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Research Article

Design and Development of Screw-type Pellet Machine for Aquatic Feeds with Dual Operations

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Abstract: Fishes and many animals have always been fed in a primitive way; this involves grinding of cereals on stones into meals. In this research work, a screw-type pellet machine was developed for aquatic feeds with dual-operations system whereby the electric motor was used to run the machine electrically and a handle was used to replace the motor in the absent of National Grid to operate the machine manually. Three dies with different holes diameters (2 mm, 3 mm and 4 mm holes diameters) were used to test the performance of the machine. The result revealed that the dryness of the feed materials is proportional to the temperature of the materials and time taken for the removal of the moisture content in the materials and 76.67% was the machine's efficiency whereas the efficiency of the pelletizing was 93.33%.

1. Introduction

Aquatic farming in developing countries is one of the developing business and it promotes food security and poverty eradication. Nigeria is blessed with rivers and lakes, but the feeds for aquatics are always increases due to inflation and devaluation of the currency.

To overcome these challenges, aquatic farmers are to produce the feeds locally for their fishes and yet this feed is not nutrient enough and there is a waste of raw materials in the process [1, 2]. Use of pelletizing machine is the modern method of production of the feeds for fishes and animals. This machine is used to extrude the raw material in a different pellet dies shape and the feed is nutrient and healthy for the fishes and animals [3]. Pelletizing machines could be operated manually or electrically. For the pelleting machine that is operated manually, the screw auger is rotated using handle whereas in an electrically operated machine, an electric motor is used to moves the auger.

Pelletizing machines can either be screw-type or roll-type machine. In 2017, Olusegun and his co-workers [4] developed a pelletizing machine with high capacity of 113 kg/h and two pellet dies of 4 mm and 6 mm diameter holes. Another pelletizing machine of screw-type was design and developed by Cian et al. [5], this machine is aimed to optimize the temperature on the die and moisture content of the pellet feed. Another pellet machine was designed by Okolie et al., [6] with a highly efficiency of capacity of 17 kg/h with pelletizing efficiency of 91 %. One

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of the problems of the pelletizing machine is the rise of die temperature due to rotation of a screw auger, Liu et al., [7] developed an advanced machine with cooling die and low moisture content. Susastriawan et al., [8] design and construct a machine of 75 kg/h capacity with roller as the extruder, the machine has cylindrical pelletizing chamber and die that produces pellet feeds of 4 mm diameter and 4 mm in length.

Sunil et al., [9] developed a pelletizing machine for animal feeds with different dies using a multilevel inverter that has a problem related to variation in the capacitor voltage. The ratio of length to the diameter of the pelletizing machine is among the factors affecting the performance of the machine. In 2018, Ambalkar [10] designed a pelletizing machine, the result shows that the ratio of length to the diameter is inversely proportional to the energy consumption by the machine. The amount of moisture and operating speed are other factors that affect the efficiency of the pelletizing machine, Burmanu et al., [11] developed a pelletizing machine for fish feed with a hand operation and the machine was 88% efficient. A pelletizing machine incorporated with drying system was developed by Ojediran et al., [12] whereby the machine produces the drying feeds for fishes. The results revealed that when the moisture contents of the raw materials were 10 and 18%, the machine efficiencies of were 18 ± 2% and 72 ± 5%, respectively.

Following the frequent break down of the national grid and insufficient power supply in most of developing countries especially rural areas, this study tends to develop a dual operation pelletizing machine for aquatic feed.

2. Materials and Method

2.1 Description of the Machine

The machine includes the feed container (hopper) which is welded to a cylindrical barrel (pelletizing chamber) and inside the chamber there is screw auger mounted over the shaft that carried the raw materials to the die extruder of the machine. One end of the shaft is connected with the pulley (driven) and another pulley on the electric motor were connected using V-belt. The driving pulley rotates the driven pulley when the machine is on, the raw material is poured into the hopper whereby the auger conveys it towards the die after the auger break the raw material in small piece. The feed is the flow out through the die and it then collected for drying process after cut it into smaller size for ease swallowing by the aquatics.

2.2 Design Considerations and Requirements

In design of the machine's components, the following points were considered:

a. Physical and chemical properties of the materials used for construction of the machine. should be checked to ensured that it has no harmful to the aquatics.
b. The maintainability of the machine should be ease.
c. The cost of production should be considered when selection of materials.
d. The electric motor operates under steady state condition.

