

# Development of Feed Plant for Ruminant Livestock

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**Abstract - Livestock business in Nigeria is being challenged by problems such as high cost of feedstuff, farmers-herders clashes, drying up of Lake Chad basin, inadequate utilization of agro-wastes for feed, desert encroachment, urbanization, population growth, inconsistencies and poor implementation of government policies. Ministry of livestock development was recently created by Federal Government of Nigeria to tackle farmers-herders clashes and develop the livestock sector. Some of the core mandates of the ministry are development and maintenance of livestock infrastructure to support sustainable growth. Towards developing the livestock sector, this project is aimed at developing a feed plant for production of balanced feed ration for ruminant livestock in ranches and grazing reserves. The feed plant developed consists of a multi-purpose cutting machine, a pneumatic conveyor chute and a horizontal mixer. Geometric modeling of the parts of the feed plant was done with Pro/Engineer® software. Theoretical design calculations led to the selection of 2.24 kW high speed three phase motor and 0.75 kW low speed gear motor as prime movers for the multipurpose cutter and horizontal mixer, respectively. Materials for the fabrication of the plant were sourced locally, while fabrication methods used include cutting, welding, drilling, turning, boring and grinding. Performance evaluation of the cutter and feed plant yielded 140 kg/hr and 30 kg/hr as their throughput capacities, respectively; cutting efficiency of the cutter was 94.44 %. Velocities of air that blew the chopped straws into the mixer were measured with an anemometer as 37.02 m/s at the exit of the blower and 5.46 m/s at the exit of the cyclone. This implies that the velocity of air decreases with distance. The use of this feed plant will shore-up productivity of ranches and grazing reserves and reduce farmers-herders clashes.**

**Keywords:** Livestock, Ruminant, Animal Feed, Cutter, Mixer.

## I. INTRODUCTION

In recent times, the Federal Government of Nigeria has made efforts towards ending the farmers-herders clashes through introduction of programmes that will restrict the movement of cows, while ensuring proper nutrition and protection of the herds. The introduction of the Rural Grazing Area (RUGA) settlement in year 2019 was rejected by many

States; however, the Government did not rest on its oars but introduced Livestock Intervention Programme in year 2021. Additionally, many State Governments adopted passed into law anti-open grazing bill and recommended establishment of ranches [1,2,3]. Population growth, urbanization and gains in real per capita income will result in an increased demand for livestock products [4]. Presently, Nigeria has a population of over 200 million people with increasing urbanization drive in many States and Federal Capital Territory. Building on lands that could be used as pasture areas and inability of the governments at Federal and State levels to manage housing needs of the populace contribute to the challenges of livestock investors.

On the 9th of July, 2024, President Bola Ahmed Tinubu created the Ministry of Livestock Development. The core mandates of the Ministry are: (a) formulation, implementation and monitoring of livestock development and animal health policies and programs; (b) development of grazing reserves, ranches, pastoral welfare initiatives and conflict mitigation strategies; (c) establishment of efficient national animal health management services, including the One Health approach; (d) development and maintenance of livestock infrastructure to support sustainable growth; and (e) promotion of public-private sector investment in the livestock industry [5]. Specific objectives of the research are to: design a ruminant livestock feed plant; fabricate the feed plant; and evaluate the performance of the feed plant. The outcome of this research will help the new Ministry achieve mandate (d) and (e), as the feed plant can be proliferated in grazing reserves and ranches for the production of quality feed for ruminant livestock.

Additionally, there are two major types of mixers, namely, the vertical mixer and horizontal mixer. Feed for poultry birds and aquatic animals are produced with vertical mixers, while animal feed for cattle, goats, sheep, horse, camel and so on, are produced with horizontal mixers. It has been shown that mixer type, sequencing of ingredients, length of mixing time, ingredient particle size and density affect mixing efficiency [6]. An animal feed chopping or cutting machine is used for chopping the farm waste products such as corn cob, maize and millet stalk, and so on [7]. Most researchers worked on either the feed cutting machine or the mixer; however, this research seeks to develop the two important machines and connect them with a pneumatic chute conveyor. This will

reduce manual handling of the feed material during production.

