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Design of an NPK Fertilizer Pelletizer

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Abstract

Fertilizer application to boost crop yield has become inevitable and can be a source of environmental concern. In this study, the design of simple pelletizing equipment was considered to process fertilizer powder into pellets. This equipment was designed to convey, compact and extrude the NPK compound via a screw conveyor, through a die and into pellets. On the basis of the size of this home-made system and the bulk density of inorganic NPK compounds, a 1492 watts (2hp) motor and a 25mm diameter shaft of screw conveyor was used to convey the NPK compound at a rate of $3.0m^3/h$, and then compacted and extruded it into pellets. The octahedral shear stress failure criterion helped to determine how well the pelleting pressure chamber designed with mild steel, holds up against the radial (σ_r), hoop (σ_h) and axial (σ_z) stresses generated which amounted to an octahedral shear stress (σ_{oct}) of $1.5N/mm^2$, which is well below the yield stress of mild steel. The use of this equipment to produce inorganic NPK compounds into pellets helps improve fertilizer use efficiency and also militates against the environmental challenges posed by NPK fertilizer usage

Keywords: Design, NPK fertilizer, Pelletizer, Octahedral shear stress, Slow release fertilizer.

1.0 INTRODUCTION

The use of fertilizers has become inevitable in modern times and the attendant challenges associated with its use and overuse is becoming a source of worry. Administering fertilizers to boost crop yield is a necessity and its consistent use may degrade the environment by way of nutrient losses due to volatilization, or the leaching of nitrates into underground water bodies which is the source of our drinking water [2].

Producing NPK chemical fertilizers in pellets, sometimes with suitable binders has been known to achieve slow release of the plant nutrients to the crops, which maximizes the availability of nutrients to the crop and at the same time reduce the negative impact of its use to the environment as nutrient losses to the environment by way of leaching and volatilization is drastically reduced. Pelleting therefore, improves fertilizer use efficiency [17].

The sourcing and processing of NPK fertilizers into pellets, from locally sourced raw materials using a locally fabricated equipment has rarely been studied in Nigeria. There is need for "know-how" to aid and increase the efficient production of pelletized NPK chemical fertilizers locally which are environmentally safe and easy to handle by farmers. Pelletization techniques are diverse, ranging from extrusion-spheronization, balling, compression, cryopelletization, dry powder layering, hot melt extrusion amongst others [4]. There exists literature on the pelletization of Biomass for fuel [1,10,21], and in the pharmaceutical field [7,14]. But on the local scene, the subject of producing pellets using a locally fabricated equipment for human and animal feed appears to be more common at the moment [3,11-13,18-20]. Inorganic NPK fertilizers are known to have higher bulk densities than organic fertilizers, as well as human and animal feed [5]. Hence, this difference in bulk density will influence the design for the pelleting system and may also influence the magnitude of stresses experienced in the machine elements and the pressurized chamber of the pelletizer. Most inorganic NPK fertilizer compounds such as urea, triple superphosphate and the muriate of potash are hygroscopic in nature and require special handling, most especially during storage to avoid agglomeration/caking. This study therefore seeks to design a simple homemade system (pelletizer) to process NPK fertilizer into pellets to improve nutrient use efficiency.

2.0 METHODOLOGY

The design considerations bring into view, the power required from an electric motor to power the shaft carrying the auger which conveys, compacts and extrudes the NPK compounds through the die to produce the pellets. The design of the pelleting chamber is also critical to ensure it does not fail under operation. The shaft thickness required to transmit the required power, the die design/thickness, belt drive and bearing selection, was

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among design considerations made to aid in material selection to develop equipment fit for purpose. The NPK compounds of urea, triple superphosphate and muriate of potash were locally sourced. The average bulk densities of these three compounds using the upper limit is $1043 kg/m^3$[6]. Cold water starch solution of 1 litre is used as a binder (1 sachet of cold water starch 20grams / 1 litre of water). This solution was finely sprayed to add a little moisture to the NPK compound before it is fed into the hopper to commence pelleting. When the pellets are dried out later, the solution serves as a binder.

2.1 Design Analysis

2.1.1 Electric motor selection

The dimensions and capacity of the horizontal screw conveyor was chosen and determined, and the electric motor power rating computed.

