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ORIGINAL RESEARCH ARTICLE

MODIFICATION AND PERFORMANCE EVALUATION OF A FISH FEED PELLETIZING MACHINE

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ABSTRACT

A hand operated fish feed pelletizing machine for the production of fish feed with through put capacity of 2.56 kg/h was modified, fabricated and evaluated due to non-availability of electricity in the rural area, drudgery and low throughput capacity. It consists of a hopper, barrel that houses the screw conveyor (auger), the cutting knife, and the die orifice. Power supply to the machine is a 6-kw petrol engine. It was observed that the pelletizing efficiency and throughput capacity increase with proportionality of smallness of die diameter. The modified machine test results showed highest throughput capacity of 162.8 kg/h with maximum pelletizing efficiency of 85.3%. The total production capacity of the machine was 150 tons per day, which is adequately to feed up to 3,000 fish per day. The adoption of the pelletizing machine by farmers will enable them produce their own feed from local plant and animal waste source thereby alleviating the problems associated with the sourcing of imported feeds.

1.0 Introduction

Aquaculture is fast developing in Nigeria, though the yields obtained from the fish farms are still insufficient. The low yield has been attributed to inadequate supply of balanced fish diets (Faturoti and Akinbote, 1986; Gabriel et al., 2007; Galen et al., 2008). Now, only few organizations are engaged potential feed manufacturing in the country and it is still not possible to meet the large potential demands for feeds. However, there is a large potential of feed ingredients from local plant and animal waste sources, which are capable of supplying the nutritive requirement of fish (Mercier, 1980). Pellet presses for the production of fish feed was first introduced in the mid-1920, (McEllhiney, 1987). Since then, production and demand for pelletized feeds for fish has grown until now. Over 98 percent of all fish feeds are fed in pelletized form in Europe and North America. (Diarra et al., 2001; Booth et al., 2002 and Eyo, 2002). Yet, the demand and production of pelletized feeds for fish are high in many African countries, in spite of the known feeding and handling advantages of pelletized feeds (Anon et al., 1991; FAO 2000; Burmamu et al., 2015 and Heuzé et al., 2015).

A pelletizer consists 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 (Mercier, 1980; Ikedudu et al., 2015). The feed is forced through a restricted opening (the die) at the discharge end of the screw. Fish feed technology is one of the least developed sectors of aquaculture particularly in Africa and other developing countries of the world.

It is one of the fundamental challenges facing the development and growth of aquaculture in African. Fish feed development in Sub-Saharan African has not made any significant progress in aquaculture as expected. It has been observed that the research on inexpensive feed ingredients have not contributed meaningfully to aquaculture development in Africa and suggested that more researches on how best plants proteins can be used, as fish feeds are required. Development and management of feed play very vital role in aqua cultural growth and expansion. In fact, a major factor that determines the profitability of aquaculture venture. Feed accounts for at least 60% of the total cost of fish production in Africa and this largely, determines the viability and profitability of the fish farming enterprise, (Orimaye et al., 2019; Regupathi, 2019). As aquaculture becomes intensive, most farmers in, Africa and Nigeria inclusive depend largely on imported fish feeds. According to (Harper, 1989; Del Valle and Aguilera, 1991), factors that influence the nature of the pelletized product are the operating condition of the machine such as the temperature, pressure, diameter of the die aperture and the shear stress. Others includes the rheological properties of the feed components such as moisture content; the physical state of the materials used; and their chemical composition, particularly the amount and type of starches. Protein and fats content also are factors that influence the nature of the pelletize produce. Leakage flow, which is similar to pressure flow, which was driven by a pressure gradient. This flow occurs in the clearance between the screw flights and the barrel within any slot in the barrel wall or surfaces and can as well affect the nature of the pelletize products.

From preliminary investigation, there are some existing manually (hand operated) feed pelletizing machines. However, these machines have the following limitations: low efficiency because of low speed from hand auger driven, and rapid wear and tear of the auger shaft, (Adapa et al., 2002; El-Nono, 2005; Amadi, 2007) and wobbling of shaft. Therefore, this study presents a modification of hand-operated pelletizing machine. Its throughput capacity was increased and its efficiency evaluated.

