which sink slowly into the pond and remain intact without dissolving for two or more days to allow the fish eat [6].

B. Effect of die speed on pellet produced

There was no significant difference in the output from the pelletizing machine at the speeds of 507 rpm (34.3 kg/hr) and 761 rpm (40.4 kg/hr) at 30% moisture content. This meant that the die-roller action even though faster at 761 rpm led to output that was not statistically significant.

However, a higher speed beyond 761 rpm may increase pellet output. Increase in speed means increase in the power of the electric motor to drive the pelletizer [10]. The speed of rotation of the die was linearly related to the tangential velocity with which pellets were discharged through the pelletizer discharge tray. At low speed, the pellets did not emerge efficiently as strands.

IV. CONCLUSION

The developed fish feed pelletizer is a way forward for the production of fish pellets for small scale farms in Nigeria. The pelletizer operates best at a moisture content level of 30%, forming high water stable pellets. At 30%

MC, pellet yield and formation was highest for both 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.

It was observed that at the speed of 507 rpm, the velocity of pellets discharged from the machine was low as pellets emerge slowly from the discharge tray. Pellets discharged at 761 rpm were faster than that discharged at 507 rpm. Thus an increase in speed of the machine led to an increase in the pellet discharge rate. Though there was no statistical significant difference in the speeds used, a higher speed greater than 761 rpm may prove otherwise. The operation of the machine does not require any high technical expertise, so the small scale fish farmer can conveniently use the machine. It is also affordable.

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