Design, Fabrication and Performance Evaluation of Indigenous Fish Feed Pelletizing Machine for Low Income Farmers in Nigeria

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Authors’ contributions

This work was carried out in collaboration between all authors. Author POA did the design of the machine, supervised the fabrication and performance evaluation of the machine. Authors OSO and IOO wrote the first draft of the manuscript, managed the literature searches, carried out the performance evaluation and did the statistical analysis. All authors read and approved the final manuscript.

ABSTRACT

The design, fabrication and performance evaluation of a fish feed pelletizing machine for low income farmers was carried out with the view to encourage local technology, as most of the fish feed pelletizing machines available are imported. The fish feed pelletizer is powered by an electric motor and it works by the rotation of a screw auger which propels the feed mix through a die. The screw auger is enclosed in the auger casing and is propelled by an electric motor with the aid of belt and pulleys. The screw auger is fed through a hopper, which is able to hold a large quantity of the feed mix at a time. The machine was tested using different die diameters of 2 mm, 4 mm and 6 mm. The test was conducted at different moisture content of 10%, 15%, 20%, 25%, 30% and 35% wet basis. The machine test results showed that the pelletizing efficiency increases as moisture content and die diameter increase. The machine throughput also increases with both moisture content and die diameter.
content and die diameter. Highest efficiency of 98% was obtained when the moisture content was maintained at 25% wet basis and the feed materials were made to pass through 6 mm die diameter. The total cost of the design and construction of this pelletizing machine was one hundred and five thousand naira (N105, 000.00) which is still reasonably affordable by small scale farmers.

Keywords: Design; fabrication; performance evaluation; fish feed; locally made; pelletizing machine.

1. INTRODUCTION

In Africa, fish is a significant source of animal protein accounting for up to 80% of daily animal protein intake [1]. Fish is an important part of the household diet in Nigeria which is the most populous nation in Africa. Fish makes up around 40% of the country's protein intake, with fish consumption at 13.3 kg/person/per year. Total fish production per year is more than 1 million metric tons (313,231 metric tons from aquaculture and 759,828 metric tons from fisheries). The majority of this fish is consumed domestically, while around 10% is exported [2].

The supply of fish in Africa is in crisis, the sub-Saharan African (SSA) region is the only region of the world where there is either no notable increase in per capita supply is declining and the apparent per capita fish consumption is the lowest in the world [3]. A report by Daily Trust [4], stated that Nigerian fish production dropped in 2017. This was attributed to high cost of fish feeds, poor market, non-access to credit facilities, aquatic pests and diseases, among others. High cost of fish feeds happens to be the major setback to production of fish in Nigeria. Due to devaluation of naira by Nigerian government in 2016, in the last two years, fish farmers have shown more preference for locally produced fish feed as they can no longer afford to buy imported feed. Studies have shown that, the challenges in making fish feeds in Nigeria are not in sourcing the ingredient but on the techniques involved in formulation and processing [5]. There are two types of pellet making machines that are known universally. These are the disc-die type, and ring die type, [6]. Asians and Europeans have produced pelletizing machines of these types. Most fish feed pelletizing machines imported from Europe and America, process fish feeds by extrusion and these feeds exhibit floating characteristics. The downside is that the machines are not affordable by low income aquaculture farmers. Local production of fish feed is very crucial to the development and sustainability of aquaculture in Africa especially, in the rural areas. For aquaculture to thrive and to bridge the already existing wide gap between fish demand and supply, the vital role of locally produced fish feed in reducing production cost, thereby making fish far attractive to both private and commercial investors and ultimately boost fish production cannot be overemphasized. In other to meet the demand for fish in the market, there is need to increase the production of fish in the market. Considering the low production by the Fish farmers, this has been traced to the inadequate fish feed which is caused by the high cost of importing fish feed and fish feed making machine in the market. Hence there is need to improvise a domestic locally fabricated machine which will help meet up with the demand of fish feed in the production of fish for adequate protein in the food chain. Technological advanced pelletizing machine imported from Europe and America are too expensive and complex to operate by small and medium scale fish and livestock farmers in Nigeria. Therefore, it is necessary to design and fabricate a pelletizer that is durable, affordable and safe to operate. Also, it is essential to have a locally made fish feed pelletizing machine which is durable and affordable to small and medium scale fish and livestock farmers in the country in order to reduce the burden of high cost of imported pelletizing machine.

Therefore, this paper is majorly about the design, construction and performance evaluation of locally fabricated fish feed pelletizing machine to produced fish feed in enhancing the development, growth and expansion of aquaculture in Africa.

2. DESCRIPTION AND DESIGN OF THE MACHINE

2.1 Machine Description

The fish feed pelletizing machine comprises of some basic components like the hopper through which the feed meal is fed into the machine. The
pelletizing chamber consists of auger or screw which propels the fish feeds towards the orifice. The fish feed pelletizing machine is powered by 5hp electric motor. The discharge output pellets are formed by compacting and forcing the fish feed through a die. The die has opening orifices through which the fish feed comes out in pellet form. Three different dies of orifice diameters of 2 mm, 4 mm and 6 mm were produced for the machine. The orthographic and isometric drawings are respectively presented in Fig. 1(a) and 1(b).

2.2 Design Considerations and Calculations

In designing the machine, cost, corrosion, durability, overall weight and size were considered. Stainless steel was used for all parts of the machine making contact with fish feed in order to make it durable and to avoid corrosion; while the frame and other components were made with mild steel. The machine components are detachable in order to make it portable. The summary of design consideration and calculations is as follows:

2.2.1 Cost

The design of the fish pelletizing machine is aimed at using cheap and affordable materials for cost reduction and affordability of the pelletizing machine. Stainless steel and mild steel were the preferred choice of materials used.

2.2.2 Resilience

The component parts used posed the resilience properties to absorb energy, resist shock and impact loads. These properties were considered based on the ability of the pelletizing machine to resist any external shock or load.

2.2.3 Durability

The component parts selected are strong and durable with corrosion resistance and longer life span in order to give the users the expected satisfactions with profitable potentials of the fish pelletizing machine.

2.2.4 Hopper capacity

This is made of mild steel plate of 2 mm thick. It is the container in which the substrates (i.e. the materials to be pelletized) are fed through.

2.2.5 Industrial bearing

Two industrial bearings were placed in position with bolts and nuts on three points of the shaft. The bearings were enclosed in the bearing house through which they are bolted to the bearing seat of the pelletizing chamber.
2.2.6 Screw design

The degree of intermeshing is determined by the shaft center line and the desired screw distance with zero clearance fully intermeshing. The design of the screw is to compromise between power and the available volume of materials for convey.

2.2.7 Screw speed

The degree of barrel fill has a direct effect on the screw speed, and the shear stress on the material to be pelletized. The screw speed is a factor for the determination of maximum volumetric output of the pelletizing machine and it is one of the main reasons why many manufacturers design machine to run at the maximum speed with mechanical tolerance usually 1400-1500 rpm.

2.2.8 Die design

The die area of a pelletizing machine is the section where the pelletizing of the materials occurs after the feed materials leave the pelletizing screw. It consists of transition, distribution and dies plate.