Capacity of horizontal screw conveyor

$$I_V = 60 \times D^2 \pi \times S \times n \times \varphi \times K \qquad (1)$$

According to [8]
where;
I_V is the Capacity in m^3/h of the screw conveyor
Diameter of the screw in meter (D) = 0.076
Screw pitch in meter (S) = 0.06
Revolutions per minute (n) = 750
Fill factor for high density/lightly abrasive material [8], (φ) = 0.25
for horizontal screw, k = 1

Substituting into Equation (1),

$$I_V = 60 \times \frac{0.076^2 \times \pi}{4} \times 0.06 \times 750 \times 0.25 \times 1$$
$$= 3.0 m^3/h$$

I_v (conveyor screw capacity) is obtained to be $3.0 m^3/h$.

To obtain the Electric motor power rating.

$$P = \rho_V \times I_V \times (L \times f \pm H) \ \ in\, Watts\ [8] \qquad (2)$$

Bulk density

$$\rho_V = 1043 kg/m^3$$

Volumetric screw capacity (I_V) = 3.0 m^3/h
Horizontal distance of start and end points (L) = 0.22
Height difference, start and end points (Zero for horizontal screw) H = 0
General resistance factor or bulk material factor (f) = 2.0

Substituting into Equation (2), power rating (P) is thus,

$$P = 1043 \times 3.0 \times (0.22 \times 2.0 + 0)$$
$$P = 1377 Watts\ (1.8 h.p)$$

Hence, a 1492 Watts (2.0hp) motor was selected which is readily available in the market.

Consult material factor from bulk material table, phosphate sand is 2.0, potash is 2.0 and urea is 1.2. Therefore, we apply 2.0 for NPK [8].

2.1.2 Belt selection

To ensure a firm grip between the belt and the pulley, the required length (L) of the belt was determined thus:

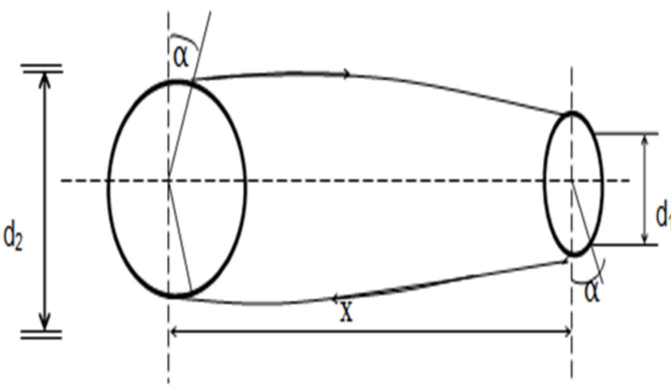

Figure 1: Belt arrangement

$$L = 2x + \frac{\pi}{2}(d_2 - d_1) + \frac{(d_2 - d_1)}{4x} \qquad (3)$$

where; L= Length of belt required
Diameter of driving electric motor pulley (d_1) = 0.09m
Diameter of driven pulley (d_2) = 0.12m
Distance between the center of both pulleys (x) = 0.4m
Substituting into Equation (3),

$$L = 2 \times 0.4 + \frac{\pi}{2}(0.12 + 0.09) + \frac{(0.12 - 0.09)^2}{4 \times 0.4}$$
$$= 1.14m$$

2.1.3 Shaft thickness (driving shaft)

To obtain the shaft thickness, we must first determine the torque generated, tensions experienced on the belt drive, the maximum bending moment on the shaft and the Equivalent twisting moment on the shaft.

Torque generated by shaft, T

$$T = \frac{P \times 60}{2\pi N} \quad (4)$$

P = 1492 Watts (2h.p) Power required
N = 750 rpm
π= Constant 3.142

$$T = \frac{1492 \times 60}{2\pi \times 750} = 19Nm \cong 20Nm$$

Hence, Torque generated is 20Nm rounded up to the nearest ten.

