American Journal of Engineering Research (AJER)
e-ISSN: 2320-0847 p-ISSN : 2320-0936
Volume-7, Issue-1, pp-32-41
www.ajer.org
Research Paper Open Access

Design and Fabrication of Polythene Pelletizing Machine for Urban Communities in Nigeria

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ABSTRACT: *The high level of uncontrolled biodegradable waste constantly dumped in our surroundings on a daily basis constitutes nuisance in urban communities in Nigeria. This necessitated the need for a detailed design and construction of a pelletizing machine. This machine is important in the recycling process because it can be used to reduce the size and bulk density of waste polythene materials for ease of transportation and processing in the industry. The pelletizing machine was designed and constructed with a screw thread conveyor in a barrel to convey molded polythene. The screw thread is driven by a belt drive. The barrel was constructed to sear low density polythene(LDPE) at a temperature of 80°C. The waste polythene was fed through the feed hopper and extruded through a die. The output becomes useful raw material for plastic industries. The machine developed would be useful in polythenewaste management in urban cities in Nigeria. The pelletized materials will generate income as it serves as raw materials to polythene industries and provide employment opportunity for youths.*

Keywords*: barrel, conveyor, hopper, palletizing machine, Polythene,*

Date of Submission: 04-12-2017 Date of acceptance: 09-01-2018

I. INTRODUCTION

There is great interest in waste plastic recycling all over the globe because of its negative environmental impact. Plastic recycling is the process of recovering scraps of waste plastics for useful products.In Nigeria, it has been observed that there is high level of uncontrolled non-biodegradable waste in form of polythene waste such as sachet table water, nylon bags etc., dumped randomly in some urban communities. Hence, the need for efficient, available and cost effective waste polythenerecycle machine becomes necessary. The design and fabrication of plastic waste recycle machine in Nigeria has been studied[1-4]. However these machines were not easily accessible for efficient application locally.Therefore, this research focuses on the design, fabrication of a low cost, easily accessible and operatedpolythene pelletizing machine that could mold waste polythene materials efficiently for ease of transportation to production facilities.

II. MATERIALS AND METHODS

2.1 Material Sourcing

Waste polythene materials were sourced from within and outside the community of Federal University of Petroleum Resources, Effurun,Delta State, Nigeria. The materials sourced are non-biodegradable waste in the form of polythene/nylon.

2.2 Design Consideration and Fabrication of a Palletizing Machine

The significant considerations for the design of the polythene pelletizing machine include; design concepts, design specification, design calculations, choice of material and economic evaluations. The machine was designed for safe use, ease of operation at low maintenance cost.The fabrication process includes; metal cutting, welding of the component parts andassembly. The components of the pelletizing machine are as follows: Feed Hooper, screw thread, barrel and feed throat, heating elements, skid (stand), die, DC Motor, thrust bearing assembly and temperature controller with sensor.

2.3 Design of Extruder Screw Thread

The fundamental component of the machine was the extruder screw, designed with feed forward technique to facilitate the heating process of waste polythene materials. The screw is a cylindrical rod with constant outside diameter in the extruder. The ratio of circularallowance to screw diameter is about 0.001. The screw rotates within the hardened liner of the barrel. As the screw rotates, itforces the resin in the channel forward which is heated, melted and compressed out of the barrel. This screw has three zones [5]. The first zone is the feed zone which forces the polythene materials into the barrel; the second zone is referred to as the melting zone which facilitates the melting process of the polymer; the third and final zone is called the metering or conveying section which mixes the melted particles to a uniform temperature and composition. The standard for screw thread of 50mm for a pelletizing machine was employed as follows [6]:

i. Total length.(L) = 10D; L = 10 x 50mm = 500mm (1)
ii. Length of feed section(L_f)= 2D; L_f = 2 x 5mm = 100mm (2)
iii. Length of metering section (L_m) =3D therefore L_m = 3 x 50mm = 150mm (3)
iv. Length of compression section $L_c = L – (L_f + L_m)$; L_c= 500 – (150 + 100) = 250mm (4)
v. Channel depth in feed section H_f=0.075 D; H_f= 0.075 x 50mm = 3.75mm (5)
vi. Metering section H_m= 0.025D; H_m= 0.025 x 50mm = 1.25cm (6)
vii. Helix angle (φ) = 18^0 (7)
viii. Flight pitch = D/2 = 25mm (8)
ix. Flight width = 0.1D; flight width = 0.1 x 50 = 5mm (9)
x. N= Screw speed in revolutions per minute = 80rpm (10)
xi. ρ_{bulk} = Bulk density in pounds per cubic inch