Table 1. Material selection

<table>
<thead>
<tr>
<th>S/N</th>
<th>Machine components</th>
<th>Materials</th>
<th>Factor</th>
<th>Reason for selection</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Hopper</td>
<td>Mild Steel</td>
<td>Rigidity</td>
<td>Cheap, Available, Reliable and Durable</td>
</tr>
<tr>
<td>2</td>
<td>Support base</td>
<td>Mild Steel</td>
<td>Strength</td>
<td>Strong, Cheap, Available</td>
</tr>
<tr>
<td>3</td>
<td>Pulley</td>
<td>Mild Steel</td>
<td>Strong and Tough</td>
<td>Strong and not easily defected</td>
</tr>
<tr>
<td>4</td>
<td>Shaft</td>
<td>Stainless rod</td>
<td>Hard and Tough</td>
<td>Corrosion resistance, Strong, Availability and not easily deflected</td>
</tr>
<tr>
<td>5</td>
<td>Auger</td>
<td>Stainless Steel</td>
<td>Strong and ability to withstand impact stress</td>
<td>Corrosion resistance and Strength</td>
</tr>
<tr>
<td>6</td>
<td>Concave Drum</td>
<td>Stainless Steel</td>
<td>Hard and Tough</td>
<td>Very strong and Corrosion Resistance</td>
</tr>
</tbody>
</table>

2.3 Design Calculations

2.3.1 Hopper

Fig. 1c. Truncated Pyramid

Fig. 1d.
AB = 360mm  
BC = 380mm  
h = 350mm  
FG = 135mm  
EF = 120mm  

The upper length AB of the hopper was calculated as:

\[ \frac{FG}{AB} = 1:3 \]
\[ 1:3 = 120 \times AB \]
\[ AB = \frac{120 \times 3}{1} = 360\text{mm} \]

The height h, between the upper and the lower face of the hopper is calculated as:

\[ \tan 68^\circ = \frac{h}{120} \]
\[ h = 120 \times \tan 68^\circ \]
\[ h = 297.010\text{mm} \]
\[ h = 300\text{mm} \]

\[ H = h + H^1 \]
\[ H = 300 + H^1 \]
\[ FJ/\text{DI} = H^1/h + H^1 \]
\[ 60/180 = H^1/300 + H^1 \]
\[ H^1(180) = 60(300 + H^1) \]
\[ 180H^1 - 60H^1 = 1800 \]
\[ H^1 = 18-00/120 \]
\[ H^1 = 150\text{mm} \]

Therefore total height, \( H = (300 + 150) \text{ mm} \)

\( H = 4 \)

Volume of hopper = Volume of larger pyramid \( - \) Volume of smaller pyramid

Volume of hopper \( = \frac{1}{3} \) base area \( \times \) height

\[ = \frac{1}{3} a^2H - \frac{1}{3} b^2H^1 \]
\[ = \frac{1}{3} (a^2H - b^2H^1) \]
\[ = \frac{1}{3} (360^2 \times 450) - (120^2 \times 150) \]
\[ = 19440000 - 720000 \]
\[ = 18720000\text{mm}^3 \]
\[ = 18.720000\text{cm}^3 \]
\[ = 0.01872\text{m}^3 \]
2.4 Determination of the Driven Pulley Diameter

The diameter of motor is 65 mm = 6.5 cm and the motor speed chosen for electric motor is 1400 rpm.

Assuming the machine works averagely between 45% to 50% efficiency, the machine speed will be 650 rpm [7].

Machine pulley diameter, $D_2 = ?$
Motor Pulley diameter, $D_1 = 6.5 cm$
Electric motor Speed, $N_1 = 1400$ rpm
Machine speed, $N_2 = 650$ rpm

Therefore;

$$N_1 D_1 = N_2 D_2$$  \hspace{1cm} (2)

$$D_2 = \frac{(N_1 D_1)}{N_2}$$

$$= \frac{(1400 \times 6.5)}{650}$$

$$= 9100 \div 650$$

$$D_2 = 14 \text{ cm}$$

Transmission ratio is given as $D_2 / D_1$

$$\frac{D_2}{D_1} = 14 / 6.5$$

$$= 2.15$$

Therefore the transmission ration is calculated as;

1: 2.15

2.5 Determination of Belt Length

In determining the length of belt, the relation is given as;

$$L = 2C + 1.57 (D + d) + \left(\frac{(D + d)^2}{4C}\right)$$  \hspace{1cm} (3)

Where;
- $L$ = length of belt
- $C$ = centre distance between two pulleys
- $D$ = Larger pulley diameter
- $d$ = smaller puller diameter

For standard belt, Centre distance is given as 59 cm = 590 mm.

$D = 14$ cm, previously calculated
$d = 6.5$ cm, assumed

$$L = 2(59 + 1.57 (14 + 6.5) + \left(\frac{(14 + 6.5)^2}{4(59)}\right)$$

$$L = 118 + 32.185 + \frac{56.25}{236}$$

$$= 118 + 32.185 + 0.2383$$

$$= 150.42 \text{ cm}$$

$$= 150.42 \times 10^{-2} \text{ m}$$
2.6 Determination of Belt Speed

Belt speed is represented by:

\[ V = \frac{\pi DN}{60} \]

Where;

\( V \) = speed of belt (m/s)
\( D \) = diameter of the smaller pulley (6.5cm = 6.5 \times 10^{-2}); assumed.
\( N \) = number of revolution per minute

(Assuming the machine is to be operated at 90% maximum speed)

Actual speed will be = \( 1400 \times \frac{90}{100} \)
= 1260rpm

Belt Speed;

\[ V = \frac{\pi DN}{60} \frac{3.142 \times 6.5 \times 1260}{60} \]
\[ = \frac{10^2 \times 25732}{60} \]
\[ = \frac{25733}{60} \]
\[ = 4.29\text{m/s} \]

2.7 Determination of Belt Tension

![Diagram of belt on drive and driven pulley]

Fig. 2. The belt on the drive and driven pulley

Where,

\( T_1 \) = Belt tension on the tight side
\( T_2 \) = Belt tension on the slack side
\( \beta \) = Angle of inclination of the belt
\( \alpha \beta \) = Angle of wrap on the bigger pulley
\( \alpha S \) = Angle of wrap on the smaller pulley

\[ \sin \beta = \frac{R-r}{C} \]  

(5)
Where,

\[ C = \text{Centre distance} \]
\[ R = \text{Radius of bigger pulley} \]
\[ \omega S = 180^\circ - 2\sin^{-1}\left(\frac{R-r}{C}\right) \] (6)
\[ \omega \beta = 180^\circ + 2\sin^{-1}\left(\frac{R-r}{C}\right) \]
\[ \omega S = 180^\circ - 2\sin^{-1}\left(\frac{70-32.5}{590}\right) \]
\[ = 180 - 7.3 \]
\[ = 172.7^\circ \]
\[ = 3.01 \text{ rad} \]
\[ \omega \beta = 180^\circ + 2\sin^{-1}\left(\frac{70-32.5}{590}\right) \]
\[ = 180 + 7.3^\circ \]
\[ = 187.3^\circ \]
\[ = 3.27 \text{ rad} \]

For smaller pulley,

Since \( \omega S = 3.01 \text{ rad} \),
Groove angle \( \theta' = 35^\circ \) for V-belt
Coefficient of friction \( \mu = 0.15 \)
\[ \mu \omega \theta = \frac{\mu \omega \theta}{2\sin \theta} \]
\[ = 0.15 \times \frac{3.01}{2\sin 35} \]
\[ \mu \omega \theta = 4.49 \]

For larger pulley,

Since \( \omega \beta = 3.27 \text{ rad} \),
Groove angle \( \theta' = 35^\circ \) for V-belt
Coefficient of friction \( \mu = 0.25 \)
\[ \mu \omega \theta = \frac{\mu \omega \theta}{2\sin \theta} \]
\[ = 0.25 \times \frac{3.27}{2\sin 35} \]
\[ \mu \omega \theta = 15.16 \]

The pulley that governs the design is the one with smallest angle of wrap [7].

\[ \frac{W_2}{W_1} = \frac{h}{h+t} \] (8)

Where,

\( W_1 = \text{Nominal top width of the belt} \)
\( W_2 = \text{Nominal bottom width of the belt} \)
\( t = \text{Nominal height (thickness)} \)
Groove angle = \( 35^\circ \) as earlier stated

For standard V-belt,

\( W_1 = 3.125 \text{cm} \)
Thickness = 1.875cm (assumed)
\( h = 1.5625 \times 1/ \tan 17.5 \)
\( = 4.96 \text{cm} \)
From equation (8),
\[
W_2 = \frac{h}{h + t}
\]
\[
W_1 = \frac{h}{h + t}
\]
\[
W_2 = W_1 h (h + t)
\]
\[
= 3.125 \times 4.96 / (4.96 + 1.875)
\]
\[
= 15.488 / 6.831
\]
\[
= 2.27 \text{ cm}
\]