Tension experienced in the belt drive
As the motor powers the horizontal screw conveyor via the pulley, the belt drive experiences tensions T_1 on the tight side and T_2 on the slack side as illustrated in Fig 2. [9]

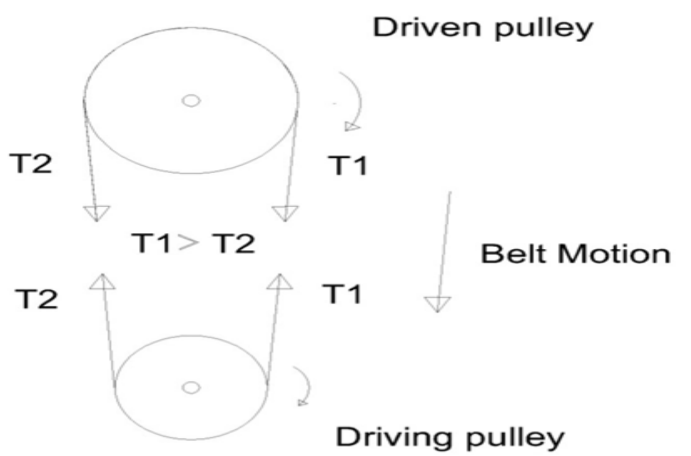

Figure 2: Belt tensions (T_1 and T_2)

Torque, T

$$T = (T_1 - T_2)r_1 \quad (5)$$

And

$$2.3\log\left(\frac{T_1}{T_2}\right) = \mu\theta \quad (6)$$

Where

$$\vartheta = (180 - 2\alpha)\frac{\pi}{180} \quad (7)$$

and

$$\alpha = \sin^{-1}\left(\frac{r_1 - r_2}{x}\right) \quad (8)$$

For open belts.

Where; Ө = Angle of contact between belt and pulley
x= distance between centers of both pulleys
μ = 0.3 friction between belt and pulley [9]
r_1 = radius of driving pulley
r_2 = radius of driven pulley

$$\alpha = \sin^{-1}\left(\frac{0.06 - 0.045}{0.4}\right)$$

Angle position in degree is shown in Fig 1.

$$\vartheta = [180 - 2(2.15)] \times \frac{\pi}{180} = 3.06rad$$

Input α into Equations (7) to obtain Ө. This will enable us work equations (5) and (6) to obtain $T_1$and T_2 by substitution. Torque (T) has previously been obtained as 20Nm.
Tensions T_1 and T_2 are 740N and 296N respectively.

Resultant bending moment on the shaft
The free body, shear force and bending moment diagrams is shown in Fig 3.

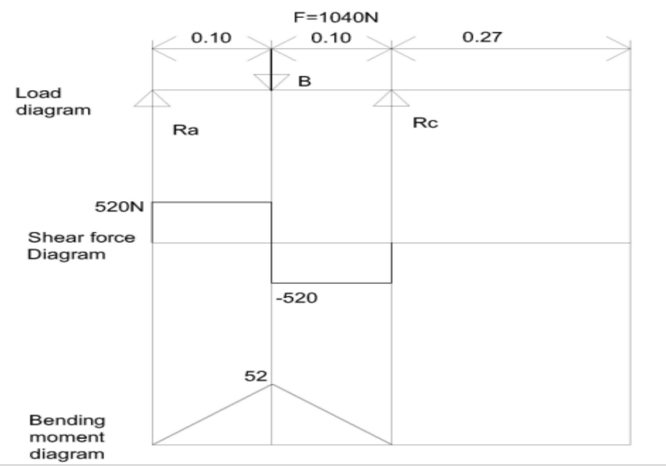

Figure 3: Free body, shear force and bending moment diagrams

As shown in Fig 3, the various loading on the screw conveyor shaft is represented as the load diagram. R_a and R_C are the reaction forces at the position where the bearings are located which is as a result of the downward force (F= 1040N) at point B. The force (F) is acting downward at point B on the shaft and is thus:

$$F = T_1 + T_2 + w \quad (9)$$

Where T_1= Tight side tension; T_2= Slack side tension and w= weight in Newtons of pulley all acting at point B on the free body diagram.