2.0 Materials and Method

2.1 Materials

All the materials for the modification of the pelletizing machine were sourced locally.
Materials used in the construction of the Pelletizing Machine incudes: Metal sheet, Angle iron bars, Pulleys, belts and Prime mover.

2.2 Design Considerations

The following factors were put into considerations in carrying out the modification; weight of the machine, physical characteristics of the feed materials (rolling resistance, friction), screw auger speed, prime mover power output and the fabrication materials selection as reported by (Harper, 1989; Abubakre, 2014; Ambalkar 2018). Materials selection for modification of pelletizing machine are presented in Table 1.

Table 1: Materials Selection for Modification of Pelletizing Machine

SN	Machine Component	Materials	Factor	Reason For Selection
1	Hopper	Mild Steel	Rigidity	Cheap available and durable
2	Support Base	Mild Steel	Strength	Strong , Cheap and available
3	Pulley	Mild Steel	Strong and Tough	Strong not easily defected
4	Shaft	Stainless Rod	Hard and Tough	Corrosion resistance, strong available and not easily defected
5	Auger	Mild Steel	Strong and ability to Withstand Impact stress	Corrosion resistance and strong
6	Concave Drum	Mild Steel	Hard and tough	Very strong and corrosion resistance.

2.2 Design Calculations

The following design calculations for the various components of the Pelletizing Machine were considered and carried out as reported by (Harper, 1989; Veronica, 2018).

2.2.1 Power Required by the Screw Auger

The power (P) required in operating the screw auger was computed using equation expressed by (Harper, 1989) as:

$$P = 0.7355\ CLQ \tag{1}$$

where: P = power required, kW;
C = constant, 0.3;
L = length of conveyor, m;
Q = capacity of screw auger drive (tones/hours) $10\text{kg} = \frac{10}{1000} = 0.01\ \text{t/hr}$

2.2.2 The Drive

A V-belt and pulley arrangement was selected to transmit power from the prime mover to the shaft of the machine's mixing unit. This was because the v-belt drive is flexible, simple to use, and requires low maintenance cost. Moreover, the v-belt has the ability to absorb shocks thereby mitigating the effects of vibratory forces.

2.2.3 Pulley Diameters

The diameter of the pulley for the screw auger was calculated using the expression by equation 2 below:

$$D_2 = \frac{N_1 D_1}{N_2} \tag{2}$$

where:
N_1, N_2 = Speeds of prime mover pulley and mixing auger pulley respectively in rpm;
$D_1 D_2$ = Diameters of prime mover pulley and mixing auger pulley respectively, mm.
Prime mover pulley diameter and auger pulley diameter is 1:2.4
Diameter of motor pulley $D_1 = 103$ mm

2.2.4 Belt Speed

The belt speed for the mixer driver was calculated using equation below:

$$v = \frac{\pi D_2 N_2}{60} \tag{3}$$

where: v = belt speed, m/s

2.2.5 Belt Length

The relationship below was used in determining the belt length for the mixing drive.

$$t = 2c + 1.5(d_1 + d_2) + \frac{(d_1 - d_1)^2}{2C} \tag{4}$$

where:
t =Belt length in m
c =Centre distance between pulleys (m)
d_1=Pitch diameter of driver pulley (m)
d_2= Pitch diameter of driven pulley (m)

2.2.6 Number of Belt required

The number of belt required to transmit the power from the prime mover to the shaft of the mixer auger was computed using the equation

$$N_B = P_d(T_1 - T_2)V \quad (5)$$

where:
N_B =Number of belts; P_d= designed power,
T_1, T_2= tensions on the tight side and slack side of the belts, N; v = belt speed rpm

2.2.7 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 material of moisture content higher than 20%, the hopper slant angle between 60°-70° was preferable because of the angle of repose of feed material. It was important to note that pressure is not distributed equally in all directions due to development of arches and the frictional forces between the dough.