Area of the belt = width of the belt \times \text{thickness of the belt}
\[
= 3.125 + 2.27 / (2 \times 1.875)
\]
\[
= 5.06 \text{ cm}^2
\]
\[
= 5.06 \times 10^{-4} \text{ m}^2
\]

Density of rubber belt is 1250 Kg/m$^3$ [7]

Mass of belt = Density \times \text{Area} \times \text{Length}
\[
= 1250 \times 5.06 \times 10^{-4} \times 150.42 \times 10^{-2}
\]
\[
= 0.95 \text{ Kg}
\]

Belt tension can now be determined by using,
\[
T_1 = \frac{MV_2}{M} \frac{\mu \omega \theta}{\sin \theta / 2}
\]  \hspace{1cm} (9)

Where,
\[
\mu = \text{coefficient of friction} = 0.15
\]
\[
\omega = 3.01 \text{ rad}
\]
\[
\text{Mass per unit length} = 1250 \times 5.055 \times 10^{-4}
\]
\[
= 0.63188 \text{ kg/m}
\]
\[
V = \text{belt speed} = 4.29 \text{ m/s}
\]
\[
\theta = \text{angle of groove} = 35^\circ
\]

\[
T_1 = \text{tension on the tight side of the belt (N)}
\]
\[
T_2 = \text{tension on the slack side of the belt (N)}
\]

Mass of belt per meter = Density \times \text{Area}
\[
= 1250 \times 5.055 \times 10^{-4}
\]
\[
= 0.63188 \text{ kg/m}
\]
\[
T_1 - \frac{MV_2}{T_2} - MV_2^2 = \mu \omega \theta
\]  \hspace{1cm} (9)

Recall
\[
T_1 - \frac{0.63188 \times (4.29)^2}{T_2} = 0.63188 \times (4.29)^2 = \frac{0.15 \times 3.01}{\sin 1/2 (35)}
\]

\[
T_1 - \frac{11.63}{T_2} - 11.3 = 4.49
\]
\[
4.49(T_2 - 11.3) = T_1 - 11.63
\]
\[
4.49(T_2 - 11.3) + 11.63 = T_1
\]
\[
4.49T_2 - 52.22 + 11.63 = T_1 \hspace{1cm} \text{.........(i)}
\]

Note, Power transmitted by motor, $P$ is given as
\[
P = (T_1 - T_2) V
\]  \hspace{1cm} (10)
For 5.5hp motor power transmitted will be 4.29kw

\[
\text{Since } 1\text{hp} = 745.699872w \\
1\text{hp} = 0.74569\text{kw} \\
5.5\text{hp} = (0.74569 \times 5.5) \text{ k}W \\
= 4.29 \\
4.29 = (T_1 - T_2)4.29 \\
(4.29 \times 1000) w = (T_1 - T_2)4.29 \\
4290 = (T_1 - T_2)4.29 \\
(T_1 - T_2) = 4290/4.29 \\
T_1 - T_2 = 1000 \\
T_1 = 1000 + T_2 \hspace{1cm} \text{(ii)}
\]

Putting Equation (ii) in (i) above

\[
4.49T_2 - 52.22 +11.63 =1000 T_2 \\
4.49T_2 - 40.59 = 1000 + T_2 \\
4.49T_2 - T_2 - 40.59 = 1000 \\
3.49T_2 - 40.59 =1000 \\
3.49T_2 = 1000 + 40.59 \\
3.49T_2 = 1040.59 \\
T_2 = 1040.59 \\
3.49 \\
T_2 = 298.16N
\]

From equation (ii)

\[
T_1 = 1000 + T_2 \\
= 1000 + 298.16 \\
= 1298.16N
\]

Resultant belt tension; \( T_1 + T_2 \)

\[
= 1298.16 + 298.16 \\
= 1,596.32N
\]

The resultant torque \( T \), is given as

\[
T = (T_1 - T_2) r_p
\]

Where \( r_p \) is the radius of the bigger pulley (m)

\[
T = (1298.16 + 298.16) \times 7 \times 10^{-2} \\
T = (1298.16 + 298.16) \times 0.07 \\
T = 36.7 \text{Nm}
\]

2.8 Determination of the Pulley Weight

Radius of the driven pulley,

\[
r = 7\text{cm} \\
= 7 \times 10^{-2}\text{m}
\]

Density of the mild steel, \( \ell 7820\text{kg/m}^2 \)

Width of the pulley,

\[
h = 2\text{cm} \\
= 2 \times 10^{-2}\text{m}
\]
Volume of the pulley = \( \pi r^2 h \)
\[
V = 3.142 \times (0.07)^2 \times (0.02) = 308 \times 10^{-4} \text{m}^3
\]
Mass = density x volume
\[
= 7820 \times 3.08 \times 10^{-4} = 2.4086 \text{kg}
\]
Pulley weight = \( m \times g \); where; \( g = 9.81 \text{m/s} \)
\[
= 2.41 \times 9.81 = 23.64 \text{N}
\]

2.9 Determination of Pelletizing Rod’s Weight

Diameter of the rod = 25mm
\[
= 0.025 \text{m}
\]
Length of the rod = 45mm
\[
= 0.045 \text{m}
\]
Volume of the rod = \( \pi r^2 h \)
Where,
\[
r = 0.125
\]
\[
V = 3.142 \times (0.0125)^2 \times 0.045 = 2.2092 \times 10^{-5} \text{m}^3
\]
Since the density of mild steel is 7820kg/m\(^3\)
\[
\text{Mass of the rod} = 7820 \times 2.2092 \times 10^{-5} \text{m} = 0.1727 \text{kg}
\]
Weight = \( mg \)
\[
= 0.1727 \times 9.81 = 1.694 \text{N/m}
\]

2.10 Design Procedure for Screw Conveyor (Auger)

Length of the shaft cover by the auger = 180mm
\[
= 0.18 \text{m}
\]
WO = 2.5 friction factor of the material on mild steel \( \ell = 0.40 \)
Efficiency for \( v \) – belt transmission \( \mu = 0.92 \)
Factor of inclination of screw shaft to horizontal; at angle \( \beta = 0, C = 1.0 \)
Screw diameter, \( D = 125\text{mm} \)
\[
= 0.125 \text{m}
\]
V, speed of the screw shaft is the speed of machine which is 650rpm
Pitch of the screw, \( s = 50\text{mm} \)
\[
= 0.05 \text{m}
\]
Loading efficiency, \( \frac{1}{4} \) or 0.25
Bulk density of convey materials \( \ell = 1.20\text{tons/m}^3 \)[7]
Capacity of conveyor $Q = 15 \pi D^2 sv φ c$  

$$Q = 15 \times 3.142 \times (0.125)^2 \times 0.05 \times 650 \times 0.25 \times 1.2 \times 1.0$$

$$= 7.1796 \text{ tons/hr}$$

$$= 7.18 \text{ tons/hr}$$

Power requirement to drive the screw and the shaft under no loading:

$$PE = YW$$  (12)

Where $Y = \frac{1}{2} I_o w^2$  (13)

And, $w = \frac{2 \pi n}{60}$, \quad n = 650 rpm

$I_o = \text{second moment of the pelletizing rod.}$

$W = \frac{2 \pi n}{60}$

$$= 2 \times 3.142 \times 650 \times \frac{60}{60}$$

$$= 68.08 \text{rd/sec}$$

$I_o = 1/12 \text{ m (a x b)}$

Where,

$m = \text{mass of the rod}$

$$= 2.41 \text{kg}$$

$a = \text{breadth of thin plate conveyor}$

$$= 125 \text{mm}$$

$$= 0.125 \text{m}$$

$b = \text{length of thin plate conveyor}$

$$= 140 \text{mm}$$

$$= 0.14 \text{m}$$

$Io = \frac{1}{12} m (a \times b)$

$$= \frac{1}{12} \times 2.41 (0.125 \times 0.14)$$

$$= 0.0035146$$

$Y = \frac{1}{2} I_o W^2$

$$= \frac{1}{2}(0.0035146) (68.08)^2$$

$$= 8.1448 \text{Nm}$$

$$= 8.145 \text{Nm}$$

$PE = YW$

$$= 8.145 \times 68.08$$

$$= 554.51 \text{watts}$$

$$= 0.5545 \text{kw}$$

Power requirement to drive the screw and shaft under loading:

$$\frac{PLQL}{367} \times \frac{(Wo + \sin \beta)}{\mu}$$  (14)