Substituting values T_1 = 740N, T_2 = 296N and w = 3.4N into equation (9),

$$F = 740 + 296 + 3.4 = 1039 \approx 1040N$$

To obtain the Reactions at R_a and R_c;

$$R_a + R_c = 1040$$

Taking moment about point A

$$1040 \times 100 = R_c \times 200$$

$$R_c = \frac{1040 \times 100}{200} = 520N$$

Substituting R_c = 520N into (10),

$$R_c = 1040 - 520 = 520N$$

A little consideration will show that the maximum bending moment will occur at point B. The bending moment about point B from point R_C,

$$M_B = R_c \times 100 = 520 \times 100 = 52KN - mm = 52Nm$$

Bending moment at point B, about point R_C:

$$1040 \times 100 = 104KN - mm = 104Nm$$

The maximum bending moment transmitted by the shaft

$$M = M_C = 104Nm$$

Equivalent twisting moment on the shaft (T_e)

$$T_e = [(K_m \times M)^2 + ((K_t \times T)^2]^{1/2} \qquad (11)$$

Combined shock and fatigue factor for bending moment (K_m) = 1.5
Combined shock and fatigue factor for torsional moment (K_t) = 2.0
Resultant bending moment on shaft (104 Nm)
(M) = 104Nm
Resultant torsional moment $(T) = 20nM$
For suddenly applied load with minor shocks only,

$$Km = 1.5 \; and \; Kt = 2.0 \; [9]$$

Substituting into equation (11),

$$T_e = [(1.5 \times 104)^2 + ((2.0 \times 20)^2]^{1/2} = 161Nm$$

Shaft thickness (Driving shaft)

$$d^3 = \frac{T_e \times 16}{\sigma_t \times \pi} \qquad (12)$$

Where (d) is the shaft diameter required.
Equivalent twisting moment of shaft

$$(Te) = 161Nm \; (161{,}000Nmm)$$

Allowable shear stress (σ_t) = 52N/mm^2
Pie (π) = 3.142
Substituting these values into equation (12),

$$d^3 = \frac{161 \times 10^3 \times 16}{56 \times 3.142}$$

$$d = (14.06)^2 = 24.5mm \approx 25mm$$

2.1.4 Cylinder selections

Pressure acting against cylinder walls (P_1)

$$P_1 = \frac{F}{\pi \times r_1^2} \; [15] \qquad (13)$$

Pie (π) = 3.142
Radius of inner wall of cylinder r_1 = 40mm
Radius of external wall of cylinder r_2 = 47mm
Torque generated by the shaft = 20Nm, radius of shaft in meters = 0.0125m, Therefore, Force generated by the shaft is thus;

$$F = \frac{20Nm}{0.0125m} = 1600$$

Substituting these values into equation (13),

$$P_1 = \frac{1600}{\pi \times (40mm)^2} = 0.318N/mm^2$$

Therefore, pressure acting against cylinder walls (P_1) is 0.318N/mm^2.

The pelleting chamber experiences an internal pressure of P_1 and external ambient pressure of zero. It is expected to be a thick walled cylinder where thickness t ≥ $d/20$.

It is evident that the maximum values of both the radial and hoop stress occur at the inner surface as shown in Fig 4 and Fig 5 [15].

Hence, radial stress σ_r= P_1 = 0.318 N/mm^2

$$\sigma_h = P_1 \left[\frac{r_2^2 + r_1^2}{r_2^2 + r_1^2}\right]$$

$$\sigma_h = \left[\frac{47^2 + 40^2}{47^2 - 40^2}\right] = 1.9 \approx 2.0N/mm^2$$

The axial stress,

$$\sigma_z = P_1\left[\frac{\pi \times r_1^2}{\pi(r_2^2 - r_1^2)}\right]$$

$$\sigma_z = 0.318\left[\frac{\pi \times 40^2}{\pi(47^2 - 40^2)}\right] = 0.8N/mm^2$$