2.3 Materials Selections

The cost, reliability, functionality and processability factors are considered while selection of materials used for construction of the machine [13].

Table 1 shows the components of the system, materials used and reason(s) for selections:

Table 1. Materials Selected for Construction of the System

Components	Materials Selected	Reason(s)
Hopper	Mild steel	Weldability, High tensile and impact strength [14]
Pelletizing chamber	Mild steel	Weldability, High tensile and impact strength [14]
Screw auger	Cast iron sheet	Deformability and fatigue resistant [15]
Shaft	Stainless Steel	Corrosion resistant, durability [15]
Supporting Stand	Mild steel	Weldability, High tensile and impact strength [14]

2.4 Design Calculations for the Machine's Components

2.4.1 Design of Hopper

The hopper is made up of mild steel in the form of truncated frustum of the pyramid. Therefore, the volume of the hopper is equal to the volume of truncated frustum of pyramid and it can be calculated using the equation given as:

$$V_h = \frac{h_h(A_1 + A_2 + \sqrt{A_1 A_2})}{3} \quad (1)$$

Where: V_h is Volume of the feed container (hopper) (mm^3), h_h is Height of the feed container (hopper) (350mm) (See Figure 1), A_1 is Area of the trapezium (mm^2) and A_2 is Area of rectangle (mm^2).

The area of the trapezium and that of rectangle were determined using equations (2) and (3) respectively as:

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

and,

$$A_2 = LB \quad (3)$$

Where: a and b are two opposite sides of the trapezium (150mm and 48.8mm respectively), h = height of the trapezium (100mm), L = Length of the rectangle (250mm) and B = Breadth of the rectangle (150mm) (See Figure 1).

Johnson equation is used to calculate the mass flow rate of the raw material through the hopper to the pelletizing chamber and the equation is given as:

$$\dot{m} = \rho_b A \sqrt{\frac{Bg}{2tan\emptyset}} \quad (4)$$

Where: $\dot{m}$ = mass flow rate (kg/s), ρ_b = Bulk density of the raw materials (1.3 g/m^3), A = surface area of the hopper (m^2), g = acceleration due to gravity (9.81 m/s^2) and $\emptyset$ = angle of inclination of the hopper (45^o) (Selected).

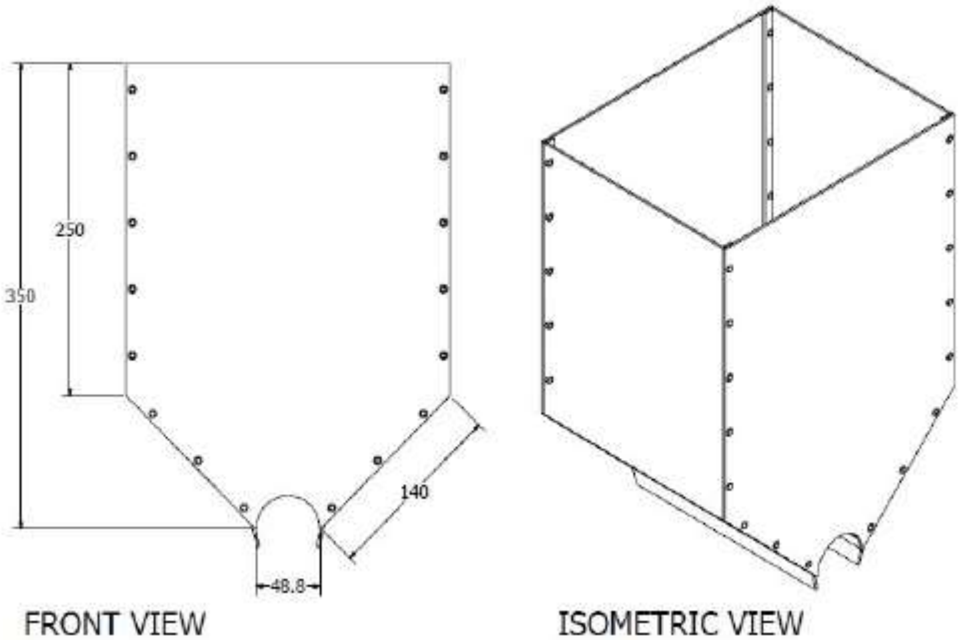

Figure 1: Front and Isomeric Views of Hopper

2.4.2 Design of the Barrel

The barrel consists of hollow cylinder and screw auger is inside the chamber. The volume of the barrel is obtained using equation (5):