Where:

$Q = \text{capacity of conveyor}$,

$L = \text{length of the shaft covered by screw conveyor and rods}$

$Wo = \text{material factor which is 2.5}$

$F = \text{factor of inclination of screw shaft to horizontal at } \beta = 0$

$\mu = \text{efficiency for v-belt transmission}$

$Q = 10.8 \text{ ton/hr.}$
\[ L = (0.14 + 0.25)m = 0.39m \]
\[ \mu = 0.92 \]
\[ P_L = \frac{10.81 \times 0.39/367 (2.5)}{0.92} = 4.2159/367 \times 2.5 \times 1.087 = 0.0312kw \]

Total power requires \( P_L + PE \)
\[ Tp = 0.0312 + 1.5256 = 1.5568kw \]

Therefore, 3hp motor of 2.25kw is recommended

Torque on a screw shaft (auger)
\[ M = 975 \times \frac{H}{n} \quad (15) \]

Where,
- \( H \) = horse power in watts
  - = 2.25kw
- \( n \) = speed of the machine
  - = 650rpm
- \( M = 975 \times \frac{2.25}{650} = 3.38Nm. \)

Load propulsion speed
\[ V = \frac{S \times n}{60} \quad (16) \]

Where,
- \( S \) = pitch
  - = 50mm
  - = 0.05m
- \( n \) = shaft revolution per minutes
  - = 650rpm
- \( V = 0.05 \times 650 \]
  - 60
  - = 0.65m/s

Load per meter length of conveyor
\[ q = \frac{Q}{3.6V} \quad (17) \]

Where,
- \( q \) = load per meter length of conveyor
- \( Q \) = conveyor’s capacity
  - = 10.81 tons/hr
- \( V \) = load propulsion speed
  - = 0.65m/s
- \( q = \frac{10.81}{3.6 \times 0.65} = 4.62N \)

Axial thrust on screw
\[ P = q \mu \quad (18) \]
Where,

\[ p = \text{axial thrust on screw} \]
\[ q = \text{load per meter length of conveyor} \]
\[ l = \text{length of the screw conveyor} \]
\[ = 140\text{mm} \]
\[ = 0.14\text{m} \]
\[ \mu = \text{coefficient of friction of feed on mild steel} \]
\[ = 0.40 \]
\[ P = 4.62 \times 0.14 \times 0.40 \]
\[ = 0.25872\text{kgN} \]
\[ = 0.25872 \times 9.81 \]
\[ = 2.538\text{N} \]

**2.11 Determination of Conveyor Weight**

The conveyor is made of mild steel with length \((0.14 + 0.25) = 0.39\text{m}\)

Height (width) \(= 0.25\text{m}\)

Thickness \(= 0.125\text{m}\)

Volume of the conveyor material \(= L \times b \times t\) \hspace{2cm} (19)

Where;
\[ L = \text{length of conveyor} \]
\[ b = \text{width of conveyor} \]
\[ t = \text{thickness of the rod} \]
\[ v = L \times b \times t \]
\[ = 0.39 \times 0.25 \times 0.125 \]
\[ = 0.0121875\text{m}^3 \]
\[ = 1.2187 \times 10^{-3}\text{m}^3 \]

Mass of conveyor, \(m = tv\) \hspace{2cm} (20)

Where,
\[ \ell = \text{density of mild steel} \]
\[ = 7820\text{kg/m}^3 \]
\[ V = \text{volume of the material} \]
\[ = 1.2187 \times 10^{-3}\text{m}^3 \]
\[ \text{Mass} = 7820 \times 1.2187 \times 10^{-3} \]
\[ = 9.53\text{kg} \]
\[ W = mg \]
\[ = 9.53 \times 9.81 \]
\[ = 93.5\text{N/m} \]

As uniformly distributed load (UDL) \[ \frac{\text{mass}}{\text{length of the screw conveyor}} = \frac{9.53}{0.14} \]
\[ = 68.07\text{N/m} \]

**2.12 Shaft Design**

In shaft design consideration, a solid shaft is used due to the following reasons;

(a) To enhance the torsion rigidity of the shaft
(b) To withstand the axial loads acting on the shaft
(c) To ease the conveyance of feed constituents during pelletizing operation.
These are the loading on the shaft:

(i) Torsion load imposed from the energy input
(ii) Bending moment imposed by various points along the shaft

Forces acting on the shaft are:

(a) The distributed loads of pelletizing rods and auger
(b) The bearing reactions
(c) The weight of pulley
(d) The shaft weight

The weight of shaft is given as $m \times g$  \hspace{1cm} (21)

Where,

$m = \text{mass of shaft in kg} \\
g = \text{acceleration due to gravity} = 9.81 \text{m/s} \\
m = 4.34 \times 9.81 \\
= 42.566 \text{N} \\
= 42.57 \text{N}$

2.13 For Vertical Loading

$R_{AV1} + R_{AV2} = 23.64$ \hspace{1cm} (i)

Taking moment vertically about $R_{AV1}$

$= -0.15 \times (23.64) + 0.25 \times (R_2) - 0 \times (0.45)$
$= -0.15 \times (23.64) + 0.25 \times (R_2)$
$= -3.546 + 0.25 \times (R_2)$
0.25R_2 = 3.546
R_2 = 3.546
0.25
R_2 = 14.184N

Substitute R_2 into equation (i) above

R_{AV1} + R_{AV2} = 23.64

R_{AV1} + 14.184 = 23.64
R_{AV1} = 23.64 – 14.184
R_{AV1} = 9.456N

2.14 For Horizontal Loading

2.15 Loading Along Vertical Axis
Considering span 1
\[ MS_1S_1 = 9.456 \times \]
at \( x = 0.15 \)
\[ MS_1S_1 = 9.456 \times 0.15 \]
\[ MS_1S_1 = 1.4184 \text{Nm} \]

Considering span 2
\[ MS_2S_2 = 9.456 \times (x - 23.64) \times (x - 0.15) \]
\[ at \ x = 0.25 \]
\[ = 9.456 \times 0.25 \times 23.64 \times (0.25 - 0.15) \]
\[ = 9.456 \times 0.25 \times 23.64 \times (0.10) \]
\[ = 2.365 - 2.364 \]
\[ = 0.001 \text{Nm} \]

Considering span 3
\[ MS_3S_3 = 9.456 \times (x - 23.64) \times (x - 0.15) + 14.184 \times (x - 0.25) \]
\[ At \ x = 0.45 \]
\[ = 9.456 \times (0.45) \times (0.45 - 23.64) \times (0.30) + 14.184 \times (0.20) \]
\[ = 4.2552 - 7.092 + 2.8368 \]
\[ = 7.092 - 7.092 \]
\[ = 0 \]

2.16 Loading along Horizontal Axis

Consider Span 1
\[ M_{S1S1} = -74.8 \times (x) \times \text{at } x = 0.15 \]
\[ = -74.8 \times 0.15 \]
\[ = -11.22 \text{Nm} \]

Considering Span 2
\[ M_{S2S2} = -74.8 (x) - 0 \times (0.15) \text{ at } 0.25 \]
\[ = -74.8 (0.25) - 0 \]
\[ = -18.7 \text{Nm} \]

Considering Span 3
\[ M_{S3S3} = -74.8 \times (0.45) + 168.3 \times (x - 0.20) \]
\[ = -33.66 + 33.66 \]
\[ = 0 \]
2.17 Bending Moment Diagram

Resultant Bm at B

\[ \text{Resultant Bm at B} = \sqrt{(1.418)^2 + (-11.22)^2} = \sqrt{127.90} = 11.309 \text{ Nm} \]