2.4 Determination of Massand Volumetric Flow Rate

Applying [7] expression for the mass flow rate and volumetric flow rate:

Mass flow rate $= D^2 \times N \times h \times \rho_{bulk}$ [lb/minute] (11)

Volumetric flow rate $= v_z \times W \times h$[in^3/minute] (12)

And

v_z = Channel Velocity $= \pi \times D \times N\cos\varphi$ (13)

where,

W= Metering channel width in inches =150mm =15cm = (15/2.54) inches = 5.9inches
h= Metering channel depth in inches =1.25mm = 0.125cm = (0.125/2.54)inches
D = Screw diameter in inches =50mm = 5cm = (5 / 2.54)inches
N= Screw speed in revolutions per minute= 80rpm
φ= Helix angle = 18^0
From[8],Bulk density =ρ_{bulk} = 43lb/ft^3 = = (43 x 0.000579)lb/$inch^3$ = 0.0249lb/$inch^3$

From equation (11) and (12)

$M_f = (50)^2$ x 80 x0.125 x 0.0249 = 0.3798lb/min = (0.3798 x 0.454) kg/min = 0.17kg/min (14)

Volumetric flow rate = 3.142 x 1.96 x 80 Cos(18°) x 5.9 x 0.0492 = 94.46.3$inch^3$/min (15)

2.5 Barrel Dimension

The proportion of circular allowance to screw diameter selected was 0.001 [6].
Total length of barrel T_b = 550mm
$\frac{R_C}{D} = 0.001$, R_c= 0.001 X 50 = 0.05mm (16)
where, Screw diameter D = 50mm, R_c = Radial clearance (mm)
Internal diameter = D + 0.05 = 50 + 0.05 = 50.05mm
Thickness of barrel = 20mm
Therefore, external diameter of barrel = 70.05mm.
The barrel is cylindrical in shape. Therefore, volume of barrel (cylinder) is given by:
$V = \pi \times R^2 \times L$ (17)
where, R =barrel radius; L =barrel length; V = barrel volume and π = 3.142
The length of barrel is 550mm. The internal diameter and external diameter were 5.05 and 7.05mm, respectively.
Volume of barrel = 3.142 x 25.025^2 x 550 = 1082000mm^3.

2.6 Heat Transfer through Barrel

Since the heating element is to be applied on the exterior part of the barrel, heat will be transferred from the external surface to the internal surface of the barrel [9-10]. Let R_1, R_2, T_1, T_2 be internal radius, external radius, internal temperature and external temperature, respectively. Rate of heat transfer in cylinder could be expressed as:

$$\dot{Q} = \frac{2\pi k \times (T_1 - T_2)}{\ln(\frac{R_2}{R_1})} \quad (18)$$

Where, Q = Amount of heat transfer (W), R_1 = inner cylinder diameter (m), R_2 = outer cylinder diameter (m) $(T_1 - T_2)$ = temperature difference (^{0}C), b = thickness of cylinder wall (m), K is proportionality constant known as Thermal conductivity (W/m^{0}C) [9],K = 43W/m^{0}C [11].

From equation (18), $\dot{Q} = \frac{2 \times 3.142 \times 43 \times (100-90)}{\ln\frac{0.007005}{0.005005}} = \frac{2702.85}{0.336}$ (19)

$$\dot{Q} = 8039.4W = 8.04kJ/s = 8.04kW \quad (20)$$

Therefore, the heat transfer in the cylinder is at a rate of $8.04kW$.

2.7 Design of the Hopper

Mild steel was selected as suitable material for the construction of the feed hopper. The feed hopper feeds the polythene materials (shredded polythene) to the extruderwhich flows into the extruder from the hopper.In order to achieve steady flow through the hopper a pyramidal hopper was selected.

2.7.1 Hopper Dimensions

The hopper base is constructed to fit the extruder wall of 8cm diameter. The pyramid hopper with four corners is extruded upwards to a height of 30cm with an angle of 28 degrees to the horizontal axis. Square top head = (30 x 30) cm; Vertical Height of hopper =30mm; Angle of inclination = 28^0; Wall thickness = 0.15cm, as shown in Fig. 1