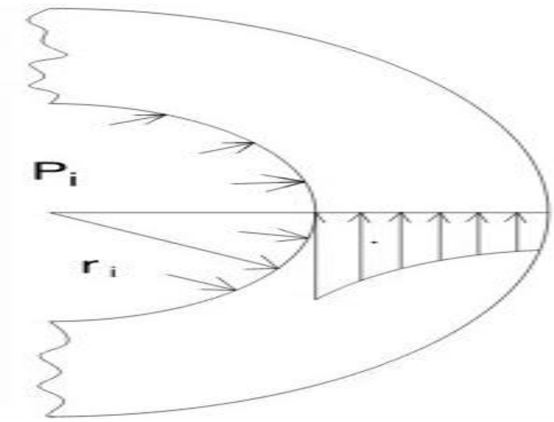

Figure 4: Radial Stress distribution

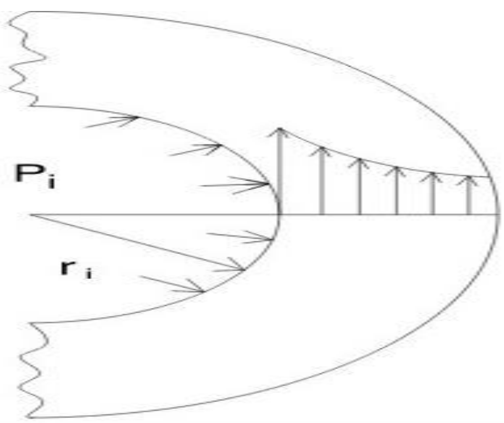

Figure 5: Hoop/circumferential Stress distribution**.**

The maximum octahedral criterion of failure for the cylinder, and assuming the ends are closed, where the die will be positioned.

$$\sigma_{oct} = \frac{1}{3}\left[\frac{(\sigma_k - \sigma_r) + (\sigma_r - \sigma_r) + (\sigma_z - \sigma_k)}{2}\right]^{1/2} = \frac{\sqrt{2}}{3}S_y$$

Therefore

$$\left[\frac{(\sigma_k - \sigma_r) + (\sigma_r - \sigma_r) + (\sigma_z - \sigma_k)}{2}\right]^{1/2} \geq S_y \quad (14)$$

Represents the criterion for failure where S_y is the yield stress of the material (mild steel = S_y = 220N/mm^2) [16].

$$\sigma_{oct} = \left[\frac{(\sigma_k - \sigma_r) + (\sigma_r - \sigma_r) + (\sigma_z - \sigma_k)}{2}\right]^{\frac{1}{2}} = (2.2504)^{1/2} = 1.5N/mm^2$$

$$\sigma_r = \frac{0.318N}{mm2}, \sigma_h = \frac{2.0N}{mm2}, \sigma_z = \frac{0.8N}{mm2}$$

and $\sigma_{oct} = 1.5N/mm2$

The stresses experienced shows that the mild steel cylinder readily available is okay for selection.

2.1.5 Die design

Die thickness;

$$t = K \times D_d\sqrt{\frac{P}{\sigma_t}} \quad (15)$$

Where, t = thickness of the die
Diameter of the die (D_d) = 94mm
Compressive stress through the die along the axis,
Axial stress (σ_z) = P = 0.8N/mm^2
Allowable design stress (σ_t) = 56 N/mm^2
Coefficient of friction for mild steel [9] (for fixed die)
K = 0.35
Substituting into equation (15),

$$t = 0.35 \times 94\sqrt{\frac{0.8}{56}}$$

$$t = 0.35 \times 94 \times 0.0754 = 3.9mm$$

Thickness required to withstand the internal pressure is t = 3.9 mm
So we adopt t = 7mm. to improve retention time in the die to form pellets.

2.1.6 Bearing selection

The shaft is rotating and making constant contact with the bearing, the required bearing type shall be the rolling contact bearing. From the free body diagram in Fig 3, the end reactions are Axial load, W_A = 520N and Radial load, W_R = 520N.

The dynamic equivalent radial load, W_D is given by the relationship below [9].

$$W_D = XVW_R + YW_A \quad (16)$$

In order to determine the radial and axial load factors, we need W_A/W_R and W_A/C_o

where C_o is the static load capacity factor.

For deep groove ball bearing, the maximum value of $\frac{W_A}{C_o} = 0.50$. Therefore, assuming the maximum value gives rise to a maximum ratio of $\frac{W_A}{W_R} = 1$.

Extracted from [9], X = 0.56, and Y = 1.0, where X is the radial load factor and Y the axial load factor. The rotational factor (V) for most of the bearings is unity (one).