Resultant Bm at C

\[ \text{Resultant Bm at C} = \sqrt{(0.001)^2 + (75.05)^2} = \sqrt{5632.50} = 75.05 \text{ Nm} \]

\[
\begin{align*}
\text{Mb}_{\text{max}} & = 75.05 \text{ Nm} \\
\text{Mb} & = 75.05 \text{ Nm} \\
\text{Mt} & = (T_1 - T_2)R \\
T_1 & = 1298.16 \\
T_2 & = 298.16
\end{align*}
\]
R = 70 mm
= 0.07m
Mt = (1298.16 N – 298.16 N) × 0.07 m
= 1000 N × 0.07 m
Mt = 70Nm
Kb = 1.5
Kt = 1.0
d³ = 16/nSS√ (Kt × Mt)² + (Kb × Mb)²
= 16/[40 × 10⁶]√ (1.0 × 70)² + (1.5 × 75.05)²
= 1.2733 × 10⁻⁷ × 132.5636852
= 1.6879 × 10⁻⁵

d = 3√ 1.6879 × 10⁻⁵
\[ d = 2.565 \times 10^{-2} \text{ m} \]
\[ d = 25.65 \text{ mm} \]

Therefore 25mm diameter was chosen.

3. PERFORMANCE TEST, RESULTS AND DISCUSSION

3.1 Machine Test Procedures

The fish feed was prepared using the standard feed formula. The fish feed content includes: maize, cassava, GNC, SBM, Fish meal, Oyster shell, premix, bone meal, lysine, oil, methionine and salt. The methods of feed formulation vary from one region to another, however it involves the combination and blending together of feed ingredients (based on individual formula) into nutritionally balanced and economically sound diet that can be used in required amount to provide the level of production desired in fish cultivation. Normally, the protein level in formulated feeds is about 30–32 percent for the nursery stage (5–20 g). This value decreases with increasing fish size, the lowest value (22–26 percent) occurring at a size of >500 g. Similarly, the lipid level of the diet changes with fish size appropriate to the requirement, which varies from 4–6 percent. Two essential amino acids which are often supplemented in the feed are methionine and lysine. Different kinds of vitamin C are also used in MPF – for instance, "stay C", which is stable at high temperature has been used in extruded pellets. Furthermore, calcium and phosphorus may be added to the diets. The FMF usually has a low protein content. The diet is usually formulated from local ingredients such as fishmeal, trash fish, soybean meal, soybean cake, rice bran, broken rice, cassava, dry fish, etc. The formulation varies with the size of the fish [8].

### Examples of feed formulations used to culture catfish.

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Fry feed</th>
<th>Fingerling feed</th>
<th>Food fish feed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(50%)a</td>
<td>(35%)</td>
<td>(32%)</td>
</tr>
<tr>
<td>Soybean meal (43%)a</td>
<td>44.2</td>
<td>41.6</td>
<td>47.0</td>
</tr>
<tr>
<td>Cottonseed meal (41%)</td>
<td>10.0</td>
<td>10.0</td>
<td>10.0</td>
</tr>
<tr>
<td>Menhaden meal (61%)</td>
<td>74.2</td>
<td>9.0</td>
<td>4.0</td>
</tr>
<tr>
<td>Corn grain</td>
<td>–</td>
<td>27.6</td>
<td>32.1</td>
</tr>
<tr>
<td>Wheat middlings</td>
<td>20.4</td>
<td>7.5</td>
<td>16.0</td>
</tr>
<tr>
<td>Dicalcium phosphate</td>
<td>0.5</td>
<td>0.5</td>
<td>0.6</td>
</tr>
<tr>
<td>Catfish vitamin mixa</td>
<td>include</td>
<td>include</td>
<td>include</td>
</tr>
<tr>
<td>Catfish mineral mixa</td>
<td>include</td>
<td>include</td>
<td>include</td>
</tr>
<tr>
<td>Fat/oilc</td>
<td>5.0</td>
<td>2.0</td>
<td>1.5</td>
</tr>
</tbody>
</table>

a Values in the parentheses represent percentage protein.
b Commercial mix that meets or exceeds all requirements for channel catfish.
c Sprayed on finished feed pellet to reduce feed dust (*fines*).

Source: University of Minnesota AgEcon - July 2006 [9]
Plate 1. The machine showing pelletizing operation

Plate 2. Pelletized fish feed of 2mm diameter

Plate 3. Pelletized fish feed of 4mm diameter
The prepared feed were mixed with water to obtain different moisture contents 10, 15, 20, 25, 30 and 35 percent wet basis. The blended or granular fish feeds were loaded into the machine at input quantity of 2.0kg. The pelletized feeds were then collected through the orifice and the time for each pelletizing operation was taken and recorded. The feed came out in a pellet strand form as shown in Plate 1. Plates 2, 3 and 4 showing the different sizes of pelletized fish feed from dies of 2mm, 4mm and 6mm diameters respectively. Pellets are small particles typically created by compressing original materials. Pellets are majorly in single shape. Some pellets are a small, compressed, hard chunk of matter, usually round “small ball” or small short cylindrical shape. The reason for producing the fish feed in pellet form is to enable the fishes have easy access and proper consumption of the feeds during feeding. The weight of feed collected through the dies was measured and recorded.

3.2 Results

The results obtained during pelletizing operation at different moisture content and die diameters are presented in Table 2, 3 and 4. The efficiency, throughput and percentage loss were calculated using the following relationships:

i. Efficiency =

\[
\frac{\text{Quantity of Pelletised (kg)}}{\text{Input Quantity (kg)}} \times 100\%
\]

ii. Throughput =

\[
\frac{\text{Input Quantity (kg)}}{\text{Time of Pelleti sin g(hr)}}
\]

The result obtained during operation at different volume of water for 400ml, 500ml, and 600ml were also recorded accurately. Further analyses of the result were taken as follows; Tables (5-13) shows the result of testing data collected during the testing of the machine.

Sample weight plus water = Input in Kilogram

Quantity pelletized = Output in Kilograms

Quantity wasted = Weight of materials remained in the machine in Kilograms

Time spent on the machine operation = T (seconds)

Total = TT

Average = A
Table 2. Result of pelletizing operation at different moisture contents with 2 mm die diameter

<table>
<thead>
<tr>
<th>Moisture content</th>
<th>Sample weight (kg)</th>
<th>Time (s)</th>
<th>Quantity pelletized (kg)</th>
<th>Quantity wasted (kg)</th>
<th>Efficiency (%)</th>
<th>Throughput (kg/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>2</td>
<td>637</td>
<td>1.56</td>
<td>0.44</td>
<td>78</td>
<td>11.30</td>
</tr>
<tr>
<td>15</td>
<td>2</td>
<td>395</td>
<td>1.60</td>
<td>0.40</td>
<td>80</td>
<td>18.22</td>
</tr>
<tr>
<td>20</td>
<td>2</td>
<td>372</td>
<td>1.62</td>
<td>0.38</td>
<td>81</td>
<td>19.35</td>
</tr>
<tr>
<td>25</td>
<td>2</td>
<td>246</td>
<td>1.66</td>
<td>0.34</td>
<td>83</td>
<td>29.27</td>
</tr>
<tr>
<td>30</td>
<td>2</td>
<td>195</td>
<td>1.60</td>
<td>0.40</td>
<td>80</td>
<td>36.92</td>
</tr>
<tr>
<td>35</td>
<td>2</td>
<td>152</td>
<td>1.50</td>
<td>0.50</td>
<td>75</td>
<td>47.37</td>
</tr>
</tbody>
</table>

Table 3. Result of pelletizing operation at different moisture contents with 4 mm die diameter