Feed mixing operation is of great importance as it is the process through which homogeneous mixture with adequate nutritional requirement can be achieved manually with a shovel or mechanically with mixers. Manual mixing is characterised by low output, less efficiency, intensive labour and may prove unsafe to the health of the animal, while mechanical mixing aids palatability of feed, minimises waste during animal feeding, facilitates easy packaging, and enhances post-production storage and preservation [8]. Seasonal variation affects livestock production in various agro-ecosystems, due to biomass availability resulting from variation in precipitation patterns or elevation. The use of mechanized feed plant will improve feed of lactating animals when forage is in short supply or of low quality by providing supplementary feed (e.g. bran, oil seed cakes), fodder (e.g. hay, straw). This has a high impact on milk yield [9].

The animal feed plant consists of two major equipment, namely animal feed cutter and horizontal mixer. Dependence on animals for food by humans all over the world is inevitable. To produce healthy and high-quality products such as meat, milk, skin, hoofs, the animal must be well fed. Feed production for livestock involves a range of activities, which include grinding, mixing, pelleting and drying operations. The growing demands for animal products have led to an increase in number of animals in the society, with a corresponding high demand for their feeds. However, good natural pasture is not in abundance, especially during dry seasons hence, the needs for supplementary feeds [7].

Large-scale animal production in Bangladesh (cattle, buffalo, sheep, goats, and poultry) is generally based on commercial feeds rather than the provision of fodders and forages, while marginal and small farmers feed their livestock with different crop residues and grasses. [10]. Use of programmable control systems for controlling a feed production line has been shown to increase productivity, save energy and cost [11]. Deployment of animal feed plants in ranches and grazing reserves in Nigeria will shore-up the productivity of livestock farmers. Diet of Nigerians is dominated by plant foods that do not contain all the substances necessary for good health. The importance of animal nutrient cannot be overemphasized. Animal production will be enhanced by conversion of agricultural wastes to animal feed [12]. Crop production is accompanied by large amounts of agricultural by-products; such by-products include stems, husks, leaves, brans, roots, cobs, straws and stalks [13].

A conveyor system has been defined as a common piece of mechanical handling equipment that moves materials from

one location to another. So many types of conveyors exist, but the ones mostly employed in animal feed industry are: screw, pneumatic, vibrating, belt, bucket, chute, wheel, gravity roller and chain conveyors. The physical characteristics of the material to be handled should be considered before selecting an appropriate conveying device. In particular, the following properties are relevant for agricultural products: moisture content, average weight per unit volume, angle of repose, and particle size. Grain flow rate, distance, incline available space, environment, and economics influence conveyor design and operating parameters [14,15].

It has been revealed that pneumatic conveying systems are basically composed of a suitable source of gaseous fluid, a system for feeding material to be conveyed, a conveyor system for material displacement, a container for material packaging and a filtering system for gas separation after transport. The transport of dry bulk particulate materials: powder, granular, flakes by means of fluid (typically air) flow in a pipe. The working principle consists of imposing compressed air or inert gas flow down a pressure gradient in a pipeline conveying the solids. In summary, conveying takes place by imposing a gas flow and suspending powdered or granulated material through a pipe. Chute conveyor is one of the least expensive methods of conveying materials. It is the simplest example of gravity operated conveyor. A spiral chute can be used to convey items between floor with minimum amount of space required [16,17].

Challenges identified by researchers in livestock feed machinery are summarized as follows: drudgery, poor mixing efficiency and lower production capacity are associated with manual mixing of livestock feed [18]. Poor feed resource management, inadequacy of proper feed ration in quantity and quality have been identified as impediments in livestock sector in Ethiopia [19]. Manual mixing is characterized by low output, less efficiency and high labour intensity [20]. Similarly, manual chopping of agro-wastes takes much effort, longer time and result in non-acceptable cut size of grass and improper mixing of grasses and additives [7]. Manual mixing increases overhead cost, takes longer time and involves much manpower, reduced feed uniformity [21]. Manual method of mixing feed ingredients is generally characterized by low output, less efficient, labour intensive and may prove unsafe, hence, hazardous to the health of the intended animals, birds or fishes for which the feed is prepared [22].