$$V_b = V_e - V_i - V_a \tag{5}$$

Where: V_b = Volume of the pelletizing chamber (mm^3), V_e = Exterior volume of the cylinder (mm^3), V_i = Interior volume of the cylinder (mm^3) and V_a = Volume of the Screw auger (mm^3).

The exterior volume of the cylinder is:

$$V_e = \frac{\pi D^2 h_b}{4} \tag{6}$$

The interior volume of the cylinder is:

$$V_i = \frac{\pi d^2 h_b}{4} \tag{7}$$

And the exterior volume of the cylinder is:

$$V_a = \frac{\pi x^2 h_b}{4} \tag{8}$$

Where: D = External diameter of cylinder (40mm), d = Internal diameter of cylinder (10mm), x = Diameter of the Screw auger (10mm) and h_b = Height of the Screw auger (260mm) (See Figure 2).

2.4.3 Design of the Screw auger and Shaft

For the shaft to adopt torsional and bending strength, the following equation was used to determine the diameter of the shaft as given by [14]:

$$d_s^{\,3} = \frac{16T_s}{0.27\pi\sigma_y} \tag{9}$$

Where: d_s = Shaft diameter (m), T_s = Torque transmitted by the shaft (10Nmm) (Electric motor Specification) and σ_y = Yield stress of the material of the shaft (200N/m^2) [14].

The power required to drive the screw auger can be found using the equation given as:

$$P_a = \frac{Q h_b \omega_o}{367} \tag{10}$$

Where: P_a = Power of the screw auger (W), Q = Capacity of the screw auger (N/s) and ω_o = 4.0 for the slow-flowing abrasive materials [16].

Figures 2 and 3 show the front and end views of the screw auger and isometric drawing of the screw auger.

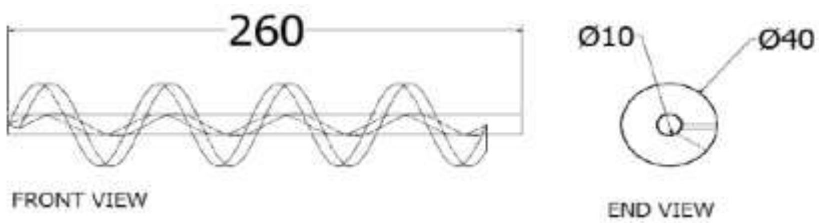

Figure 2: Front and End Views of the Screw Auger

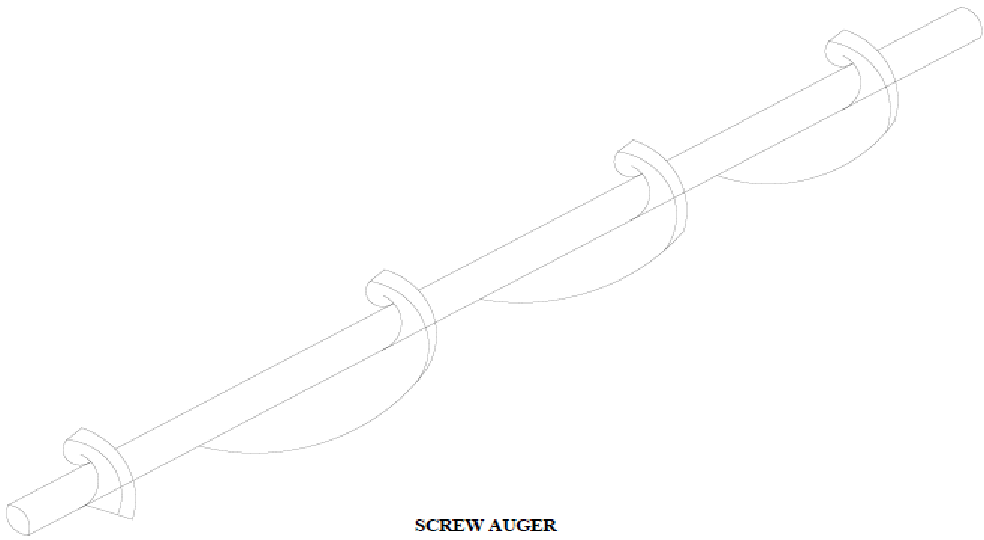

Figure 3: Isometric Drawing of the Screw Auger

2.4.4 Design of the Pulley and Belt Drive

For design of the drive system (Pulley and Belt), the following parameters are to be determine:

a. Diameter of the pulley;
b. Length of the belt;
c. Tensions acting on the belt and;
d. Power transmitted by the belt.

The above parameters were determined as follows:

a. Pulley's Diameter

The diameter of the pulley can be calculated using the equation given by Khurmi and Gupta [14] as:

$$D_2 = \frac{D_1 N_1}{N_2} \quad (11)$$

Where: D_2 is Diameter of the driven pulley (mm), N_2 is Speed of the driven pulley (1200rpm) (Selected), D_1 is Diameter of the driving pulley (30mm) (Available Pulley Specification) and N_1 = Speed of the driving pulley (200rpm) (Selected).

b. Length of the belt

Equation (12) is used to obtain the length of the belt to join the two pulleys (Driven and driving pulleys as:

$$L_b = \frac{D_2 - D_1}{4C} + \frac{\pi(D_1 + D_2)}{2} + 2C \quad (12)$$

Where: L_b = V-belt Length (mm) and C = Two pulleys distance apart (200mm) (Selected).

c. Tensions acting on the belt

Two opposite tensions are acting on the belt in the same direction. We let T_1 and T_2 as the tensions acting on the tight side and slack side of the belt respectively.

The tension acting on the slack side of the belt is found using the equation (13):

$$T_2 = \frac{T_1}{e^{\mu\theta \sin(\theta/2)}} \quad (13)$$

Where: μ = Coefficient of friction between the belt and the pulley (0.4) [14] and θ = Groove angle (15°) [14].

And The tension acting on the tight side of the belt can be calculated using the expression given as:

$$T_1 = T - T_c \tag{14}$$

Where: T = Maximum tension acting on the belt (N) and Tc = Centrifugal tension acting on the belt (N).

These maximum tension and centrifugal tension are given as:

$$T = \sigma A_b \tag{15}$$

$$T_c = MV^2 \tag{16}$$

Where: σ = Allowable stress in the belt material (80N/mm^2) [14], A_b = Cross sectional area of the belt material (mm^2), M = Mass per unit length of the belt material (kg/mm) and V = Belt velocity (m/s) and its given as:

$$V = 2\pi N_b R_b \tag{17}$$

d. Power transmitted by the belt

The power transmitted by the belt can be found using the equation given as:

$$P = (T_1 - T_2)V \tag{18}$$

2.4.5 Capacity/Selection of the electric motor

For the design of pelletizing machine will not be appropriate until a suitable electric motor with the required power that can run the pulley attached to the shaft of the screw auger was selected. The power required to run the shaft of the screw auger by an electric motor is given as:

$$P_m = m\omega^3 r^2 \tag{19}$$

Where: P_m = Power required to run the shaft (W), m = Mass of the shaft (10kg), ω = Angular velocity of the electric motor (rad/s) and r = Radius of the shaft (10mm) (See figure 2).

3. Construction Process of the Machine

The feeding unit (hopper) is in the form of truncated frustum of pyramid was constructed using mild steel of thickness 1.5 mm by marking out using scriber, meter rule and try square. The portable grinding machine was used to cut out the marks on the mild steel and welding the cut part of the steel after folding to give the required shape of the hopper.

The barrel (pelletizing chamber) is made up of a cylinder using mild steel of thickness 1.5 mm and length of 900 mm using rolling machine and welding the ends of the steel. At 200 mm from one of its ends an opening was made of 170 by 170 mm where the frustum shaped hopper is attached. 1 mm thickness cast iron sheet was folded and welded on the stainless-steel shaft to form a screw auger.

The supporting base and frame were constructed using angle iron of thickness 3 mm. A hacksaw was used to cut seven pieces of 800 mm long and two pieces of 700 mm long section from two and half angle iron of 6000 mm length each. These nine sections were arranged and welded to form the frame and supporting base.