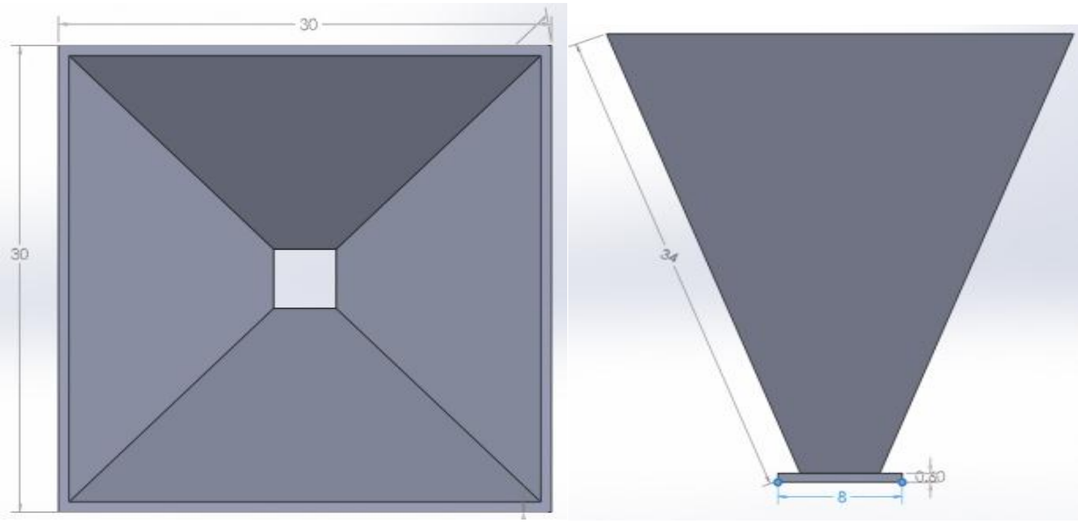

Figure1: Hopper Dimensions

2.7.2 Volume of Hopper

The volume of pyramid, V_P, could be expressed as;

Volume of pyramid $(V_P) = \frac{A \times H}{3}$ (21)

where,

Area of the hopper top (square in shape), A = (30 x 30) cm

Height of the hopper, H = 35cm

$V_P = \frac{(30 \times 30) \times 35}{3} = 10500\,cm^3$ (22)

Therefore, Volume of Hopper (V_P) = 10500cm^3 = 0.0105m^3

2.7.3Drive System
A DC motor drive was used to drive the machine. The needed screw speed is 80rpm[12].
Power requirement was computed as follows;

$P = P_{st} + P_H + P_N$ (23)
where, P_H = Startup Power of the material, P_N = Screw driving power at no load,
P_{st} = Inclination power of the conveyor, P = Total power required

2.7.4 Power Requirement
The power required to start the system could be expressed as:

$P_H = \frac{M_f \times L \times \lambda \times g}{3600}$ (Kilowatt) (24)
where:
M_f = Mass flow rate in t/hr = 0.17kg/min =(0.17 x 60)kg/h = 10.2kg/hr,
g = acceleration due to gravity (m/s^2)
λ = Progress resistance coefficient (4 was used).
Therefore,
P_H = (0.0112 x (50 x 0.394) inches x 4 x 10) / 3600 (25)
P_H = 27.12 / 3600; P_H = 2.46 x 10^{-3}kw (26)

2.7.4 Power Required to Drive Screw Conveyor, P_N
This power requirement is defined as:
$P_N = \frac{D \times L}{20}$ (27)
where,
D = Screw Nominal diameter = 5cm = 0.05m
L = Screw thread Length = 50cm = 0.5m
P_N = (0.05 x 0.5) / 20 = 1.25 x 10^{-3}kw (28)

2.7.5 Power Acquired as a Result of Inclination, P_{st}
This power acquired as is defined thus:
$P_{st} = \frac{M_f \times H \times g}{3600}$ (29)
where,
M_f is mass flow rate
H=Height
G= Acceleration due to gravity
P_{st}= (0.0112 x 0 x 10) / 3600 = 0kw (30)
H is negative for descending, H=0 (no height). Therefore P= 0kw.

2.7.6 Total Power Requirement in the System
The complete power requirement is the sum total of the power in the entire system
From equation (8) above, total power requirement (P) is:
$P = 2.46 \times 10^{-3}$kw $+ 1.25 \times 10^{-3}$kw $+$ 0kw= 3.71 x 10^{-3}kw (31)
Therefore, the power requirement for the screw conveyor is = 3.71 x 10^{-3}kw

2.8Torsional Strength of the Screw
The torque that is transmitted is a function of the power supplied to the screw (Z_{screw}), and the screw's revolutions per minute, N [13]. The relationship between these parameters was expressed as;