## II. MATERIALS AND METHODS

### 2.1 Materials

Materials used in this research can be divided into two, namely: materials for fabrication of the parts of the feed plant and materials for testing the plant. Parts of the feed plant

include: cutter shaft, cutter top housing-hopper sub-assembly, cutter impeller-blade sub-assembly, cutter base frame, cutter bottom housing, chute, mixer base frame, cyclone, cyclone base frame, mixer top cover, mixer side cover, mixing chamber, mixer-shaft stirrer sub-assembly, chain are made of low carbon steel. Low carbon steel was used because of its high tensile strength, reasonable toughness and good ductility. Consumables used during the fabrication of the feed plant are E6013 electrode, cutting disc, grinding disc and binding or filler iron wire.

Measuring instrument used include digital scale, anemometer and temperature control panel. Geometric modeling of the parts of the feed plant was achieved with Pro-Engineer® software. Rice straw was used as feed material for testing the multipurpose cutter and horizontal mixer; the rice straw was sourced from Ardo Kola local government, Taraba State, Nigeria. Bought out materials, components, prime movers and measuring instrument were sourced from Jalingo, Lagos and Jos, Nigeria.

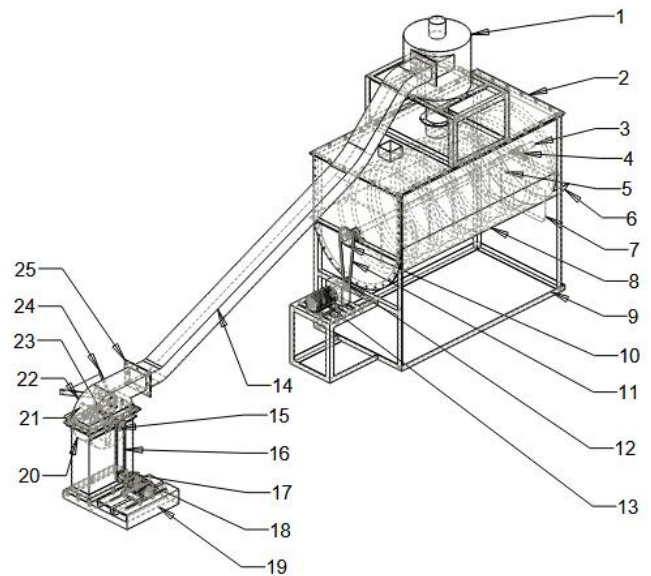


Figure 1: Isometric projection of the ruminant livestock feed plant

Table 1: List of components of the ruminant livestock feed plant

S/N	Component name	Qty
1	Cyclone	1
2	Mixer top cover	1
3	Mixer shaft	1
4	Journal bearing	4
5	Ribbon stirrer	1
6	Discharge spout	1
7	Discharge cover	1
8	Mixing chamber	1
9	Mixer base frame	1
10	42T Sprocket	1
11	Chain	1
12	14T Sprocket	1
13	Gear motor	1
14	Chute conveyor	1
15	Cutter driven pulley	1
16	B-Belt	1
17	Cutter driver pulley	1
18	High speed motor	1
19	Cutter base frame	1
20	Cutter bottom housing	1
21	Cutter shaft	1
22	Cutter top housing	1
23	Cutter blade-impeller	1
24	Cutter charging tray	1
25	Cutter discharge spout	1

## 2.2 Methods

Towards achieving the project objectives, the stages accomplished in the course of the project are summarized in the conceptual framework outlined as follows: review on nutritional needs of selected livestock; identification of feedstuff, fodder and agricultural wastes used in making ruminant livestock feeds; selection of materials for development and evaluation of the ruminant livestock feed plant; geometric modeling of the plant; theoretical design of the plant; sourcing of materials and components for the production of the ruminant livestock feed plant; fabricating of the plant; sourcing of feed stuff for the evaluation of the plant; and performance evaluation of the ruminant livestock feed plant.

### 2.2.1 Geometric Modeling of the Ruminant Livestock Feed Plant

Parts of the multipurpose feed cutter, chute conveyor and horizontal mixer were drawn with Pro-Engineer® software. Also, mass properties of the parts in the cutting and mixing chambers were generated from the software and used in theoretical design of the feed plant. Isometric projection of the ruminant feed plant, showing the internal parts in hidden lines is presented in Fig. 1.