<table>
<thead>
<tr>
<th>Moisture content</th>
<th>Sample weight (kg)</th>
<th>Time (s)</th>
<th>Quantity pelletized (kg)</th>
<th>Quantity wasted (kg)</th>
<th>Efficiency (%)</th>
<th>Throughput (kg/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>2</td>
<td>235</td>
<td>1.78</td>
<td>0.22</td>
<td>89</td>
<td>30.64</td>
</tr>
<tr>
<td>15</td>
<td>2</td>
<td>211</td>
<td>1.82</td>
<td>0.18</td>
<td>91</td>
<td>34.12</td>
</tr>
<tr>
<td>20</td>
<td>2</td>
<td>196</td>
<td>1.88</td>
<td>0.12</td>
<td>94</td>
<td>36.73</td>
</tr>
<tr>
<td>25</td>
<td>2</td>
<td>155</td>
<td>1.90</td>
<td>0.10</td>
<td>95</td>
<td>46.45</td>
</tr>
<tr>
<td>30</td>
<td>2</td>
<td>120</td>
<td>1.88</td>
<td>0.12</td>
<td>94</td>
<td>60.00</td>
</tr>
<tr>
<td>35</td>
<td>2</td>
<td>108</td>
<td>1.80</td>
<td>0.20</td>
<td>90</td>
<td>66.67</td>
</tr>
</tbody>
</table>

Table 4. Result of pelletizing operation at different moisture contents with 6 mm die diameter

<table>
<thead>
<tr>
<th>Moisture content</th>
<th>Sample weight (kg)</th>
<th>Time (s)</th>
<th>Quantity pelletized (kg)</th>
<th>Quantity wasted (kg)</th>
<th>Efficiency (%)</th>
<th>Throughput (kg/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>2</td>
<td>107</td>
<td>1.80</td>
<td>0.20</td>
<td>90</td>
<td>62.29</td>
</tr>
<tr>
<td>15</td>
<td>2</td>
<td>94</td>
<td>1.88</td>
<td>0.12</td>
<td>94</td>
<td>76.60</td>
</tr>
<tr>
<td>20</td>
<td>2</td>
<td>83</td>
<td>1.92</td>
<td>0.08</td>
<td>96</td>
<td>86.75</td>
</tr>
<tr>
<td>25</td>
<td>2</td>
<td>83</td>
<td>1.96</td>
<td>0.04</td>
<td>98</td>
<td>86.75</td>
</tr>
<tr>
<td>30</td>
<td>2</td>
<td>78</td>
<td>1.92</td>
<td>0.04</td>
<td>96</td>
<td>92.31</td>
</tr>
<tr>
<td>35</td>
<td>2</td>
<td>74</td>
<td>1.90</td>
<td>0.10</td>
<td>95</td>
<td>97.30</td>
</tr>
</tbody>
</table>
Table 5. Pelletizing result of 2 mm diameter die with 400 ml of water = 0.4 Kg

<table>
<thead>
<tr>
<th>S/N</th>
<th>Moisture content</th>
<th>Sample weight (Kg)</th>
<th>Sample weight plus water (Kg)</th>
<th>Time (S)</th>
<th>Quantity pelletized (Kg)</th>
<th>Quantity wasted (Kg)</th>
<th>Efficiency (%)</th>
<th>Throughput (Kg/Hr)</th>
<th>% Loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>26.1</td>
<td>1.0</td>
<td>1.4</td>
<td>1112</td>
<td>1.2</td>
<td>0.2</td>
<td>85</td>
<td>0.38</td>
<td>14.28</td>
</tr>
<tr>
<td>2</td>
<td>24.5</td>
<td>1.4</td>
<td>1.8</td>
<td>1746</td>
<td>1.5</td>
<td>0.3</td>
<td>83</td>
<td>0.31</td>
<td>16.67</td>
</tr>
<tr>
<td>TT</td>
<td>50.6</td>
<td>2.4</td>
<td>3.2</td>
<td>2858</td>
<td>2.7</td>
<td>0.5</td>
<td>168</td>
<td>0.69</td>
<td>30.95</td>
</tr>
<tr>
<td>A</td>
<td>25.3</td>
<td>1.2</td>
<td>1.6</td>
<td>1429</td>
<td>1.35</td>
<td>0.25</td>
<td>84</td>
<td>0.345</td>
<td>15.475</td>
</tr>
</tbody>
</table>

Table 6. Pelletizing result of 2 mm diameter die with 500 ml of water = 0.5 Kg

<table>
<thead>
<tr>
<th>S/N</th>
<th>Moisture content</th>
<th>Sample weight (Kg)</th>
<th>Sample weight plus water (Kg)</th>
<th>Time (s)</th>
<th>Quantity pelletized (Kg)</th>
<th>Quantity wasted (Kg)</th>
<th>Efficiency (%)</th>
<th>Throughput (kg/hr)</th>
<th>% Loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>18.1</td>
<td>1.0</td>
<td>1.5</td>
<td>395</td>
<td>1.2</td>
<td>0.3</td>
<td>80</td>
<td>1.10</td>
<td>20.00</td>
</tr>
<tr>
<td>2</td>
<td>15.7</td>
<td>1.4</td>
<td>1.9</td>
<td>637</td>
<td>1.7</td>
<td>0.2</td>
<td>89</td>
<td>1.00</td>
<td>10.50</td>
</tr>
<tr>
<td>TT</td>
<td>33.8</td>
<td>2.4</td>
<td>3.4</td>
<td>1032</td>
<td>2.9</td>
<td>0.5</td>
<td>169</td>
<td>2.10</td>
<td>30.5</td>
</tr>
<tr>
<td>A</td>
<td>16.9</td>
<td>1.2</td>
<td>1.7</td>
<td>516</td>
<td>1.45</td>
<td>0.25</td>
<td>84.5</td>
<td>1.05</td>
<td>15.25</td>
</tr>
</tbody>
</table>

Table 7. Pelletizing result of 2 mm diameter die with 600 ml of water = 0.6 Kg

<table>
<thead>
<tr>
<th>S/n</th>
<th>Moisture content</th>
<th>Sample weight (Kg)</th>
<th>Sample weight plus water (Kg)</th>
<th>Time (s)</th>
<th>Quantity pelletized (Kg)</th>
<th>Quantity wasted (Kg)</th>
<th>Efficiency (%)</th>
<th>Throughput (kg/hr)</th>
<th>% loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>24.3</td>
<td>1.0</td>
<td>1.6</td>
<td>272</td>
<td>1.3</td>
<td>0.3</td>
<td>81</td>
<td>1.72</td>
<td>18.75</td>
</tr>
<tr>
<td>2</td>
<td>25.0</td>
<td>1.4</td>
<td>2.0</td>
<td>495</td>
<td>1.8</td>
<td>0.2</td>
<td>90</td>
<td>1.31</td>
<td>10.00</td>
</tr>
<tr>
<td>TT</td>
<td>49.3</td>
<td>2.4</td>
<td>3.6</td>
<td>767</td>
<td>3.1</td>
<td>0.5</td>
<td>171</td>
<td>3.03</td>
<td>28.75</td>
</tr>
<tr>
<td>A</td>
<td>24.65</td>
<td>1.2</td>
<td>1.8</td>
<td>383.5</td>
<td>1.55</td>
<td>0.25</td>
<td>85.5</td>
<td>1.515</td>
<td>14.375</td>
</tr>
</tbody>
</table>
Table 8. Pelletizing result of 4 mm diameter die with 400 ml of water = 0.4 Kg

<table>
<thead>
<tr>
<th>S/N</th>
<th>Moisture content</th>
<th>Sample weight (kg)</th>
<th>Sample weight plus water (kg)</th>
<th>Time (s)</th>
<th>Quantity pelletized (kg)</th>
<th>Quantity wasted (kg)</th>
<th>Efficiency (%)</th>
<th>Throughput (kg/hr)</th>
<th>% loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>23.4</td>
<td>1.0</td>
<td>1.4</td>
<td>108</td>
<td>1.25</td>
<td>0.15</td>
<td>89</td>
<td>4.17</td>
<td>10.7</td>
</tr>
<tr>
<td>2</td>
<td>24.1</td>
<td>1.4</td>
<td>1.8</td>
<td>195</td>
<td>1.60</td>
<td>0.20</td>
<td>88.9</td>
<td>2.95</td>
<td>11.1</td>
</tr>
<tr>
<td>TT</td>
<td>47.5</td>
<td>2.4</td>
<td>3.2</td>
<td>303</td>
<td>2.85</td>
<td>0.35</td>
<td>177.9</td>
<td>7.12</td>
<td>21.8</td>
</tr>
<tr>
<td>A</td>
<td>23.75</td>
<td>1.2</td>
<td>1.6</td>
<td>151.5</td>
<td>1.425</td>
<td>0.175</td>
<td>88.95</td>
<td>3.56</td>
<td>10.9</td>
</tr>
</tbody>
</table>