The motor bracket was constructed on another two 500 mm long, two 450 mm and two 260 mm long sections of the same angle iron. These six components were then arranged and welded to form the motor support and the bracket.

Figure 4 shows the side view of the complete designed and constructed machine for pelleting the aquatic feeds.

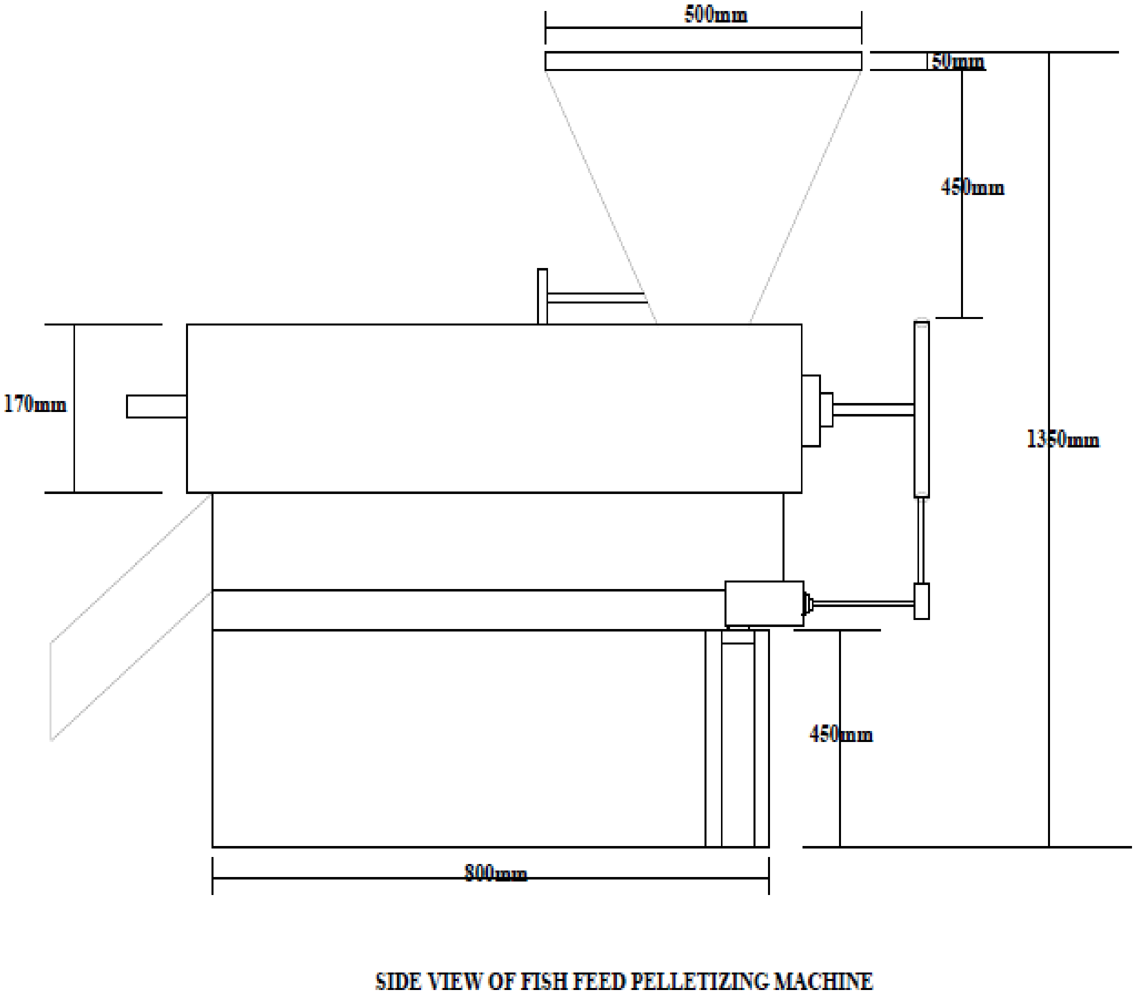

Figure 4. Side View of the Fish Feed Pelletizing Machine

4. Performance Analysis of the Machine

4.1 Cost Analysis

The cost of all the materials used in construction of the screw type pellet machine was given in the table 2.