Flow rate was determined by:

$$tB^{2.5}W = f\left(\frac{D}{B}\right) \quad (6)$$

where:
T = Time ion minutes for the flow of 100g of solid
B = Diameter of Orifice in (mm)
W = Bulk density of materials g/mm^3
D = Average diameter of particles (mm)

2.2.8 Prime Mover Power Requirement

Power = Force ×Velocity
Power = Force × Screw Circumference × rpm

$$W = P \times \pi DN/60 \quad (7)$$

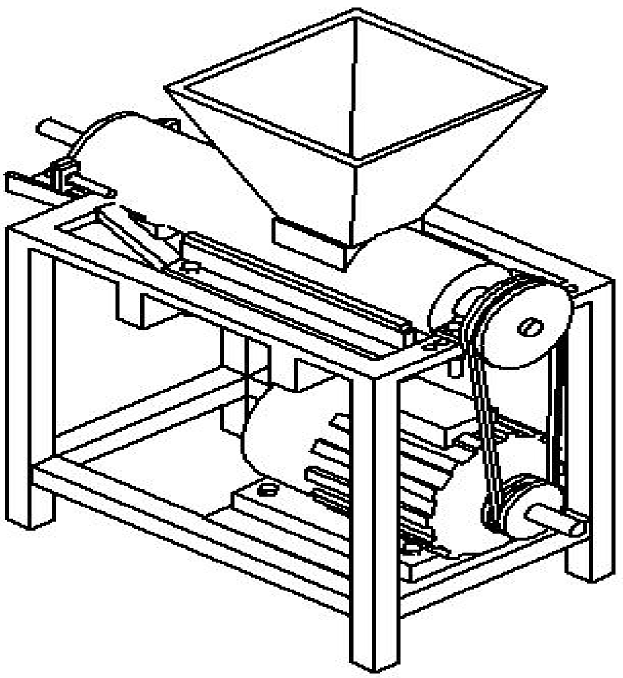
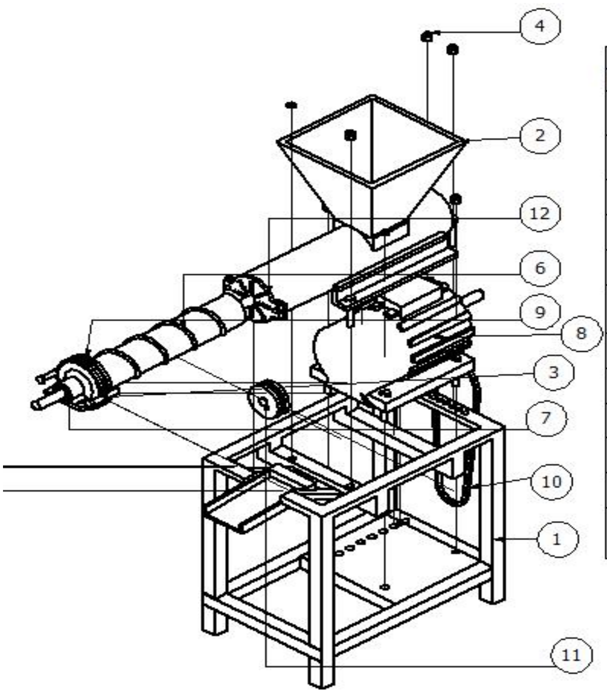


Figure 1: Isometric View of Fish Feed Pelletizing Machine



PARTS LIST		
ITEM	QTY	PART NUMBER
1	1	machine frame
2	1	machine house
3	10	bolt
4	10	washer
5	9	nut
6	1	pelletizer screw auger
7	1	bearing
8	1	electric motor
9	1	pulley
10	1	belt
11	1	pulley
12	1	pelletizer plate

Figure 2: Exploded view Drawing of Fish Feed Palletizing Machine

Figure 3: Modified Fish Feed Pelletizing Machine

2.2.9 Screw conveyor

The crew conveyor is a worm wound round a cylindrical shaft. The maximum outer diameter of the worm was 78mm to give a clearance between the screw and the barrel. The screw conveyor was carried on a solid shaft of 25mm, which is driven by pulley, Figure 2.