Therefore, Substituting the values X = 0.56, V = 1, W_R = 520N, Y = 1.0 and W_A = 520 into equation (16) to obtain the dynamic equivalent radial load (W_D);

$$W_D = 0.56 \times 1.0 \times 520 + 1.0 \times 520 = 811.2N = \\ = 0.811kN$$

Checking the SKF values for fatigue load for a shaft of ϕ25mm corresponding to the computed value. Bearings for the required shaft diameter were selected.

2.1.7 Pelleting efficiency and throughput

Pelleting efficiency (P.E) was carried out using Equation (17)

$$P.E = \frac{W_O}{W_i} \times 100\% \qquad (17)$$

A 5kg weight of NPK fertilizer was processed through the Pelletizer which produced pellets weighing 4.15kg in 50 seconds, where W_o is the total weight of NPK pellets (kg) produced and W_i is the total weight of NPK (kg) put in the system.

$$P.E = \frac{4.15kg}{5kg} \times 100\% = 83\%$$

$$Throughput = \frac{W_O}{Time\ (Seconds)} \times \frac{3600\ seconds}{1\ hour}$$

$$Throughput = \frac{4.15kg}{50secs} \times \frac{3600}{1hr} = \frac{299kg}{hr}$$

$$Throughput \approx 300kg/hr$$

Pelleting Efficiency is 83% and the production rate/throughput is 300 kg/hr.

2.2 Pelletizer Photos and Materials.

The Pelletizer after fabrication at a local workshop is shown in Plate 1. The Pelletizer and pellets produced is shown in Plate 2, and also, the materials/parts of the NPK fertilizer pelletizer is listed in Table 1. Drawings of the pelletizer have been included in the appendix.

Plate 1: Pelletizer after fabrication at a local workshop

Plate 2: Pelletizer and NPK fertilizer pellets produced

Table 1: Materials/Parts of the Pelletizer

Item	**Quantity**	**Part Name**
1	1	Hopper
2	1	Conveyor Screw
3	1	Compression chamber/cylinder
4	2	Pulley
5	1	Die Plate

Item	Quantity	Part Name
6	2	Bearing
7	1	Electric Motor 1492watts (2hp)
8	8	Bolt and nut
9	1	Coupler

3.0 RESULTS AND DISCUSSION

The NPK fertilizer pelletizing equipment was designed for processing NPK compounds into pellets which improves fertilizer use efficiency. From the design considerations and analysis, the machine parameters and specifications are highlighted in Table 2.

Table 2: Machine Parameters and Specification

S/No	Design Parameters	Specifications
1	Capacity of screw conveyor	$3.0\,m^3/h$
2	Electric Motor Capacity	1492 Watts (2.0 Horse Power)
3	Diameter of Shaft (Power transmission)	25mm
4	Generated Torque	20Nm

The pressure acting against the cylinder wall is 0.318N/mm^2. The octahedral shear stress failure theory was used to determine how well the cylindrical pelleting pressure chamber holds up during its service life with a computed octahedral shear stress (σ_{oct}) of 1.5N/mm^2 which is lower than the yield stress for mild steel. This shows that the pelleting chamber design is robust enough for its service life under the stresses which will be experienced.

4.0 CONCLUSION AND RECOMMENDATION

4.1 Conclusion

The pelletizer for the production of NPK fertilizer was successfully designed and fabricated. It has a pelleting efficiency of 83% and a throughput rate of 300kg/hr. This simply designed equipment can be of use to small and medium scale enterprises to process fertilizer compounds to pellets. If an increase in production is required, more of this small sized equipment can function in a line operation to increase daily output. Our local farmers too, should be able to afford this equipment to enable them process organic wastes around them; such as poultry and cattle dung etc., into pellets to use in their farms.

The use of NPK pellets in the place of NPK powder, helps improve fertilizer use efficiency by increasing nutrient availability time to plants and reduce nutrient losses to the environment. Most inorganic NPK compounds contain urea, potash or triple superphosphate which are hygroscopic in nature and as a result require special handling. Hygroscopic bulk solids always aim to reach a moisture balance with the ambient air and as a result, are sensitive to temperature and ambient humidity. Hence, they should be stored in insulated containers and silos.

These inorganic NPK compounds should be kept in air tight containers before and after pelleting. If the pellets require drying out after pelleting, it is best to dry the pellets using a blower (dry air) before bagging. After bagging, they should be stored under cool dry storage conditions which helps to avoid agglomeration/caking which keeps the product in good physical condition.