$T = C \times \frac{Z_{screw}}{N}$ (32)
where, Z_{screw}= power of the screw;N = rotational speed of the screw; C = conversion constant
If Z is expressed in horsepower and N in rev/min., the constant C equals 7120.9 to give a torque expressed in Newton-meter. If Z is expressed in kilowatt, constant C equals 9549.3.
In equation (32), the power to the screw is related to the motor power by;

$Z_{screw} = Z_{motor} \times Eff_{motor} \times Eff_{transmissio\ n}$ ` (33)

where,
Power of the motor, Z_{motor}= 0.2kw

Efficiency of the motorEff$_{motor}$ = 0.75 and

Efficiency of the transmissionEff$_{transmission}$ = 1

Z_{screw} = 0.2kw x (0.75 x 1) = 0.15kw

From equation (32), Tensional strength of the screw is given by

$$T = C \times \frac{Z_{screw}}{N} \quad (34)$$

where, Z_{screw} = 0.15kw, C = 9549.3, N = 80rpm

Inputting these parameters into equation (34), we have

$$T = 9549.3 \times \frac{0.15}{80} \quad (35)$$

$$T = 9549.3 \times 0.001875 = 17.91Nm \quad (36)$$

Therefore, the torsional strength of the screw is 17.91Nm.

2.9 Temperature Control

Microprocessor-based controllers offer great flexibility in that controller function can be changed readily by simply changing a few steps in the program. In this work, mica band is selected because of its strength.

Energy generated by Heater (Q) = Current (I) x Voltage (V) x Time (T) (36)

But,

$$\text{Current} = \frac{\text{power}}{\text{voltage}} \quad (37)$$

The values for power and voltage are specified on the heaters to be 2000watts and 220volts respectively.
Therefore current is calculated to be;

$$\text{Current} = \frac{2000}{220} = 9.09 \quad \text{Therefore, amperage is} = 9.09\text{A} \quad (38)$$

Two heaters were used for optimum performance of the heating system.
This makes the total amperage now becomes;
(9.09 x 2) = 18.2Amps.

From equation (36), energy generated by the two heaters per second could be expressed as;
Q = (18.2 x 220 x 1) = 3999.6 Joules = 3.9996 KJ (39)
Therefore, Electric energy produced by the heaters in one second is 4.0KJ.

The heaters were designed to heat the barrel and to increase the temperature of the barrel as long as power was in constant supply. For the pelletizing machine to function effectively, it was necessary to input a control system that monitor the temperature in the system. To achieve this, several components are required: temperature controller (800volts), contactor (25Amps), relay (220volts), switches and LED display lights.

2.10 Electrical Control System Operation

The heaters generate heat energy to the barrel. A temperature controller with sensor was used. The sensor was installed in the barrel to evaluate the temperature variation. A relay receives signal from the temperature controller and forwards the signal to the contactor. When power is supplied to the circuit, the temperature was regulated to a set point on the temperature controller and the heater switches were activated accordingly. As the temperature of the heaters increase, the temperature sensor monitors the temperature inside the barrel. When the temperature in the barrel rises to the set point, the temperature controller sends the signal to the contactor and the contactor switches off power to the heaters. When the temperature drops below the set point, the sensor sends signal to the contactor for the heaters to be switched on. The control system is represented in Fig. 2

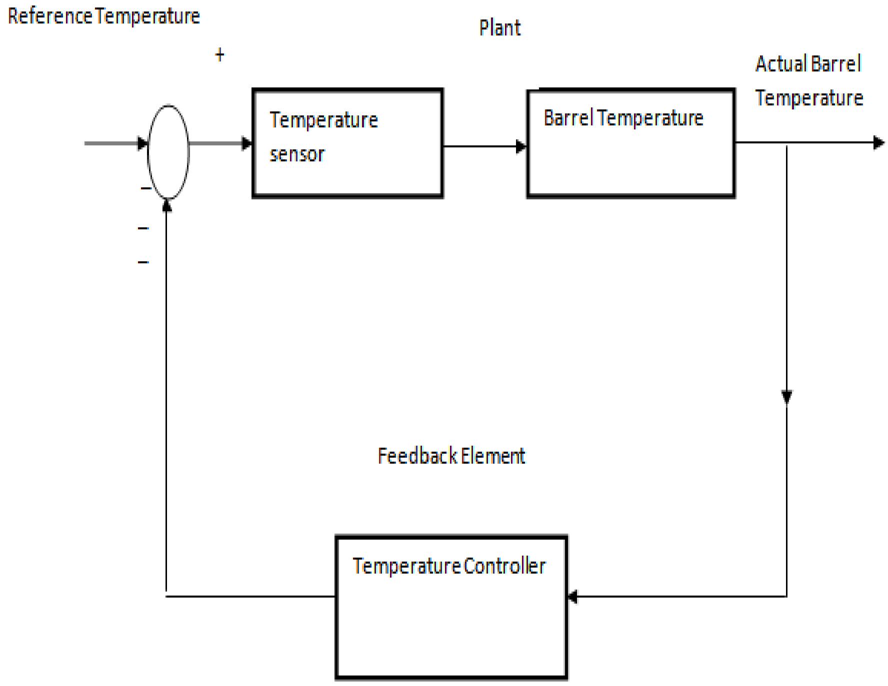

Figure 2: Feedback Control System

The electrical circuit diagram of temperature is shown in figure 3.

