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DESIGN OF LOW DENSITY PILOT POLYETHENE RECYCLING SYSTEM FOR WASTE MANAGEMENT AND POLLUTION CONTROL

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ABSTRACT

Due to problems arising from low density polyethene waste especially" pure water" sachets and advantages associated to its recycling, it is important to have a low cost system for its recycling. This research work focused on local design of low density pilot polyethene recycling system. It is powered electrically; it can be used for small scale recycling activities. This system uses a plasticating screw for propelling the melted low density polyethene through the die. The plasticating screw encased in the barrel is driven by electric motor. The system uses band heaters to melt the material. The crushed low density polyethene is fed through the hopper which is able to hold a large quantity of crushed polyethene at a time. The extruded strands of low density polyethene are cooled by means of water contained in the water basin and fed into the cutting zone by means of feeding rollers. A rotating cutter is utilized to bring the extruder strands of polyethene to pellet form

Keywords: Electric Motor Polyethene, Waste Recycling

INTRODUCTION

Modernization and progress has had its share of disadvantages and one of the main aspects of concern is the pollution it causes to the earth- be it land, air and water. With increase in the global population and the rising demand for food and other essentials, there has been a rise in the amount of waste being generated daily by each household. This waste is ultimately thrown into municipal waste collection centers from where it is collected by the local municipalities for further disposal into the landfills and dumps. However, either due to resource crunch or inefficient infrastructure, not all of this waste gets collected and transported to the final dumpsites. Added to this if the management and disposal is improperly done, it can cause serious health impacts.

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REVIEW OF LITERATURE

Polyethene was first discovered by two scientists, Eriz Fawel and Reginald Gibson in 1933. Plastics have polluted the world and they have nonetheless contributed immensely in saving our natural material thereby protecting our natures.

Ugoamadi *et al*. (2011) optimized the development of a plastic recycling machine that minimizes the limitations of the already existing (imported) ones to a great extent and at the same time ensuring effective waste management. The results presented show that for every used plastic fed into the hopper, about temperature of 200^0C is required to melt it.

Genssner (1981) stated that polyethylene is not compressible, and when deformed, it tends to stay out of shape undergoing permanent or plastic deformation. A substance that behaves like this is called plastic. Plastics generally are high polymers (i.e. elements consisting of large chain like molecules containing carbon), which are formed either during or after their transition from a low molecular weight chemical to a high molecular weight solid material. The higher molecular weight of the solid materials is as a result of additives or ingredients such as fillers, plasticizers and so on.

Evans and Williams (2003) suggested that the menace of plastic pollution can be controlled by these new technological breakthroughs called recycling. This is important because pollution has really become almost an intractable significant problem.

Brandrup (1996) observed that these modern plastics tend to defy disposal activities. They are generally non biodegradable, therefore not good material for composting and sanitary fills. Incineration is not a very attractive option for we end up spewing into the atmosphere obnoxious gases and particles. Recycling has been tried, and it has shown a reasonable degree of success for thermoplastics such as polyethylene and polypropylene.

Nikolaou (2002) added that recycling as an industrial process is gradually increasing in both developed and under developed countries. In a developing country like Nigeria, the need is highly indispensable so as to reduce the volume of polythene waste generated and also to serve as a means of solving environmental pollution/degradation which is currently eating deep into the fabric of our environment.

The problem of plastic waste is not only limited to Nigeria. It is a global phenomenon. The world's annual consumption of plastic materials have increased from around 5 million tons in the 50's to more Than 100 million tons; thus, twenty (20) times more plastic is produced today than 50 years ago (UNEP, 2009). This implies that more resources are being used to meet the increased demand for plastic, on the other hand, more plastic waste is being generated (UNEP, 2009, Orhorhoro et al., 2016). Looking at the volume of plastic waste generated in Nigeria, there is urgent need for proper plastic waste management.