### 2.2.2 Theoretical Design of the Feed Plant

Mass properties of the shaft-cutter-impeller sub-assembly was generated from the Pro-Engineer® software and outlines as follow:

VOLUME = 3.3063682e+05 MM<sup>3</sup>  
 SURFACE AREA = 2.1557343e+05 MM<sup>2</sup>  
 AVERAGE DENSITY = 7.8500000e-09 TONNE / MM<sup>3</sup>  
 MASS = 2.5954990e-03 TONNE = 2.6 kg

Similarly, mass properties of the mixer’s shaft-mixing ribbon sub-assembly were generated from the Pro-Engineer® software and presented as follow:

VOLUME = 6.1781751e+05 MM<sup>3</sup>  
 SURFACE AREA = 4.3624776e+05 MM<sup>2</sup>  
 DENSITY = 7.8500000e-09 TONNE / MM<sup>3</sup>  
 MASS = 4.8498675e-03 TONNE

**(a) Design of the Multipurpose Feed Cutter**

The driven parts of the cutting machine consist of a steel pipe, cutter-knives and impeller blades and pulley weighing 2.6 kg. Assuming a feed stock of mass 0.4 kg, the total mass of the driven parts and feedstuff becomes 3 kg.

Let the mass of driven parts and feedstuff being cut per time  $M_c = 3$  kg

Density of steel ( $\rho$ ) = 7850 kg/m<sup>3</sup>

Assume diameter of an equivalent steel shaft that will represent  $M_c$ ,  $D_c = 30$  mm = 0.03 m

Volume of the equivalent shaft can calculated from equation (1) as follows:

$$\rho = \frac{M_c}{V_c} [23] \quad (1)$$

$$V_c = \frac{3}{7850} = 0.0003822 \text{ m}^3$$

Length of the equivalent shaft is calculated from equation (2):

$$V_c = \pi \times D_c^2 \times L_c / 4 \quad (2)$$

By substitution,  $L_c$  becomes,

$$L_c = \frac{4 \times 0.0003822}{3.142 \times 0.03^2} = 0.54 \text{ m}$$

Torque transmitted by the equivalent shaft of the cutter is calculated from equation (3),

$$T_c = G \times \theta_c \times J_c / L_c \quad (3)$$

where.

$J_c$  is the polar moment of inertia of the equivalent shaft of the cutter driven parts,

Take angle of twist of the equivalent shaft of the cutter to be  $\theta_c$ ,  $G$  is the modulus of rigidity of the equivalent steel shaft.

$$\theta_c = 0.03^\circ = 0.03 \times \pi / 180 = 0.000524 \text{ rad.}$$

$$J_c = \pi \times D_c^4 / 32 [24] \quad (4)$$

By substitution,  $J_c$  becomes

$$J_c = 3.142 \times 0.03^4 / 32 = 7.95 \times 10^{-8} \text{ m}^4$$

$$G = 8.0 \times 10^{10} \text{ N/m}^2 [24]$$

By substitution in equation (3),  $T_c$  becomes

$$T_c = \frac{8.0 \times 10^{10} \times 0.000524 \times 7.95 \times 10^{-8}}{0.54} = 6.17 \text{ Nm}$$

Cutters usually operate at high speed; assuming the speed of the equivalent shaft of the driven parts of the cutter is  $N_c = 2800$  r.p.m.

Power transmitted by the equivalent shaft of the cutter driven parts,  $P_c$  is given by equation (5)

$$P_c = 2 \times \pi \times N_c \times T_c / 60 \quad (5)$$

By substitution,  $P_c$  becomes

$$P_c = \frac{2 \times 3.142 \times 6.17 \times 2800}{60} = 1809.37 \text{ W}$$

**(b) Selection of Prime Mover for the Cutter**

Note: The diameter of the driver and driven pulleys are the same, i.e., 0.08 m. Hence, the prime mover speed and the equivalent shaft speed are the same.

Efficiency of the pulleys-belt drive of the cutter,  $E_c$  is given by equation (6):

$$E_c = \frac{\text{Output power}}{\text{Input power}} \quad (6)$$

Assuming the efficiency of 90 %, Input power, which is the power of the electric motor that will drive the cutter driven parts is given by:

$$\begin{aligned} \text{Input power of the cutter motor} &= \frac{1809.37}{0.9} \\ &= 2010.41 \text{ W} \end{aligned}$$

Converting 2010.41 W to horsepower, gives

$$\text{Power rating of prime mover} = \frac{2010.41}{746} = 2.7 \text{ hp} \approx 3 \text{ hp}$$

Consequently, a 3 hp three phase electric motor was selected. Also, the speed of the selected motor is 2840 r.p.m.