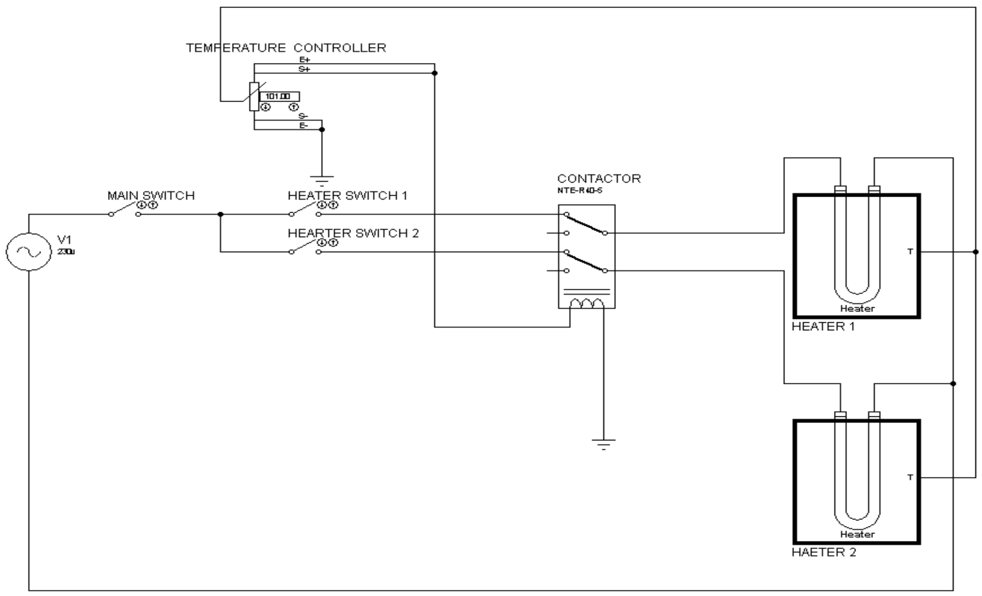

Figure 3: Circuit Diagram of Temperature

III. RESULT AND DISCUSSION

3.1 Performance Evaluation

The polythene pelletizing machine was fabricated and tested in order to evaluate its performance. The available non-biodegradable polythene materials were sorted, shredded and washed. Then the machine was powered for the operation and the heating elements were turned on. The waste polythene materials were introduced into the machine via the hopper and the barreltemperatures between 25°C to 140°C were observed, as the pelletized materials exit the chamber in droplets form at the outbound water bucket.

3.2Experimental Results

The following experimental result was obtained from the test conducted on the pelletizing machine in Table 1.

Table 1: Experimental Test Results

TRIAL	PROCEEDURE	TEMP.	RESULT/OBSERVATION
1	At room temperature the shredded polythene material was fed to the hopper	25^0C	There was free flow, the screw thread conveyed the material to the end of the barrel was not molded
2	Barrel was heated and then the materials was fed into the hopper	70^0C	The material achieved molding but was too thick to escape the die
3	Barrel Temperature was reset to a lower temperature	80^0C	The material molded and flow through the die in lumps
4	Barrel Temperature was reset and test carried out	110^0C	The material melted and it was observed that the polythene began to stick to the screw thread. (no flow)
5	Barrel temperature was increased and material was fed into the hopper.	140^0C	The material melted and polythene began to stick to the screw thread. (no flow)

3.3 Simulation Result

3.3.1 Stress Analysis

The von Mises stress plots of the extruder barrel analysis are given in Figure 4. The maximum stress at which it would fail is 182.852MPa.

3.3.2 Displacement Analysis

The displacement diagram shows negligible displacement at the points in direct contact with the heater bands. However, there was induced displacement at the inner wall of the barrel opposite the heater bands location. The maximum displacement of $1.646\text{x}10^{-3}$mm was observed at the inner wall and the space in-between the heater bands while the minimum displacement was$1.00\text{x}10^{-30}$mm as shown in figure 5.