RESEARCH METHODOLOGY

Material source and sorting

Waste low density polyethene materials were sourced from the dump site within and outside Onitsha metropolis, Anambra, State Nigeria. Sorting was done based on the physical and chemical properties of the polyethene and segregation into colors were done to categorize each polyethene into other sub-types based on their chemical properties.

Cleaning of the polyethene

The low density polyethene was washed thoroughly with clean water and detergent to remove dirt and impurities. It was sundried and crushed to break down the large particles into small particles to enable the hopper it during melting.

Design considerations of a low density pilot polyethene recycling system

The followings were considered during the design and fabrication of the low density pilot polyethene recycling system; design specification, design calculations, choice of material, economic evaluations, etc. The fabrication processes include, metal cutting, welding of the component parts and assembly. The components of the system consists of hopper, plasticating screw thread, extruder , barrel, heating elements, electric motor, cutter, feeding roller, water basin, frame, belt drive.

Design for Barrel

The inner diameter $d1 = 40mm$ and the outer diameter $d2 = 70mm,$ thickness$t = 15mm.$

Thickness$t$, to inner diameter is $\frac{t}{d_1} = 0.375.$ a cylinder with $\frac{t}{d_1} < 0.05$ is generally regarded as a thin walled cylinder, thus this barrel cylinder is a thick walled cylinder. The radial stressσ_r , the hoop stress σ_h and axial stress σ_z at diameter d in the body of the cylinder are given as

$$\sigma_r = \left(\frac{d2^2}{d2^2} - \frac{d^2}{d1^2}\right)\frac{d1^2}{d^2}.P_1 \ldots\ldots\ldots\ldots(1)$$

$$\sigma_Z = \left(\frac{d2^2}{d2^2} + \frac{d^2}{d1^2}\right)\frac{d1^2}{d^2}.P_1 \ldots\ldots\ldots\ldots(2)$$

$\sigma_h = 0$ for open ends of cylinder when an internal pressure P_1 is applied only. The maximum stress occurring at the c1ylinder bore, that is at $d = d1$, the internal pressure which is equal to the extrusion pressure

is $P_1 = {(10N)}/{4162\ x\ \pi} = \frac{0.5N}{mm^2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$

Design for plasticating screw

The plasticating screw specified has a pitch diameter,

$D_p + \sqrt{\frac{2p}{\pi 0 P_{erm}}} \ldots\ldots\ldots.(4)$

Where P = force acting along the screw

P_{erm} = Permissible mean nut pressure

$\theta = \frac{H}{d_p} = 1.2\ to\ 2.5$ for unsplit nuts and H is nut thickness………………(5)

W2e select

$\theta = 2\ and\ P_{erm} = \frac{0.80KN}{cm^2(for\ stell\ screw\ cast\ iron\ nut)}.(6)$

For $P = 10N$ and $D_p = 19.9mm \ldots\ldots\ldots\ldots\ldots\ldots(7)$ which is less than the specified pitch diameter of$27mm$, hence plasticating screw design is okay.

Design for electric motor (power requirement)

In choosing the electric motor, we have to calculate the force to overcome by the motor. This force is the frictional force occurring between the moving parts. The drag force is dependent on the area of the plasticating screw, the density of the low density polyetrhene and the velocity of the plasticating screw are constant. We have to calculate the velocity.

The electric motor speed for the design is $1500rpm$

Density of the polyethene is $925kg/m^3$

Dynamic viscosity of polyethene is $2.3Ns/m^2$

The speed of the plasticating screw is obtained using the relation; $\frac{N1}{N2}=\frac{T2}{T1}\ldots\ldots\ldots\ldots.(8)$

Where $N1$ is the speed of the electric motor

$N2$ is the speed of the plasticating screw

$T2$ is the diameter of the gear on the end of the plasticating screw

$T1$ is the diameter of the pinion on the output shaft of the electric motor

$$N2 = \frac{N1\ X\ T1}{T2} = \frac{1500\ x\ 21}{36} = 875rpm \ldots\ldots\ldots(9)$$

