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Design of an LDPE Pulverizing Machine

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ABSTRACT

The increasing use of plastics in everyday life and in the national economy of developing countries such as Nigeria makes it necessary to find a local solution to the problem of plastics waste disposal through economically sound and ecologically suitable method, rather than just burning. Thus, this work focuses on developing an economically viable waste plastic (Low Density Polyethylene (LDPE)) pulverizing machine, for cottage industry, using locally available materials. The machine was designed and developed following simple standard engineering principles. The machine uses eight fixed and four rotary blades for slicing the loaded waste plastic. The rotary blades rotate at a speed of 840 rpm and are driven by a three-phase, high torque, low speed electric motor of 15 hp and the friction generated provides the heat required to soften the waste charges. Test shows that the machine is capable of obtaining a product type, which can be mixed directly with a virgin material for polythene production, without the need to process it further through pelletization. The efficiency of the machine was found to be 84% and its capacity was 16 kg/hr.

1. INTRODUCTION

Wastes are materials that are not prime products (that is products produced for the market) for which the initial user has no further use in terms of his own purposes of production, transformation or consumption, and of which he wants to dispose (Andrew *et al*., 2012). Generally, wastes include three streams – solid, liquid and gaseous waste streams. The world's annual consumption of plastic materials has increased from around 5 million tonnes in the 1950s to more than 100 million tonnes. Thus, 20 times more plastic is produced today than 50 years ago (UNEP, 2009). In most cities and large towns of the world, particularly in developing countries, solid waste is not only heaped in huge quantities at refuse dumps but also discarded in piles in the street and in small illegal dumps on any piece of unused land (Igbinomwanhia and Ohwovoriole, 2011). A fair proportion of wastes generated in Benin metropolis, Nigeria, are the plastic wastes which constitute about 8.65% of domestic solid waste and 25.43% of commercial solid waste stream (Igbinomwanhia and Ohwovoriole, 2012). After food waste and paper waste, plastic waste is the major constitute of municipal and industrial waste in cities (Achyut, 2011). The study also revealed that open air burning without pollution control is largely practiced and a good proportion of these plastic wastes are polythene used in packaging of table water. The increasing use of polythene in everyday life and in the national economy of developing countries (such as Nigeria) makes it necessary to find an alternative local solution to the problem, rather than just burning.

A study of these waste plastic recycling system in Benin metropolis revealed that systems comprise of pulverizing and pelletizing. The pulverizing system has three machines - the washing, drying and pulverizing machine, with each driven by prime movers of 75 hp constituting a total of 225 hp. The study also revealed that the financial return from the throughput of the system is not able to meet the running cost - energy need and overhead cost of the system hence the closure of the factory.

There is therefore need for the redesign and manufacture of the plastic waste recycling system for energy efficiency. Hence the work reported in this paper is the design and manufacture of a plastic waste pulverizing unit of the recycling system for energy efficiency in Benin metropolis Nigeria.

2. METHODOLOGY

The work was carried out in three phases-preliminary study, design and manufacture of the machine and performance testing. The first phase involved literature review which include review of basic design theories associated with the design of the plastic pulverizing machine and field trip to the factories of plastic recycling systems in Benin metropolis. In the second phase, conceptual designs were considered and based on information gathered during phase one, design decision matrices were applied in selection of suitable design. In the third phase, the manufacturing of the machine was carried out using the secondary processes of manufacturing and performance testing of the machine was done.

2.1. Basic Theory

Cutting force (F) for plastic (LDPE)

The cutting force for LDPE is given as (Andrew, 2000):

$$F = A \times \tau_\beta \tag{1}$$

Where:
A = Area of cut
τ_β= Tensile stress at break for LDPE (Taken as 31Mpa) (Andrew, 2000)

$$A = L \times S \tag{2}$$

L = Length of cut of pure water sachet (200 mm)
S = Thickness of cut of pure water sachet (0.1 mm)

Therefore:

$$A = 200\times10^{-3}\times0.1\times10^{-3}= 2\times10^{-5}\ m^2$$

Thus:

$$F = 2\times10^{-5}m^2\times17\times106N/m^2 = 340\ N$$

2.1.1. Pulverizing chamber

The drum is made of galvanized steel 4 mm thick, 600 mm high and 600 mm diameter.

Volume of cylinder, V

$$V = \pi r^2 h \tag{3}$$

Where:

r = 300mm, h = 600mm

Thus:

$V = \pi \times 0.3^2 \times 0.6$

$V = 0.170m^3 (170L)$

Assuming, the effective volume of the pulverizing chamber is 75% of the actual volume.