3.3.3 Strain Analysis

From the strain plot in figure 6, we observed that the strain was maximum and minimum at the points that stress was maximum and minimum as shown in figure 4. The stress and strain plots follow the same pattern. The maximum and minimum strains were $4.567\text{x}10^{-4}$and $7.611\text{x}10^{-18}$, respectively.

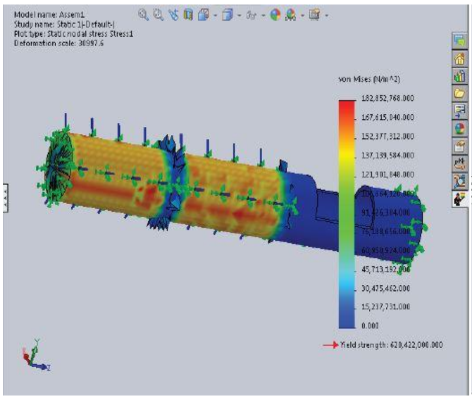

Figure 4:von Mises stress plot of the extruder barrel

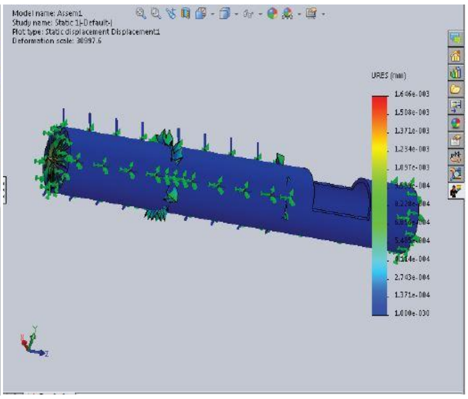

Figure 5: Displacement plot of extruder barrel

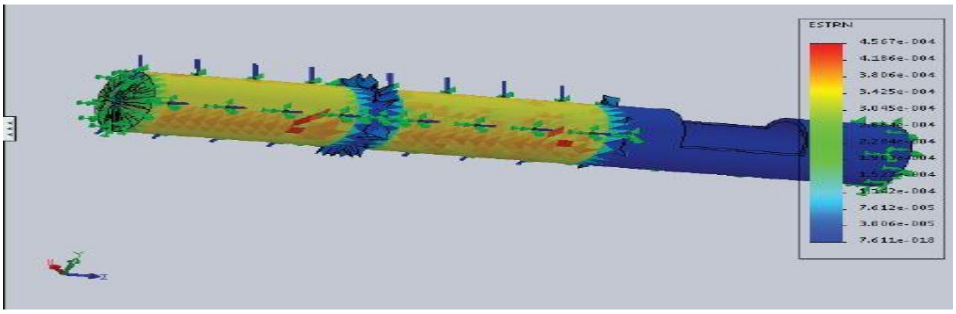

Figure 6: Strain - Strain plot of the extruder barrel

The design parameters were factored into the fabrication of the pelletizing machine. The drawings and pictorial viewof the machine were shown on figure 7 to 11.