Table 9. Pelletizing result of 4 mm diameter die with 500 ml of water = 0.5 Kg

<table>
<thead>
<tr>
<th>S/N</th>
<th>Moisture content</th>
<th>Sample weight (kg)</th>
<th>Sample weight plus water (kg)</th>
<th>Time (s)</th>
<th>Quantity pelletized (kg)</th>
<th>Quantity wasted (kg)</th>
<th>Efficiency (%)</th>
<th>Throughput (kg/hr)</th>
<th>% loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>23.8</td>
<td>1.0</td>
<td>1.6</td>
<td>120</td>
<td>1.05</td>
<td>0.45</td>
<td>70</td>
<td>3.15</td>
<td>30</td>
</tr>
<tr>
<td>2</td>
<td>20.3</td>
<td>1.4</td>
<td>1.9</td>
<td>235</td>
<td>1.60</td>
<td>0.30</td>
<td>84.2</td>
<td>2.45</td>
<td>15</td>
</tr>
<tr>
<td>TT</td>
<td>44.1</td>
<td>2.8</td>
<td>3.4</td>
<td>355</td>
<td>2.65</td>
<td>0.75</td>
<td>154.2</td>
<td>5.6</td>
<td>45</td>
</tr>
<tr>
<td>A</td>
<td>22.05</td>
<td>1.4</td>
<td>1.7</td>
<td>177.5</td>
<td>1.325</td>
<td>0.375</td>
<td>77.1</td>
<td>2.8</td>
<td>22.5</td>
</tr>
</tbody>
</table>

Table 10. Pelletizing result of 4 mm diameter die with 600 ml of water = 0.6 Kg

<table>
<thead>
<tr>
<th>S/N</th>
<th>Moisture content</th>
<th>Sample weight (Kg)</th>
<th>Sample weight plus water (Kg)</th>
<th>Time (S)</th>
<th>Quantity pelletized (Kg)</th>
<th>Quantity Wasted (Kg)</th>
<th>Efficiency (%)</th>
<th>Throughput (Kg/hr)</th>
<th>% Loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>28.2</td>
<td>1.0</td>
<td>1.6</td>
<td>196</td>
<td>1.5</td>
<td>0.1</td>
<td>94</td>
<td>2.8</td>
<td>6.25</td>
</tr>
<tr>
<td>2</td>
<td>24.8</td>
<td>1.4</td>
<td>2.0</td>
<td>211</td>
<td>1.8</td>
<td>0.2</td>
<td>90</td>
<td>3.1</td>
<td>10</td>
</tr>
<tr>
<td>TT</td>
<td>55</td>
<td>2.4</td>
<td>3.6</td>
<td>407</td>
<td>3.3</td>
<td>0.3</td>
<td>184</td>
<td>5.9</td>
<td>16.25</td>
</tr>
<tr>
<td>A</td>
<td>26.5</td>
<td>1.4</td>
<td>1.8</td>
<td>204</td>
<td>1.65</td>
<td>0.15</td>
<td>92</td>
<td>2.95</td>
<td>8.125</td>
</tr>
</tbody>
</table>
Note; (Table 5)

1ml of water = 0.001 Kg
Efficiency = Quantity Pelletized × 100
Sample + water

%Loss = Quantity Wasted × 100
Sample + water

Throughput = Quantity Pelletized × 60 ×60
Time

Average efficiency = (84 + 84.5 + 85.5)

= 84.6 %

Note;(Table-11)

1ml of water = 0.001 Kg
Efficiency = Quantity Pelletized × 100
Sample + water

%Loss = Quantity Wasted × 100
Sample + water

Throughput = Quantity Pelletized × 60 ×60
Time

Average Efficiency = (88.95 + 77.1 + 92)

3

= 86.01 %

Note;(Table 13)

1ml of water = 0.001 Kg
Efficiency = Quantity Pelletized × 100
Sample + water

%Loss = Quantity Wasted × 100
Sample + water

Throughput = Quantity Pelletized × 60 ×60
Time

Average Efficiency = (2mm die efficiency + 4mm die efficiency + 6mm die efficiency)

3

Average Efficiency = (87.5 + 86 + 91.5)

3

= 88.33 %
Table 11. Pelletizing result of 6mm diameter die with 400 ml of water = 0.4 Kg

<table>
<thead>
<tr>
<th>S/N</th>
<th>Moisture content</th>
<th>Sample weight (Kg)</th>
<th>Sample weight plus water (Kg)</th>
<th>Time (S)</th>
<th>Quantity pelletized (Kg)</th>
<th>Quantity wasted (Kg)</th>
<th>Efficiency (%)</th>
<th>Throughput (Kg/hr)</th>
<th>% Loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>23.5</td>
<td>1.0</td>
<td>1.4</td>
<td>83</td>
<td>1.2</td>
<td>0.2</td>
<td>86</td>
<td>5.2</td>
<td>14.2</td>
</tr>
<tr>
<td>2</td>
<td>14.5</td>
<td>1.4</td>
<td>1.8</td>
<td>107</td>
<td>1.6</td>
<td>0.2</td>
<td>89</td>
<td>5.4</td>
<td>11.1</td>
</tr>
<tr>
<td>TT</td>
<td>38</td>
<td>2.8</td>
<td>3.2</td>
<td>190</td>
<td>2.8</td>
<td>0.4</td>
<td>175</td>
<td>10.6</td>
<td>25.3</td>
</tr>
<tr>
<td>A</td>
<td>19</td>
<td>1.4</td>
<td>1.6</td>
<td>145</td>
<td>1.4</td>
<td>0.2</td>
<td>87.5</td>
<td>5.3</td>
<td>12.65</td>
</tr>
</tbody>
</table>

Table 12. Pelletizing result of 6mm diameter die with 500ml of water = 0.5 Kg

<table>
<thead>
<tr>
<th>S/N</th>
<th>Moisture content</th>
<th>Sample weight (Kg)</th>
<th>Sample weight plus water (Kg)</th>
<th>Time (S)</th>
<th>Quantity pelletized (Kg)</th>
<th>Quantity wasted (Kg)</th>
<th>Efficiency (%)</th>
<th>Throughput (Kg/hr)</th>
<th>% Loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>23.2</td>
<td>1.0</td>
<td>1.5</td>
<td>94</td>
<td>1.25</td>
<td>0.25</td>
<td>83</td>
<td>4.8</td>
<td>16</td>
</tr>
<tr>
<td>2</td>
<td>15.1</td>
<td>1.4</td>
<td>1.9</td>
<td>74</td>
<td>1.70</td>
<td>0.2</td>
<td>89</td>
<td>8.2</td>
<td>10.5</td>
</tr>
<tr>
<td>TT</td>
<td>38.3</td>
<td>2.8</td>
<td>3.4</td>
<td>168</td>
<td>2.95</td>
<td>0.45</td>
<td>172</td>
<td>13</td>
<td>26.5</td>
</tr>
<tr>
<td>A</td>
<td>19.15</td>
<td>1.4</td>
<td>1.7</td>
<td>84</td>
<td>1.475</td>
<td>0.225</td>
<td>86</td>
<td>6.5</td>
<td>13.25</td>
</tr>
</tbody>
</table>