Also angular velocity is given by;

$\alpha = \frac{2\pi N}{60} = \frac{2\ x\ \pi\ x875}{60}$ =91.6 rad/sec………………(10)

Hence, velocity of the shaft is given by

$V = \alpha R$, where $R = \frac{D}{2}\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.(11)$

$$V = \frac{91.6\ x\ \left(\frac{40}{2}\right)}{1000} = 1.9m/s$$

We substitute this value of velocity into drag force equation

$$F_D = {}^1\!/_2\left(C_D A_\rho V^2\right)\ldots\ldots\ldots\ldots..(12)$$

$F_D =$ Drag force in Newton (N)……………………..(13)

C_D= drag coefficient which is dimensionless= 0.396

A = cross sectional area perpendicular to the direction of motion = $0.00125m^2$

P=$925kg/m^3$

V=$1.9m/s$

$$F_D = \frac{0.396\ x0.00125x925x1.9^2}{2} = 0.826KN \ldots(14)$$

We added 20% of the drag force to the account for the frictional forces i.e. $\left(\frac{20}{100}\right)\ x(0.826) = 0.1652KN$

Therefore, $F_D = 0.1652 + 0.826 = 0.9912KN = 991.2N$ ……………(15)

Using force analysis equation for the helical gears, we were able to calculate the required power of the electric motor $W_t = \frac{60\ x10^3}{\pi dN}H\ldots\ldots\ldots\ldots\ldots\ldots\ldots(16)$

Where W_t = transmitted load (force generated by the motor) which should equal or slightly exceed 991.2N.

H= electric motor power in kw

d= diameter of the pinion = 0.04m

N= speed of the pinion = 1500rpm

$$H = \frac{W_t\pi dN}{60\ x\ 10^3} = \frac{991.2\ x\ \pi\ x0.04\ x1500}{60\ x10^3} = 3kW\ldots\ldots\ldots\ldots.(17)$$

The electric motors in the market are rated in horse power (hp)

1hp= 746W……………….. (18)

Therefore

3kW = 3000/746 =4.02hp, hence the rating of the electric motor to be used is 4.02hp, 1500rpm, and 220-230V. We used electric motor of 7.5hp since it will drive the roller of the pilot polyethene recycling system.

Design of heating element

The processing temperature of low density polyethene is between 163°C and 200°C even though it melts between 108°C- 121°C, we chose 200°C as the target temperature of the heating chamber. The materials must be raised from room temperature 25°C to 200°C.

The maximum volume of the material that can be handled in the operation is given by;

Volume of the barrel – volume of the crew

$$V_{max} = \frac{\pi x D^2 x L}{4} - \frac{\pi x d^2 x L}{4}\ldots\ldots\ldots\ldots\ldots\ldots\ldots(19)$$

Where D = initial diameter of the barrel = 0.04m

d= diameter of the plasticating screw = 0.03m

L = length of the barrel = 0.665m

It is assumed that the length of the screw is equal to the length of the barrel

Therefore

$$V_{max} = \frac{\pi x 0.04^2 x\ 0.665}{4} - \frac{\pi x\ 0.03^2 x\ 0.665}{4}$$
$$= 0.000836 - 0.00047$$
$$= 0.000366m^3$$

Density of low density polyethene is 925kg/m^3

Mass of polyethene of volume 0.046m^3 is given by $\rho = \frac{m}{v} \dots \dots \dots \dots \dots \dots .. (20)$