**(c) Design of the Horizontal Mixer**

The driven parts of the consist of a steel pipe, non-continuous ribbon mixing mechanism and sprocket weighing 4.85 kg. Assuming the mass of chopped grass and additives is 1.5 kg, the total mass of the driven parts and feedstuff undergoing mixing becomes 6.35 kg.

Let the mass of driven parts and feedstuff being mixed per time,  $M_m = 6.35$  kg

Density of steel ( $\rho$ ) = 7850 kg/m<sup>3</sup>

Assume diameter of an equivalent steel shaft that will represent  $M_m$ ,  $D_m = 30$  mm = 0.03 m

Volume of the equivalent shaft can be calculated from equation (7) as follows:

$$\rho = \frac{M_m}{V_m} \quad (7)$$

$$V_m = \frac{6.35}{7850} = 0.0008089 \text{ m}^3$$

Length of the equivalent shaft is calculated from equation (8):

$$V_m = \pi \times D_m^2 \times L_m / 4 \quad (8)$$

By substitution,  $L_m$  becomes,

$$L_m = \frac{4 \times 0.0008089}{3.142 \times 0.03^2} = 1.144 \text{ m}$$

Torque transmitted by the equivalent shaft of the mixer is calculated from equation (9),

$$T_m = G \times \theta_m \times J_m / L_m \quad (9)$$

where,

$J_m$  is the polar moment of inertia of the equivalent shaft of the mixer driven parts, which is calculated with equation (10)

Take angle of twist of the equivalent shaft of the mixer to be  $\theta_m$ ,  $G$  is the modulus of rigidity of the equivalent steel shaft.

$$\theta_m = 0.5^\circ = 0.5 \times \pi / 180 = 0.00873 \text{ rad.}$$

$$J_m = \pi \times D_m^4 / 32 \quad (10)$$

By substitution,  $J_c$  becomes

$$J_m = 3.142 \times 0.03^4 / 32 = 7.95 \times 10^{-8} \text{ m}^4$$

$$G = 8.0 \times 10^{10} \text{ N/m}^2 \text{ [24]}$$

By substitution in equation (9),  $T_m$  becomes

$$T_m = \frac{8.0 \times 10^{10} \times 0.00873 \times 7.95 \times 10^{-8}}{1.144} = 48.53 \text{ Nm}$$

Mixers usually operate at low speed; assuming the speed of the equivalent shaft of the driven parts of the mixer,  $N_m$  is 90 r.p.m.

Power transmitted by the equivalent shaft of the mixer driven parts,  $P_m$  is given by equation (11)

$$P_m = 2 \times \pi \times N_m \times T_m / 60 \quad (11)$$

By substitution,  $P_m$  becomes

$$P_m = \frac{2 \times 3.142 \times 48.53 \times 90}{60} = 457.44 \text{ W}$$

**(d) Selection of Prime Mover for the mixer**

Efficiency of the sprockets-chain drive of the mixer,  $E_m$  is given by equation (12):

$$E_m = \frac{\text{Output power}}{\text{Input power}} \quad (12)$$

Assuming the efficiency of 70 %, Input power, which is the power of the electric motor that will drive the mixer's driven parts is given by:

$$\text{Input power of mixer motor} = \frac{457.44}{0.7} = 653.49 \text{ W}$$

Converting 653.49 W to horsepower, gives

$$\text{Power of prime mover} = \frac{653.49}{746} = 0.88 \text{ hp} \approx 1 \text{ hp}$$

To achieve a low speed of 90 r.p.m., there is need to use a gear motor. Given that: Speed of the driver sprocket,  $N_1 = ?$

Speed of the driven sprocket,  $N_2 = 90$  r.p.m.

Number of teeth on the driver sprocket,  $T_1 = 14$

Number of teeth on the driven sprocket,  $T_2 = 42$

Velocity ratio of a chain drive is given by equation (13) as follows:

$$\text{V.R.} = \frac{N_1}{N_2} = \frac{T_2}{T_1} \quad [24] \quad (13)$$

By substitution,

$$N_1 = \frac{42 \times 90}{14} = 270 \text{ r.p.m.}$$

Considering the calculated power and output speed of the motor, a gear motor of 1 hp having motor input speed of 1380 r.p.m. and a speed ratio of 1:5.