Table 13. Pelletizing result of 6mm diameter die with 600ml of water = 0.6 Kg

<table>
<thead>
<tr>
<th>S/N</th>
<th>Moisture content</th>
<th>Sample weight (Kg)</th>
<th>Sample weight plus water (Kg)</th>
<th>Time (S)</th>
<th>Quantity pelletized (Kg)</th>
<th>Quantity wasted (Kg)</th>
<th>Efficiency (%)</th>
<th>Throughput (Kg/hr)</th>
<th>% Loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>23.4</td>
<td>1.0</td>
<td>1.6</td>
<td>78</td>
<td>1.4</td>
<td>0.2</td>
<td>88</td>
<td>6.5</td>
<td>12.5</td>
</tr>
<tr>
<td>2</td>
<td>14.8</td>
<td>1.4</td>
<td>2.0</td>
<td>83</td>
<td>1.9</td>
<td>0.1</td>
<td>95</td>
<td>8.2</td>
<td>5</td>
</tr>
<tr>
<td>TT</td>
<td>38.2</td>
<td>2.8</td>
<td>3.6</td>
<td>161</td>
<td>3.3</td>
<td>0.3</td>
<td>183</td>
<td>14.7</td>
<td>17.5</td>
</tr>
<tr>
<td>A</td>
<td>19.1</td>
<td>1.4</td>
<td>1.8</td>
<td>80.5</td>
<td>1.65</td>
<td>0.15</td>
<td>91.5</td>
<td>7.35</td>
<td>8.75</td>
</tr>
</tbody>
</table>
Fig. 3. The Graph of the relationship between the efficiency and the water content of 2mm die

Fig. 4. The Graph of the relationship between the efficiency and the water content of 4mm die

The tables 14, 15 and 16 below shows the relationship between the efficiency and the water content.

**Table 14. Relationship between Efficiency and water content on 2 mm die**

<table>
<thead>
<tr>
<th>S/N</th>
<th>2 mm Die 1 at 1.0kg</th>
<th>S/N</th>
<th>2 mm Die 1 at 1.4kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Water content 400 ml</td>
<td>1</td>
<td>Water content 400 ml</td>
</tr>
<tr>
<td>2</td>
<td>Efficiency 85</td>
<td>2</td>
<td>Efficiency 83</td>
</tr>
</tbody>
</table>
Table 15. Relationship between Efficiency and water content on 4 mm die

<table>
<thead>
<tr>
<th>S/N</th>
<th>4 mm Die 1 at 1.0kg</th>
<th>S/N</th>
<th>4 mm Die 1 at 1.4kg</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Water content</td>
<td></td>
<td>Water content</td>
</tr>
<tr>
<td>1</td>
<td>400 ml</td>
<td>1</td>
<td>400 ml</td>
</tr>
<tr>
<td>2</td>
<td>Efficiency 89</td>
<td>2</td>
<td>Efficiency 88.9</td>
</tr>
<tr>
<td></td>
<td>70</td>
<td></td>
<td>84.2</td>
</tr>
<tr>
<td></td>
<td>94</td>
<td></td>
<td>90</td>
</tr>
</tbody>
</table>

Table 16. Relationship between Efficiency and water content on 6 mm die

<table>
<thead>
<tr>
<th>S/N</th>
<th>6 mm Die 1 at 1.0kg</th>
<th>S/N</th>
<th>6 mm Die 1 at 1.4 kg</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Water content</td>
<td></td>
<td>Water content</td>
</tr>
<tr>
<td>1</td>
<td>400 ml</td>
<td>1</td>
<td>400 ml</td>
</tr>
<tr>
<td>2</td>
<td>Efficiency 86</td>
<td>2</td>
<td>Efficiency 89</td>
</tr>
<tr>
<td></td>
<td>83</td>
<td></td>
<td>89</td>
</tr>
<tr>
<td></td>
<td>88</td>
<td></td>
<td>95</td>
</tr>
</tbody>
</table>

The Tables 17, 18 and 19 below shows the relationship between the efficiency and feed rate.

Table 17. Relationship between Efficiency and feed rate on 2 mm die

<table>
<thead>
<tr>
<th>S/N</th>
<th>400 ml</th>
<th>500 ml</th>
<th>600 ml</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feed Rate</td>
<td>1.0</td>
<td>1.4</td>
<td>1.0</td>
</tr>
<tr>
<td>Efficiency</td>
<td>85</td>
<td>83</td>
<td>80</td>
</tr>
</tbody>
</table>

Table 18. Relationship between Efficiency and feed rate on 4 mm die

<table>
<thead>
<tr>
<th>S/N</th>
<th>400 ml</th>
<th>500 ml</th>
<th>600 ml</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feed Rate</td>
<td>1.0</td>
<td>1.4</td>
<td>1.0</td>
</tr>
<tr>
<td>Efficiency</td>
<td>89</td>
<td>88.9</td>
<td>70</td>
</tr>
</tbody>
</table>

Table 19. Relationship between Efficiency and feed rate on 6 mm die

<table>
<thead>
<tr>
<th>S/N</th>
<th>400 ml</th>
<th>500 ml</th>
<th>600 ml</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feed Rate</td>
<td>1.0</td>
<td>1.4</td>
<td>1.0</td>
</tr>
<tr>
<td>Efficiency</td>
<td>86</td>
<td>89</td>
<td>83</td>
</tr>
</tbody>
</table>

Fig. 5. The Graph of the relationship between the efficiency and the water content of 6 mm die
3.3 Discussion

The maximum machine efficiency is 91.5% at 600ml of water for the 6mm pellet orifice size. This may be due to relatively easy passage offered for the fish feed to feed due to its large size. The efficiencies of the machine with 4mm and 2mm orifice size are 86.01% and 84.6% respectively while the average total efficiency is around 88%. This also is applicable to its capacity. Hence, the composition of the feedstock is very important to its pelletization. From Table 13, the optimum feedstock to water is 600 ml of water to 1.4 kg of dry feed.

Comparing the relationship between the quantities of water used to the quantity of dry feed, the graph illustrates that the efficiency of the machine when 600ml of water is added to dry feed is at its optimum level. Hence the quantity of
Fig. 8. The Graph of the relationship between the efficiency and the feed rate at 6mm die

water used in mixing the dry feed has an impact on the production thereby influencing the efficiency of the machine.

It was also observed that the pelletizing efficiency increases with moisture content at around 25% when the efficiency of the machine started to decrease. This may be due to clogging of wet feed between the barrel and the die disc as moisture content increases. For the moisture content of the fish feed ranging from 10% to 35%, the highest efficiency of pelletizing was obtained at 25% moisture for all the die diameters as seen in Table 2, 3 and 4. 6mm die gave the highest value at 98% efficiency. This is comparable to the result obtained by Olusegun et al [10]. It was also observed that both the pelletizing efficiency and throughput of the machine increases with die diameters. This may be due to relatively easy passage offered for the fish feed as the die diameter increases. This also agrees with the result obtained by Abubakre et al. [11]. Kaankuka and Osu [6] who developed a revolving die and roller fish feed pelletizer also reported that pellets forming rate does decrease as moisture content decreases. The overall assessment of the machine showed that pelletizing operation at 25% moisture content using 6mm die diameter gave the highest efficiency of 98% and throughput of 86.75kg/hr.

4. CONCLUSION

In this research work, a fish feed pelletizer was designed and fabricated using locally available materials. The indigenous machine was tested using dies of different diameters and at different moisture content. The test results obtained shows that the pelletizing efficiency increases as moisture content and die diameter increase. The machine throughput also increases with both moisture content and die diameter. Highest efficiency of 98% was obtained when the moisture content was maintained at 25% wet basis and the feed materials were made to pass through 6mm die diameter.

5. RECOMMENDATIONS

a) The feed stuff should not be too dry or too wet during pelletizing operation.
b) Government should subsidize and encourage the mass production of indigenous fabricated machines and make it affordable to local farmers.
c) There is need to orientate fish farmers about the formulation of nutritionally balanced, high quality feeds.
d) Further analysis or test should be carried out on the machine with other compositions of feedstock.
e) The machine should be operated by well-trained local operator for smooth operation and in order to achieve best output.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES


9. AgEcon. Examples of feed formulations used to culture catfish. University of Minnesota AgEcon; 2006. (Online Retrieved, October 15, 2018)