Where ρ is the density

M= mass

V= volume

Hence,$m = \rho v = 925\ x\ 0.000366 = 0.34kg$

However, the quantity of heat needed to raise the temperature of this mass from 25°C to 200°C can be calculated from [(heat needed to raise the material to its melting point) + (heat needed to raise to melt the entire mass) + (heat needed to raise the temperature of the melting polyethene to 200°C)]

$$Q_{25} - 200 = (mcp\ \Delta t_1) + (ML) + (mcp\ \Delta t_1)(21)$$

Where m= mass of the material

Cp= specific heat capacity of the material = 2.004kJ/kgK

Δt_1= temperature change

M has been calculated as 0.3kig and Cp is known

Δt_1= 121- 25 = 96°C

Δt_2= 200- 121= 79°C

L = specific latent heat of fusion given to be 74.8kJ/kg

Hence,

$$Q_{25} - 200 = (0.34\ x 2.004\ x\ 96) + (0.34\ x\ 7.48) + (0.34\ x\ 2.004 nx\ 79) = 121.781KJ$$

Hence, the quantity of heat needed to raise the temperature of this mass from 25°C to 200°C= $121.781KJ$

This heat source was able to generate the amount of heat that will be lost through the walls of the heating chambers

Heat supplied by the source = heat lost through the walls + heat used in raising the temperature of the material

Heat lost through the walls of the chamber by conduction is given by

$$Q_c = \frac{2\pi KL(\theta_{1-\theta_2})}{In_{\frac{r2}{r1}}} \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots (22)$$

Where

L= length of the heating chamber which is cylindrical in shape = 0.665m

θ_1= temperature of the heating chamber (internal) = 200°C

θ_2= temperature of the heating chamber (external) = 25°C

K_A= thermal conductivity of the inside steel layer =45w/Mk

r1= internal radius of the heating chamber = 0.04m

r2= external radius of the heating chamber = 0.07m

$$Q_c = \frac{2\pi\ x\ 45(200 - 25)}{In_{\frac{0.07}{0.04}}} = 58797.9W$$

The above value accounts for the heat lost through the walls of the cylinder.

It is expected that $Q_{25} - 200$ will be generated in thirty minutes which requires a power input of $\frac{58797.9}{30\ x\ 60} = 32.67W$

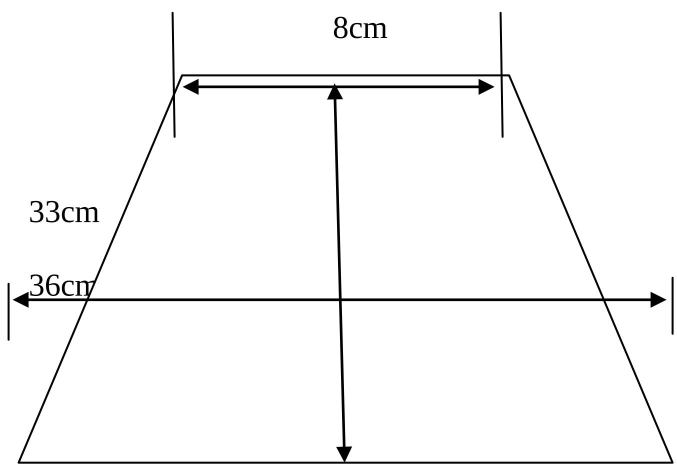

Figure 1: The hopper design

Figure 2: The Designed and fabricated low density pilot Polythene recycling system