Output speed of the gear motor,  $N_g$  is given by equation (14),

$$N_g = \text{Motor input speed} \times \text{Speed ratio} \quad (14)$$

$$N_g = 1380 \times \frac{1}{5} = 276 \text{ r.p.m}$$

The value of  $N_g$  is close to  $N_1$ ; hence, the selection of the 1 hp, 1380 r.p.m., 1:5 speed ratio gear motor as prime mover for the mixer.

### (e) Calculation of the Volume of the Mixing Chamber

The mixing chamber has a combination of cuboidal and semi-cylindrical shape. The sides of the cuboidal shape be A, B and C. Also, let the radius and length of the semi-cylindrical side be D and C, respectively. Hence, volume of the mixing chamber,  $V_{mc}$ , is given by equation (15).

$$V_{mc} = A \times B \times C + \frac{1}{2}(\pi \times D^2 \times C) \quad (15)$$

where,

$$A = 330 \text{ mm} = 0.33 \text{ m}, B = 280 \text{ mm} = 0.28 \text{ m}, C = 770 \text{ mm} = 0.77 \text{ m} \text{ and } D = 150 \text{ mm} = 0.15 \text{ m}.$$

By substitution,  $V_{mc}$  becomes

$$V_{mc} = 0.33 \times 0.28 \times 0.77 + 0.5 \times 3.142 \times 0.15^2 \times 0.77 = 0.0984 \text{ m}^3$$

From the generated mass properties of the pipe-ribbon stirrer sub-assembly, volume of the pipe-ribbon stirrer is 617,817.51 mm<sup>3</sup>. Actual volume of the mixing chamber is given by volume of the pipe-ribbon stirrer sub-assembly minus volume of pipe outside the mixing chamber.

Let the volume of pipe outside the mixing chamber be  $V_{po}$  and actual volume of the mixing chamber be  $V_{am}$ . Therefore,  $V_{po}$  is calculated from equation (16) as follows:

$$V_{po} = \frac{\pi}{4}(D_1^2 - D_2^2) \times l \quad (16)$$

Where,  $D_1 = 30 \text{ mm} = 0.03 \text{ m}$ ,  $D_2 = 25 = 0.025 \text{ m}$  and  $l = 400 \text{ mm} = 0.4 \text{ m}$

By substitution,  $V_{po}$  becomes

$$V_{po} = 3.142 \times 5 \times 55 \times 400 / 4 = 86,405 \text{ mm}^3$$

Let volume of the pipe-ribbon stirrer sub-assembly in the mixing chamber be  $V_{pr}$

$$V_{pr} = 617,817.61 - 86,405 = 531,412.51 \text{ mm}^3$$

$$= 0.0005314 \text{ m}^3$$

Then, actual volume available for mixing of chopped grass and additives is given by equation (1)

$$V_{am} = V_{mc} - V_{pr} \quad (17)$$

$$V_{am} = 0.00984 - 0.0005314 = 0.09787 \text{ m}^3$$

### 2.2.3 Fabrication of the Ruminant Livestock Feed Plant

The fabrication processes used in developing the parts of the ruminant livestock feed plants are outlined as follow:

**Cutter shaft:** The shaft was measured a measuring tape, marked with a scribe and cut to size with angle grinder. Thereafter, the shaft was turned to size with a lathe machine.

**Cutter housing (top and bottom):** Parts of the top and bottom housing of the cutter were marked out on a mild steel sheet and subjected to cutting, rolling, drilling, welding and grinding operations prior to assembling.

**Cutter impeller-blade sub-assembly:** Parts of this component were cut after marking, drilled, welded and ground before assembling it with other parts. The blades were sharpened with angle grinder.

**Cutter base frame:** Lengths of angle bars were marked and cut to size, joined by welding, drilled for fastening of bearings and ground to obtain good finishing before assembling.

**Chute:** The chute square pipe was formed using cutting, welding and grinding operations, after marking. Holes were drilled on both end flanges for assembling to the cutter on one end and mixer on the other end.

**Cyclone base frame:** This component was fabricated by marking out, cutting, welding of the cut parts, grinding of welded sections and drilling of holes for fastening to the top cover of the mixer.