Then, effective volume:

$V_e = 75\% \times 0.170$

$V_e = 0.128m^3$

Also, mass, m = Volume × Density of material ($940kg/m^3$ for LDPE) (Andrew, 2000):

Therefore, m = 0.128 × 940

m = 120kg

2.1.2. Power of electric motor (P)

The power of the electric motor is given as:

$$P = FV \tag{4}$$

$$V = \omega r \tag{5}$$

$$\omega = 2\pi N/60 \tag{6}$$

Where:

N= Speed of motor taken as 1400rev/min (Khurmi and Gupta, 2005)

$\omega = (2\times\pi\times1400)/60 = 146.6$ rad/s

Radius of cutter, r= 200mm (0.20m)

P = 340×146.6×0.20 = 9,968.8watts

Assuming 10% of the power is lost to friction in the belt used.

Power loss by friction:

P_f= 9,968.8×10% = 996.88Watts

Thus, nominal power (P_n):

$$P_n = P + P_f \tag{7}$$

P_n =10.97 kW (15 hp)

2.1.3. Belt design

The length of motor plate = 900 mm (Figure 8)

The length of drum plate = 700 mm (Figure 9)

Therefore, distance between the centre

$$X = \frac{900}{2} + \frac{700}{2} = 800mm$$

2.1.4. Length of belt

The length of belt is given as (Khurmi and Gupta, 2005):

$$L = \frac{\pi}{2}(d_1 + d_2) + 2X + \frac{(d_2 - d_1)^4}{4X} \tag{8}$$

Where d_1 = diameter of motor pulley = 0.150m

d_2 = diameter of drive pulley = 0.25 m

$L = 2.19m$

2.1.5. Area of cross section of belt

The cross-sectional area of the belt was obtained as follows:

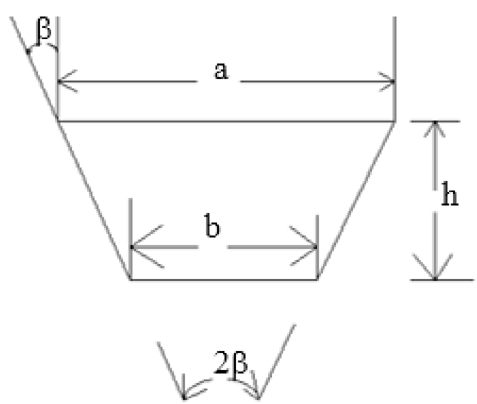


Figure 1: Belt cross section

Area of trapezium, $A = \frac{1}{2}(a+b)h$ (9)

a = 12mm = 0.012m

b = 6mm = 0.006m

h = 10mm = 0.01m

Thus:

A = 9×10^{-5} m^2

2.1.6. Mass of the belt per meter length (m)

This was obtained as follows:

m = Area × Length × density (10)

Density of belt material (Double woven Reinforced rubber) = 1250 kg/m^3 (Khurmi and Gupta, 2005)

Therefore:

m = $9\times10^{-5} \times 1\times 1250$ = 0.113 kg/m

2.1.7. Grove angle

Using the trigonometric ratio:

$$\beta = \tan^{-1}\left(\frac{3}{10}\right) = 17^0$$

Therefore, groove angle = 34^o

2.1.8. Angle of contact between the belt and each pulley (θ)

For an open belt drive, this is given as (Rattan, 2009):

$$\sin\alpha = \frac{(d_2 - d_1)}{2X} \tag{11}$$

Therefore, α=4.5^0

Angel of lap on the smaller pulley, $\theta = 180^0 - 2\alpha$

Therefore, θ = 2.98 rad

2.1.9. Belt tension

This was obtained as follows:

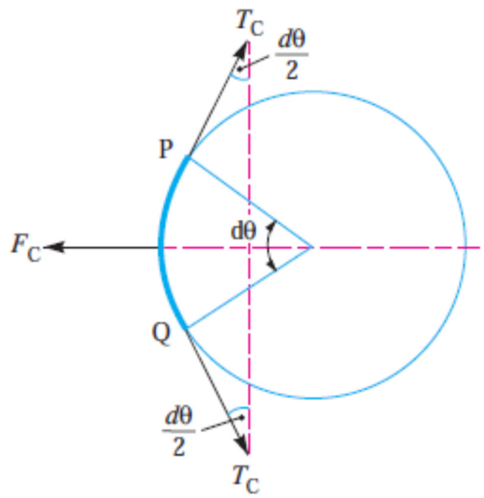


Figure 2: Centrifugal tension

T_C = centrifugal tension

T_1 = tension in the tight side of the belt

T_2 = tension in the stack side of the belt

T = maximum tension in the belt

σ = the maximum allowable tension stress of belt (taken as 4.0 MN/m^2) for rubber