2.2.9 Shaft Diameter

The shaft used in construction of the palletizing machine was classified as transmission shaft. Also using the allowable shear stress as 42 Mpa, the line shaft is rotating at 400rpm and transmitting 18Kw. To find the diameter of the shaft;

$$T = P\frac{60}{2\pi N} \tag{8}$$

where:

T =Transmitting force (N),

P = Power (W)

$P = 18 \times 10^3 . \frac{60}{2\pi} \times 400.$

$430\mathrm{Nm}$ or 430 x 103Nmm

But, $T = \frac{\pi}{16} \times \tau \times d^3 430 \times 10^3$

= $\frac{\pi}{16} \times 42 \times d^3 430 \times \frac{10^3}{16}$

d = 25.08mm

d≃ 25mm

2.3 Construction and Assembling of Component of Pelletizing Machine

Construction and Fabrication of the Pelletizing Machine was carried out through various stages and processes, which includes marking and cutting out required dimensions of materials, welding, bore-ring, coupling, filling and painting process. The processes were carried out in stages and gradually.

2.4 Machine Test and Evaluation Procedure

The machine evaluation procedure used in this study was adopted from (Rosen, et al., 1979). Compounded fish feed prepared by locally sourced materials was used for the test. The ingredients were soya bean meal, groundnut cake, maize, fishmeal, palm kernel, cottonseed, leguminous crops, green plant meals, and premix.

Some starch and little water that serve as binders were added to the compounded feed, and it was thoroughly mixed with hand manually. The compounded mix was fed through the machine's hopper. Three worm-like fish pellet die diameters were used. They are the 6mm diameter die (for worm-like feeds for day old to 4 weeks old fish), 10mm diameter die (for worm-liked feeds for 5-11weeks old fish), and 13 mm diameter die (for fish 12 weeks old to harvest time), according to fish farmer's association annual report, 2019. Then the machine was put on. After two minutes, 50 mm length worm-like pellets were produced and cut off. The cutting was done automatically by a cutter at the end of the drum. The machine was working for half an hour after which the products were weighed and the data obtained were analyzed.

2.5 Data Collection and Analysis

Data were collected to study if there are any significant differences in the fish feed production rate (kg) of the palletizing machine between three worm-like fish pellet die diameters of depth 6mm diameter die, 10mm diameter dies, and 13 mm diameter die. The production rate for each diameter-die test was conducted in six (6) runs to minimize error in results. One-way Analysis of variance (ANOVA) was used to analyze the data to test if there were significant or non-significant differences among the production rate of the 6mm, 10mm, and 13mm diameter dies. LSD method of Tukey's means separation method ($\alpha < 0.05$) was deployed to determine significant differences between the mean production rates per 30 minutes using statistical analysis systems (SAS 9.2) 2010 software.

3.0 Results and Discussion

Table 1 presents the average values of the production rate of 6mm, 10mm, and 13mm dies as 150.6. kg/h, 140.9 kg/h, and 135.1 kg/h by the pelletizing machine respectively. The length of worm-like feed was 50 mm, extrusion pressure of production for the 6, 10, and 13 mm worm-like pellets were 5.2, 5.9, and 6.9 kN/m^2 respectively. The extrusion pressure was observed to have risen with an increase in the drag force when the die diameter decreased. This may be due to frictional force increased with a large contact area of die diameter.

Table 1: Average value of production rate of 6, 10, and 13 mm Dies for six (6) trials.

Worm-like pellet production rate in 30 min	1	2	3	4	5	6	Average production rate per 30 min (kg/30 min)	Average production rate per hour (kg/h)
6 mm Die (kg)	7	75.8	76.5	75.2	75.6	74.2	75.3	150.6
10 mm Die (kg)	7	69.3	70.7	71.2	69.6	71.5	70.5	140.9
13 mm Die (kg)	6	68.2	67.5	66.8	67.7	68.3	67.6	135.1

The design capacity of the screw conveyor for worn-like fish feed production was 162.8 kg/h. However, it was observed that when the machine was operated, actual production was affected by energy losses due to friction. The production capacity losses were 7.4%, 13.4% and 17% for the 6mm, 10mm and 13 mm die Pelletizer respectively. The average production rates which were 150.6 kg/h, 140.9 kg/h, and 135.1 kg/h for the 6 mm, 10 mm, and 13 mm die respectively was found to be reduced with increasing die diameter which is in agreement with studies by (Schultz, 1990) and (Olafsdottir et al., 2000).