**Cyclone:** Mixer cyclone was fabricated by marking out, cutting, rolling, welding, grinding and drilling operations, prior to assembling it to the its base frame and mounting on the top cover of the mixer.

**Mixer side cover:** Sheet metal and angle bar were marked and cut to size, the parts were drilled, welded and ground before assembling to one end of the mixer.

**Mixer shaft-ribbon stirrer sub-assembly:** Mild steel sheet were marked, cut and bent to form the ribbon stirrer. Predetermined lengths of ribbed steel were cut and used to weld the ribbon stirrer to the main shaft of the mixer.

**Mixer top cover:** Same as in mixer side cover.

**Mixing chamber:** Fabrication processes used in forming this component include marking, cutting, rolling, welding, drilling and grinding.

Upon completion of fabrication of the parts, the parts were painted and bought out parts such as pulleys, sprockets, chains, B-belt and electric motors were assembled accordingly.

**2.2.4 Performance Evaluation of the Ruminant Livestock Feed Plant**

Preliminary testing of the feed plant was carried out with rice straw. Bunches of rice straw were weighed on a digital scale and fed to the cutter for chopping of the feedstuff, while the cut materials were blown into the mixer through the chute and cyclone. Feeding of the cutting machine was incremental, ranging from 0.2 kg to 1.4 kg. A stopwatch was used to record the time it took to chopped the straw and pneumatically convey the feedstuff to the mixer. Throughput capacity of the cutter was calculated from the result of the test, while the mass of feedstuff that the mixer can handle was calculated, also. Samples of the chopped material were measured to determine the cut length of the straw. Pictorial view of the rice straw is shown in Figure 2.



Figure 2: Pictorial view of dried rice straw

Additionally, a digital anemometer was used to test the air flow rate from the discharge spout of the multipurpose cutter and exit of the cyclone. Furthermore, the mixer was tested with the cut feedstuff to ascertain its ability to mix the material. A motor control panel was developed for the switching of the high speed motor and gear motor.

Throughput capacity of the cutter, TCC is given by equation (18), while the throughput capacity of the ruminant livestock feed plant, TCP is given by equation (19).

$$TCC = \frac{\text{Mass of chopped feed}}{\text{Cutting time}} \tag{18}$$

$$TCP = \frac{\text{Mass of feedstuff produced}}{\text{Production time}} \tag{19}$$

Cutting efficiency, CE was calculated with equation (20);

$$CE = \frac{(L_a - L_b)}{L_a} \tag{20}$$

where,

$L_a$  is the initial length of rice straw (mm)

$L_b$  is the average length of chopped rice straw (mm)

**III. RESULTS AND DISCUSSIONS**

**3.1 Results**

**3.1.1 Result of the Design Calculations and Fabrication Operations**

Following the conceptualization of the ruminant livestock feed plant, geometric modeling and theoretical design calculations, components were developed and/or purchased to achieve the plant. Table 2 shows the design parameter and actual parameters of the selected electric motors.

Table 2: Design versus actual prime mover parameters

S/N	Machine	Design speed (r.p.m.)	Actual Speed (r.p.m.)	Design power (kW)	Actual power (kW)
1	Multipurpose cutter's high speed motor	2800	2840	2.01	2.24
2	Horizontal mixer's gear motor	90	276	0.65	0.75

Pictorial view of the developed ruminant livestock feed plant showing the multipurpose cutter, chute conveyor, horizontal mixer and motor control panel is shown in Figure 3.



Figure 3: Pictorial view of the ruminant livestock feed plant

### 3.1.2 Result of the Performance Evaluation of the Feed Plant

Incremental mass of dried rice straw ranging from 0.2 kg to 1.4 kg were used to test the plant. Figure 4 shows the graph of mass of the rice straw cut against the cutting time.