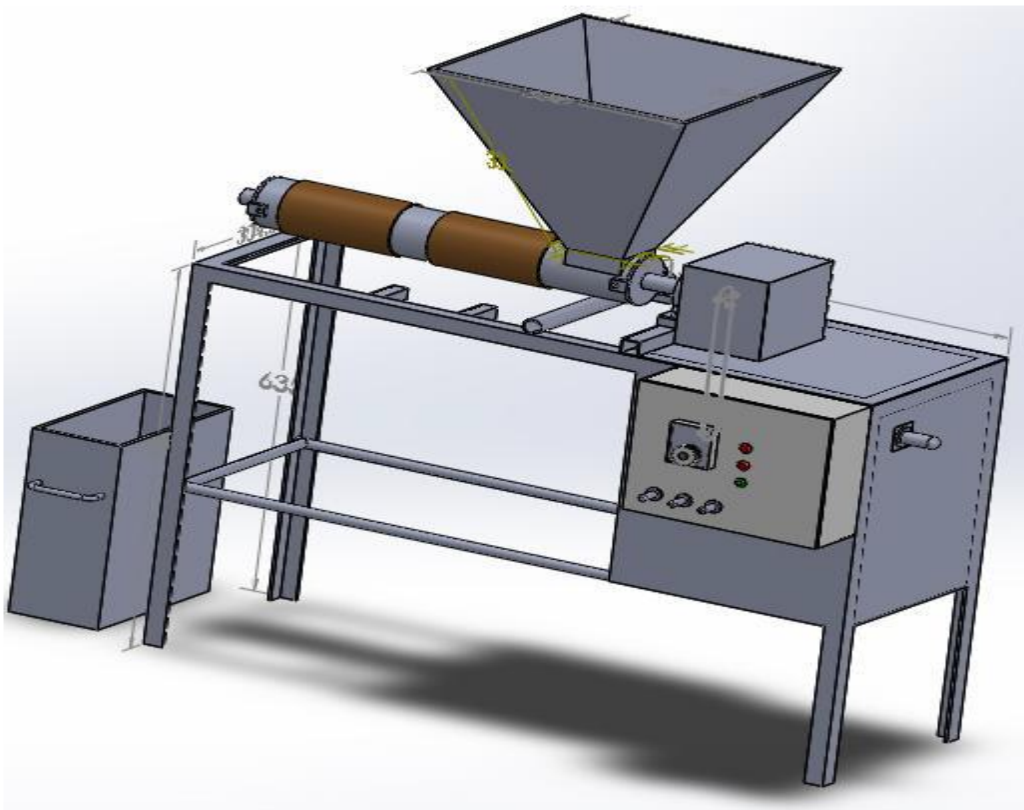

Figure 3: Drawing of the of the low density pilot polyethene recycling system.

Design for Hopper

The hopper was developrd from frustrum of a cone. The dimension is shown in the figure above.

RESULTS AND DISCUSSION

In this paper, design of a low density pilot polyethene recycling system was carried for waste management, pollution control and small scale business. With the manufacturing process in mind, it was essential to choose a material (low density polythene) that can melt easily. With all the required dimensions and by the help of conceptual design which mainly based on functional requirement and design parameters, detail design of a pilot low density polyethene recycling system was achieved.

At the end of this design and fabrication of the system in the workshop, the performance of the system as well as its efficiency were checked. The steps below shows how the performance evaluation was done

Step 1; after construction of the system, it was connected to electricity.

Step 2; the system was switched on through the control box where all circuit connections were made and allowed to run for about 1hour before introducing the material to be recycled into it.

Step 3; after ensuring that the heater is warmed ready to melt the low density polyethene, we fed the crushed low density polyethene through the hopper.

Step 4; melted material coming from the die was cooled in the water basin. The strands of this extruded polyethene were manually directed to the slots on the rollers for pelletizing or cutting.

Step 5; at the end of a successful job (testing) of the system, the system was turned off and disconnected from power source.

During testing processes, we observed that the rotation of the plasticating screw determines the speed of the recycling process and also determines the quantity of materials that will be recycled at a given time.

Finally, the overall test showed that the efficiency of the system depends on the power of the motor.

CONCLUSION

The constructed low density pilot polyethene recycling system has been found to be effective and efficient. It can be powered electrically; therefore it can be used for small scale business. It is also affordable since the cost of production is low. It can also be seen that the recycling process as was propounded by this research is to some extent different from the traditional method of recycling.

The designed system is very easy to operate and maintain. It has parts that can be disassembled completely to effect any maintenance work as it requires no special technical knowhow to operate and this makes the system suitable for everybody both educated and illiterate. It removes the restrictions posed by the high cost of existing machinery and consequently tends to increase the recycling of polyethene in Nigeria.

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