Table 2 shows the result for one-way analysis of variance (ANOVA) to determine if the production rate in the Fish feed pelletizing machine was different for worm-like fish pellet die diameters of 6mm, 10mm, and 13 mm diameter die at a production rate of 30 min/Kg. The three dies were classified into three groups: 6mm diameter die (for worm-like feeds for day old to 4 weeks old fish), 10mm diameter die (for worm-liked feeds for 5-11weeks old fish), and 13 mm diameter die (for fish 12 weeks old to harvest time), according to fish farmer's association annual report, 2019. Results indicated that There was a statistically significant difference between dies diameter as determined by a one-way ANOVA, $F(2, 15) = 145.69$, $p = .0001$.

Table 2: Analysis of Variance Worm-like pellet production rate in 30 min

Source	df	Adj SS	Adj MS	F-Value	P-Value
Die	2	183.023	91.5117	145.69	0.0001
Error	15	9.422	0.6281		
Total	17	192.445			

Figure 4 presents post-hoc comparison using Tukey's means comparison because one of the mean production rates is different among worm-like fish pellet die diameters of 6 mm, 10 mm, and 13 mm diameter die at a production rate of 30min/Kg. The post hoc test means separation is demonstrating that means with the same letters are not significantly different. The 6 mm fish pallet die gave the highest production rate of 150.60 kg/hr. the 13 mm pallet die gave a production rate of 135.1 kg/hr. The letters a,b, and c indicate that none of the mean production rate are equal. We may conclude that the 6mm pallet die will be recommended for fish palletizing operations.

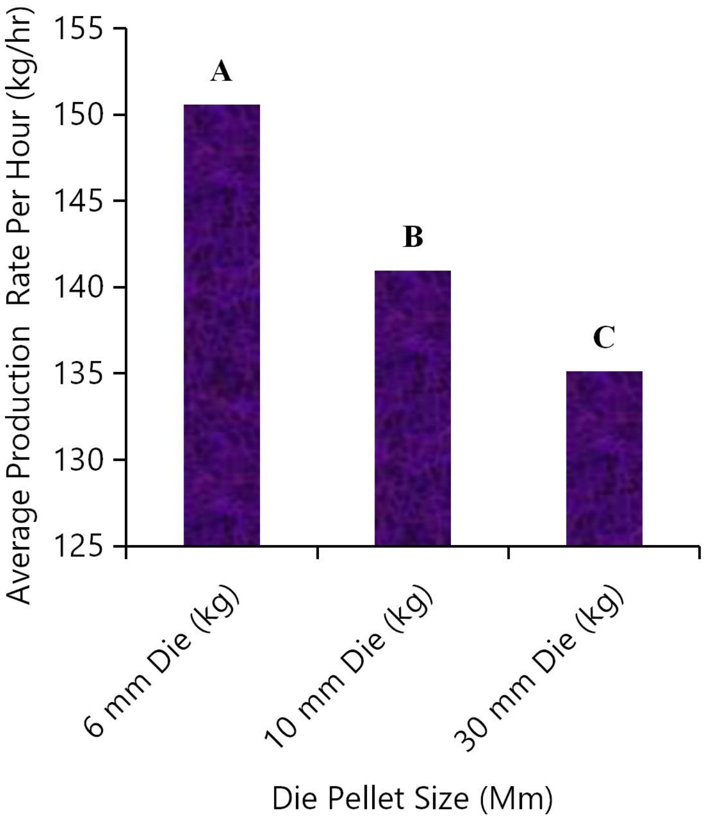


Figure 4: Achieved Average Production rate for Different Dies.

4.0 Conclusion

A Feed Pelletizing Machine was modified and evaluated. The modified machine test results showed higher throughput capacity of 162.8 kg/h with maximum efficiency of 85.3%. However, practically only 83% of the production capacity was achieved during the test of the machine because of energy loss due to friction in the die cavities.

5.0 Recommendation

The following are the recommendations made for further research work;
More pellet plate recommended standard die diameter for standard pelletize fish feed should be designed and tested with the machine to further evaluate the effect of the engine speed on the pelletizing efficiency on several plate dies.
The effects of the engine speed on the. pelletizing efficiency should further be evaluated.

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