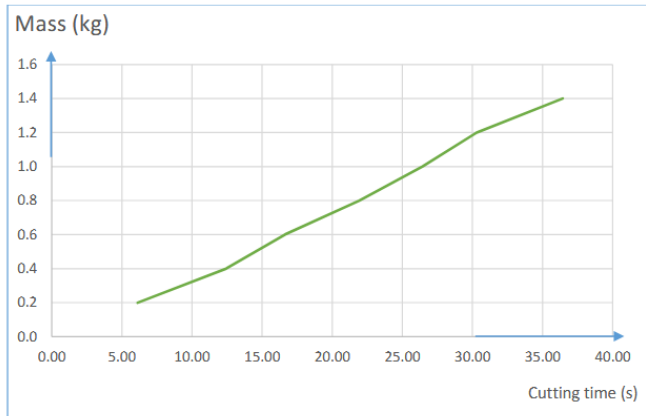


Figure 4: Graph of mass of grass (rice straw) chopped against the cutting time

Pictorial view of chopped rice straw is presented in Figure 5.



Figure 5: Pictorial view of chopped dried rice straw

Length of dried rice straw before cutting ranges from 700 mm to 900 mm; while length of chopped rice straw varied from 10 mm to 90 mm; hence, average length of chopped rice straw becomes 50 mm. Let  $L_a$  be 900 mm and  $L_b$  equals 50 mm; using equation (20), cutting efficiency is calculated as follows:

$$CE = \frac{(900 - 50)}{900} \times 100 = 94.44 \%$$

Actual volume available for mixing of grass and additives,  $V_{am} = 0.09787 \text{ m}^3$

### 3.2 Discussions

Cutting of grasses or agricultural plant wastes is usually done at high speed. The 2.24 kW three phase high speed motor performed excellently while cutting the rice straw and blowing of same through the chute, cyclone into the mixer. Most of the chopped rice straw measured above 50 mm. Cutting efficiencies of 96.36 % and 92.63 % for Asela model chopper and Selam model chopper, respectively, have been reported, when used in cutting maize stalk [25]. Hence, the cutting efficiency of the cutter aligns with that of existing cutters.

Mixing of feed materials is done at low speed. Hence, selection of low speed gear motor gave the intended performance. Velocity of air at the discharge end of the blower was 37.02m/s while 5.46 m/s was recorded at the cyclone discharge end. Anemometer was used to carry out the velocity measurement.

From Figure 4, it took approximately 36 seconds to cut and blow 1.4 kg of the rice straw into the mixer. Therefore, the throughput capacity of the cutter, TCC is calculated with equation (18) as follows:

$$TCC = \frac{1.4 \text{ kg}}{36 \text{ s}} = 140 \text{ kg/hr}$$

Given that:

Volume of the mixing chamber =  $0.09787 \text{ m}^3$

Bulk density of short grain rice straw =  $162.03 \text{ kg/m}^3$

Bulk density of long grain rice straw =  $166.29 \text{ kg/m}^3$  [26]

Average bulk density of rice straw =  $164.16 \text{ kg/m}^3$

Mass of rice straw that will occupy the mixing chamber =  $164.16 \times 0.09787 = 16.07 \text{ kg}$

Considering the size of the gear motor, a quarter of the mass of the straw is recommended.

Recommended mass of rice straw = 4 kg

Operations procedure for the feed plant is presented in Table 3.

Table 3: Ruminant livestock feed plant operations procedure

S/N	Operations	Time (Min.)
1	Measure and cut 4 kg of the rice straw with the cutter and blow through the chute and cyclone into the mixer	2
2	Add at most 1 kg additive the opening on top of the mixer	2
3	Mix the feed materials	3

	thoroughly to achieve homogenous mixture	
4	Open the discharge spout of the mixer and discharge the mixed feedstuff	3
5	Repeat the procedure for another batch of feed	

From Table 3 and equation (19), the throughput capacity of the plant, TCP can be estimated as 5 kg/ 10 min or 5 kg/1/6hr = 30 kg/hr.

#### IV. CONCLUSIONS

Geometric modeling of a 30 kg/hr capacity feed plant for ruminant livestock was achieved with Pro-Engineer® software. Locally sourced materials and basic fabrication procedures such cutting, welding, grinding, turning and boring were used in fabricating the plant. Dried rice straw was used in evaluating the feed plant. Production capacity of the multipurpose cutter was found to be higher than the overall throughput capacity of the feed plant. This implies that a mixer of higher capacity is required to match the 140 kg/hr cutter. Velocity of air from cutter decreased with increasing length of travel. The use of this plant is expected to shore-up productivity in ranches and grazing reserves and reduce farmers-herders' clashes. Also, agricultural wastes such as rice straw, maize stalk and fodders can be converted to useful feed material with the feed plant.

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