Centrifugal force, (T_C) is given as (Khurmi and Gupta, 2005):

$$T_C = mv^2 \tag{12}$$

Where m = mass per meter length of belt = 0.0113 kg/m

$$V = \frac{\pi dN}{60} \tag{13}$$

V = 11 m/s^2

And T_C = 13.67 N

Maximum allowable tension in the belt, T

$$T = \sigma \times A \tag{14}$$

σ = 4.0 MN/m^2 (Khurmi and Gupta, 2005)

A = cross section at area of belt = 9×10^{-5} m^2

T = $4.0 \times 10^6 \times 9 \times 10^{-5}$ = 360 N

Tension in the tight side of belt T_1

$$T_1 = T - T_C \quad (15)$$

T_1 = 346.33 N

Relationship between T_1 and T_2 for V- belt is given as (Rattan, 2009):

$$2.3 \log\left(\frac{T_1}{T_2}\right) = \mu\theta \cos^{-1}\beta \quad (16)$$

Where, coefficient of friction for rubber material,μ, is 0.2 (Khurmi and Gupta, 2005)

Therefore, T_2 = 45N

2.1.10. Power transmitted by belt

This is given as:

$$P = (T1 - T2)v \quad (17)$$

P = 3,314.6 W

2.1.11. Number of V-belts required

This is given as:

Number of V – belt = total power transmitted/ Power transmitted per belt (18)

Therefore:

Number of V – belt = 3V-belt

2.1.12. Force on the cutter beam

The was calculated as follows:

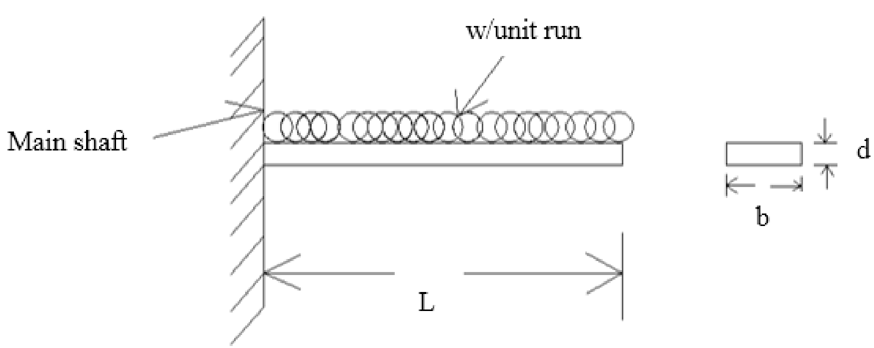


Figure 3: A cantilever of length, L, carrying uniformly distributed load, W, per unit over whole length

Maximum deflection of beam, Ymax is given as:

$$Y_{max} = \frac{WL^3}{8EI} \tag{19}$$

Where

W = load (force acting on blade)
L = length of cutter
I = moment of inertia
E = young modulus for mild steel

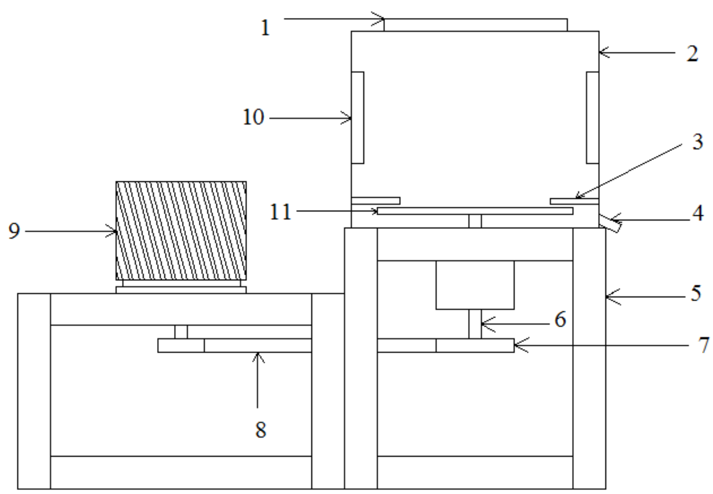
The rectangular moment of inertia is given as:

$$I = bd^3 \tag{20}$$

Combining Equations (19) and (20) yields $d = 0.006m$

2.2. Conceptual Design

Various design concepts were developed and the one shown in Figure 4 was selected and a prototype of the machine was design and fabricated. The prototype essentially consists eight fixed blades at 45º and fixed to the drum at a height of 20 mm from the base. Four rotary blades spaced at 90º were bolted to the spindle to slice the contents against the fixed blades. The spindle was connected to the main power shaft driven by a belt drive and powered by an electric motor.