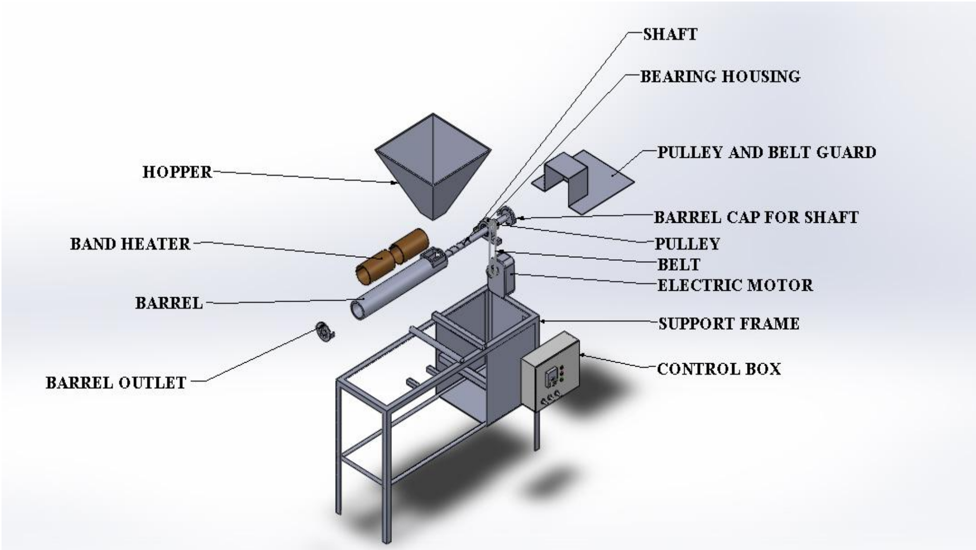

Figure 7: Exploded View of Pelletizing Machine

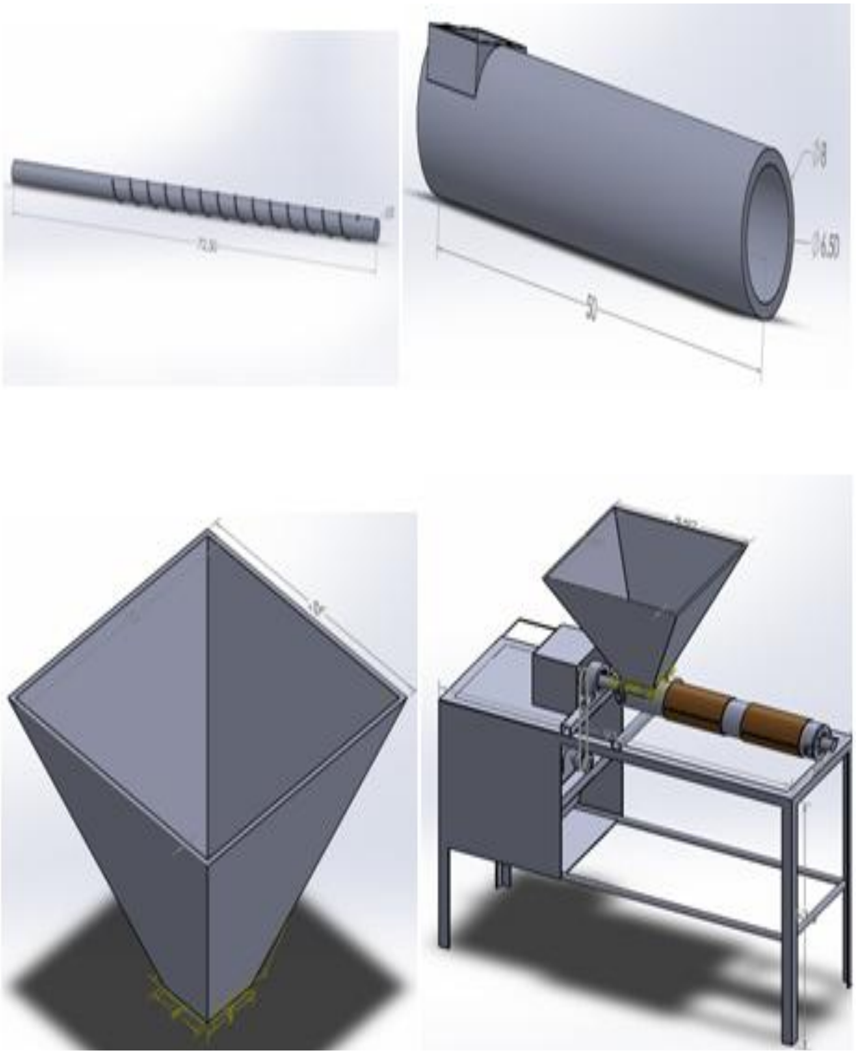

Figure 8: Drawing of the screw thread, Barrel, Hopper and Side view of the Pelletizing Machine