Table 2. Cost of the Materials Used

S/No	*Materials/Particulars*	*Quantity*	*Unit Price (₦)*	*Total Cost (₦)*
1	1.5mm mild steel	2	8,000	16,000
2	1 mm cast iron sheet	1	9,000	9,000
3	3 mm angle iron	3	6,500	19,500
4	6-inch pulley	1	3,000	3,000
5	2-inch pulley	1	2,500	2,500
6	Electric motor	1	25,000	25,000
7	'A' type belt	1	1,000	1,000
8	Bearing	4	500	2,000
9	Bolt and nut	10	80	800
10	Labor	1	30,000	30,000
11	Electrodes	2	1,000	2,000
12	Cutting disc	5	800	4,000
13	Grinding disc	1	1,000	1,000
	Total			115,800

4.2 Drying Rate, Pelletizing Percentage and Machine Percentage

Table 3 presents the rate of dryness (%) and temperature (°C) of the pellet feeds for different die holes.

Table 3. Dryness and temperature of the feeds

Dryness (%)	Temperature (°C)		
	1 mm die hole	2 mm die hole	3 mm die hole
50	103	101	97
60	148	141	138
70	192	187	184
80	238	233	229
90	275	272	267
100	302	298	293

Table 4 presents the rate of dryness (%) and time taken (minutes) for the pellet feeds to dry for different die holes.

Table 4. Dryness and time taken of the feeds

Dryness (%)	Time (min)		
	1 mm die hole	2 mm die hole	3 mm die hole
50	3	5	7
60	11	13	16
70	19	21	25
80	27	30	34
90	39	42	46
100	48	45	51

4.3 Discussion of the Results

The cost of production of the machine was ₦115,800 which is equivalent to $258 and this is far less than the cost of purchasing the machine in the market [17].

From table 3 presents the relationship between the rate of drying the moisture and temperature, it shows that when the temperature increases the dryness will also increases so also the time taken for the drying the pellet feeds as shown in the table 4. It was also observed that the temperatures were decreases when the die hole diameter was increase but the time taken for the feed materials to dry was increases as the diameter of the die hole increases for both electrical and manual operations.

The machine efficiency was calculated using equation (20) given as:

$$\eta = \frac{m_r}{m_f} \times 100\% \tag{20}$$

Where, m_f is the mass of feed sample fed into the hopper (2kg) and m_r is the mass of feed materials recovered after the pelletizing process (1.5kg).

And the pelletizing efficiency was found using equation (21) as:

$$\varepsilon = \frac{m_p}{m_r} \times 100\% \tag{21}$$

Where, m_p is the mass of pelletizing sample (1.4kg). This was obtained by weighing the pellets, which was manually separated from the recovered feed.

The machine and pelletizing efficiencies were obtained as 75% and 93.33% respectively.

The average values of the weight of the feed materials, discharge time, weight of the pelletized feed, weight of the residue materials and the loss due to non-pelletized materials were 8 kg, 2 min, 7.6 kg, 0.5 kg and 7.75%, respectively, this is in agreement with the research work done by [4, 18-20].

The moisture content of the pellets was found using equation (22) as:

$$Moisture\ content = \frac{m_1 - m_2}{m_1} \times 100\% \tag{22}$$

Where m_1 is the mass of pellets before drying for 7days (1.4kg) and m_2 is the average mass of pellets after drying period of 7days (0.95kg).

The pellet was dried on direct solar drying system (Open air) for 7days and the average moisture content of the pellets was 32.1%. The efficiency of both machine and pelletizing and the moisture content obtained in this design shows an improvement over those pelletizing machines developed by [21-24].

5. Conclusions

A screw-type pellet machine was successfully developed with different die holes diameters using electric and manual operations. The following are remarkable conclusions made:

i. The temperature of the feed materials is inversely proportional to the die holes diameters but the time taken for the pellet feeds to dry is directly proportional to the die holes diameters;
ii. The machine efficiency was found to be 75% whereas, 93.33% was the efficiency of the pelletizing and;
iii. 8 kg, 2 minutes, 7.6 kg, 0.5 kg and 7.75% were respectively found as weight of the feed materials, discharge time, weight of the pelletized feed, weight of the residue materials and the loss due to non-pelletized materials.

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