No	Description
1	Cover
2	Pulverizing Drum
3	Fixed Blade
4	Outlet Port
5	Frame
6	Shaft
7	Pulley
8	Belt
9	Electric Motor
10	Compactor
11	Rotating Blade

Figure 4: The sketch of the concept of machine

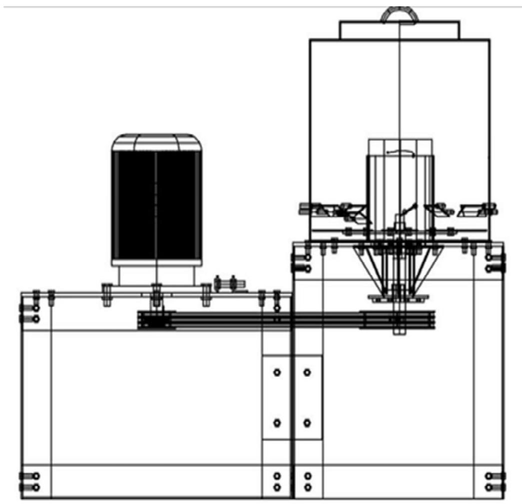


Figure 5: Front view of machine

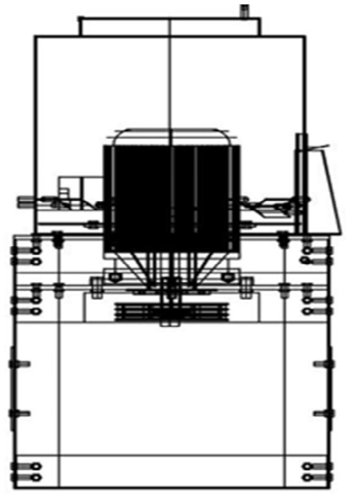


Figure 6: Side view of machine

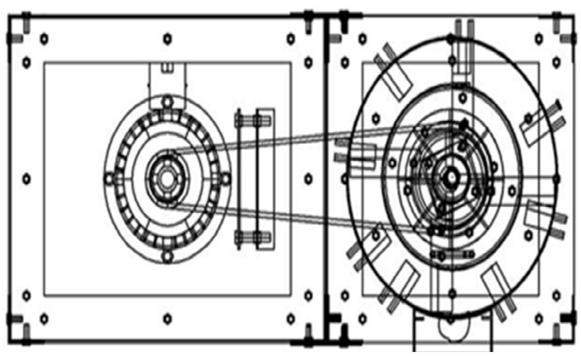


Figure 7: Top view of machine

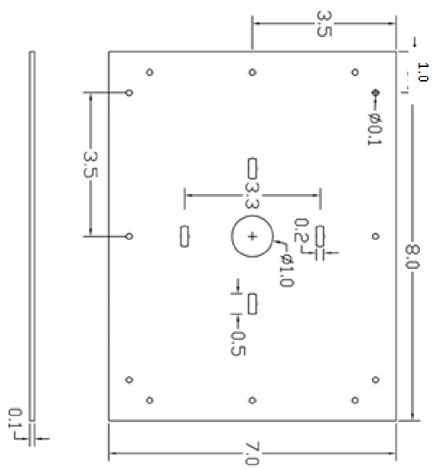


Figure 8: Motor plate

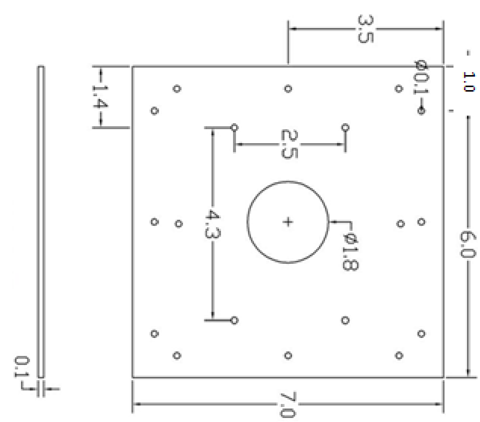


Figure 9: Drum plate

Table 1: Major components of the machine

S/N	Component	Number
1	Drum	1
2	Drum cover	1
3	Power shaft	1
4	Moving blades	4
5	Fixed blades	4
6	Spindle	1
7	Belt drive	1