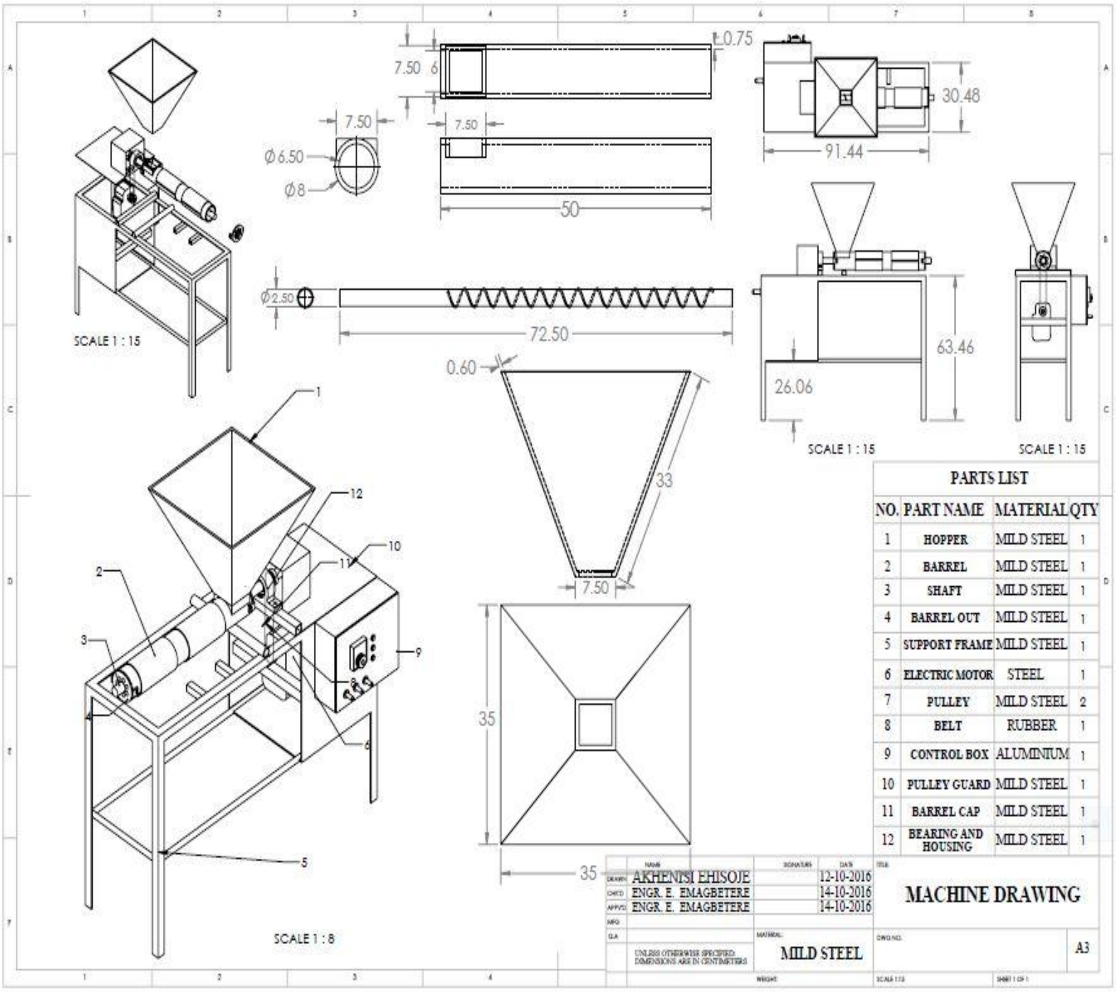

Figure 9: Part Drawing of the Pelletizing Machine

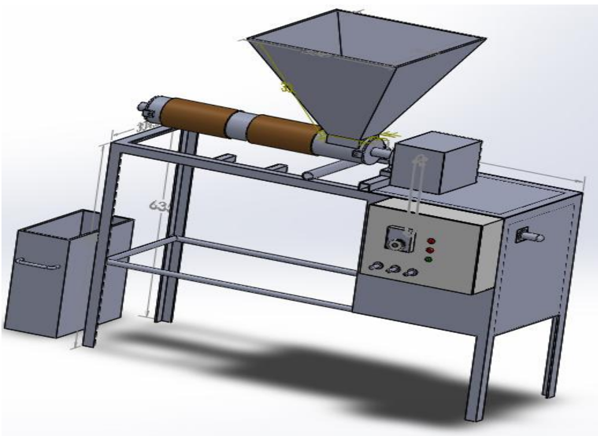

Figure 10: Drawing of Pelletizing Machine

Figure 11: Pictorial View of the Fabricated Pelletizing Machine

IV. CONCLUSION

A Polythene pelletizing machine capable of converting plastic waste (LDPE) into a molded state was designed, fabricated and tested, with the aim of converting the waste polythene materials into useful products by reducing the bulk density of the material to ease transportation to production facilities. The result obtained from the test shows that extrusion of waste polythene material could flow slowly in lumps through screw conveyor to the die at temperature of 80^0C. Other temperature values greater or lesser than 80^0C, (such as 110^0C, 180^0C or 25^0C, 70^0C) caused the material either to char, stick or not been molded. To obtain optimum temperature value of this material at the exit point of the barrel and the extruder, further work is recommended. This work has demonstrated that the production of a locally, easily accessible and operated polythene pelletizing machine is possible for urban communities in Nigeria.

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Stanley Okiy "Design And Fabrication Of Polythene Pelletizing Machine For Urban Communities In Nigeria." American Journal of Engineering Research (AJER), vol. 7, no. 01, 2018, pp. 32-41.