4.2 Recommendation for further work

An optimization and performance evaluation of the NPK fertilizer pelleting machine is recommended. The effect of some parameters, such as the die mesh of varying sizes, conveyor screw speed (rpm) and the moisture content, may be examined to unravel their effect on the pelleting efficiency, bulk density of pellets produced and the throughput.

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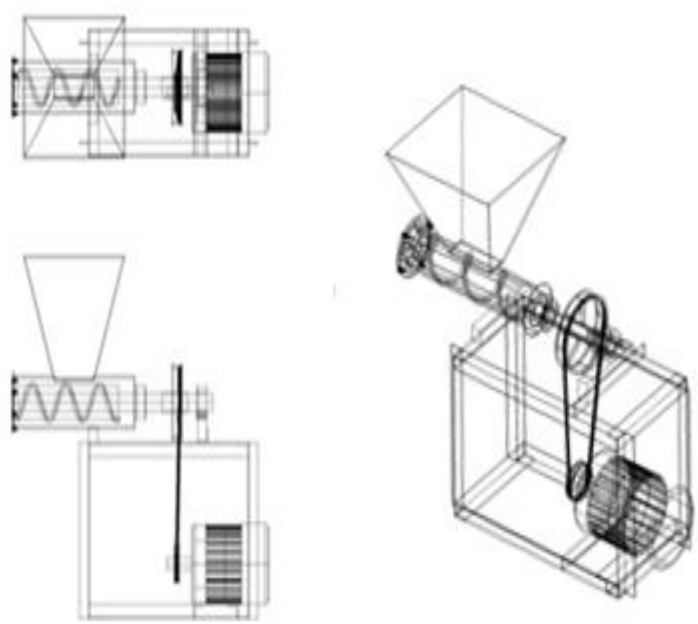
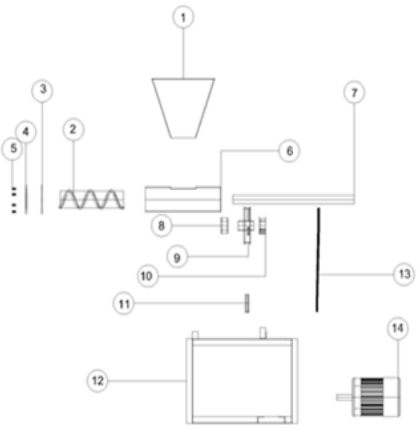
APPENDIX

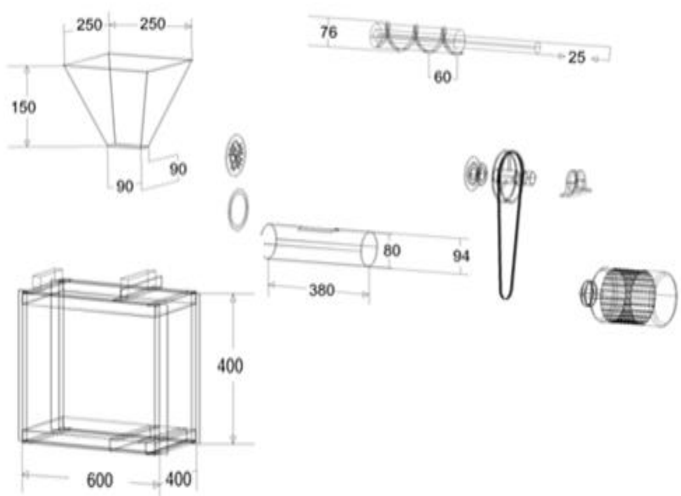


Appendix 1: Pelletizer Showing Top View, Side View and Isometric View.



No	Item
1	Hopper
2	Compression screw auger
3	Die plate couple
4	Die plate
5	Nut and bolt
6	Compression chamber
7	Shaft
8	Ball bearing
9	Pulley (big)
10	Bearing block
11	Pulley (small)
12	Frame
13	V-belt
14	Electric motor

Appendix 2. Parts of the Pelletizer Identified/Numbered.



Appendix 3: Exploded View of The Pelletizer showing Dimensions.