2.3. Prototype Design and Testing

The basic theory was applied for the detailed design of a prototype of the machine and the secondary method of manufacturing was applied for the production of the machine. The major components of the machine include-drum, rotating and fixed cutting blades, the belt drive power shaft, spindle, bearings and the frame of the machine. The results from the detail design are shown in Table 1. The machine was then tested for performance. Waste LDPE (such as materials used for packaging sachet water), was collected from household and commercial sites and used for testing the machine. The waste collected was washed manually to rid the waste materials of dirt and other contaminants. Thereafter, the waste LDPE was sun dried. Two kilograms (2 kg) of the waste LDPE was fed into the pulverizing chamber and the machine was started and left to run for sixty seconds and the product was examined for fineness and then the process was repeated for ninety, one hundred and twenty and one hundred and fifty seconds.

3. RESULTS AND DISCUSSION

Having fed two kilograms (2 kg) of the waste into the pulverizing chamber and allowed run for a maximum of one hundred and fifty seconds, the waste was pulverized into very fine shreds of the material as desired. The product obtained was found to be 1.68 kg. The products obtained are shown in the plates 2 to 5. However, the ungrounded product, which got stuck in the clearance between the drum base and the cutter plate, was carefully removed and added to the next batch for pulverizing.

Figure 10: Polythene recycling machine

Plate 1: Waste plastics and other waste in unused land


Plate 2: Product obtained after 60 s


Plate 3: Product obtained after 90 s


Plate 4: Product obtained after 120 s


Plate 5: Product obtained after 150 s

3.1. Machine Efficiency

The efficiency of the machine is given as:

$$\eta = \frac{Mass\ of\ waste\ obtained\ as\ product}{Mass\ of\ waste\ fed\ into\ the\ chamber} \times \frac{100}{1} \quad (21)$$

Where:

mass of waste obtained as product is 1.68 kg

mass of waste fed into the chamber is 2 kg

$$\eta = \frac{1.68}{2} \times 100$$

$$\eta = 84\%$$

3.2. Machine Capacity

Having fed 2 kg of waste into the machine, the capacity of the machine, using product obtained after one hundred and fifty seconds as shown in Plate 5, was about 16 kg/hr taking the time for loading and unloading the waste as 2 mins (as obtained from during testing). A review of the current system in use in the Benin metropolis revealed that a 3 phase, 75 hp electric motor was used for powering the pulverizing machine (with a capacity of about 30 kg/hr), besides that used by the waste washing and drying machines (which utilized 75 hp, electric motor each). However, the major drawback of the system was the huge amount of power consumed. Thus, the system could not be sustained. Consequently, an attempt has been made to reduce the power consumption of the system, by using a 15 hp, 3 phases electric motor, so as to improve its commercial viability. The machine is capable of obtaining a product type (as in Plate 5), which is mixed directly with a virgin material for Polythene production. Thus, this machine is usually preferred when compared to a granulator, whose products must necessarily go through a pelletizer for further processing. However, product types obtained (such as those in Plates 2 and 3), is further processed by a pelletizing machine to obtained pellets.

4. CONCLUSION

Non-biodegradable polythene wastes constitute a nuisance in all the urban areas in Nigeria, as waste materials are usually found littering all over the places in our urban cities and villages. A polythene (LDPE) pulverizing machine was therefore designed and manufactured using locally sourced and available materials. The manufactured pulverizing machine was found to be very useful in absorbing and reducing huge waste LDPE materials, thereby alleviating the nuisance posed by the latter in our country. The machine drum has a capacity of 0.170 m^3 (170 L) and an effective volume capacity of 0.128 m^3 (128 L). The power shaft of the machine utilizes a 15 hp, 1400 rpm, 3 phase-electric motor as its rotor. Upon evaluation, the efficiency of the machine was found to 84% and its capacity is 16 kg/hr.

5. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

REFERENCES

Achyut K.P. (2011). *Studies on process optimization for production of liquid fuels from waste plastics*. Ph.D. thesis, Chemical Engineering Department, National Institute of Technology, Rauskela, pp. 10-13.

Andrew J.P. (2000). *Handbook of Polyethylene*. Marcel Dekker, Inc, New York

Andrew, O.O., Festus, A.O., and Joe, K.O. (2012). Development of a polythene Recycling machine from locally sourced materials. *Journal of the International Institute for Scince Technology and Education*, 2 (6), pp. 42-50

Igbinomwanhia, D.I. and Ohwovoriole, E.N. (2011). *A study of the solid waste chain in Benin Metroplis, Nigeria. Journal of Applied Science and Environmental Management*, 15 (4), pp. 589 – 593.

Igbinomwanhia, D.I. and Ohwovoriole E.N. (2012). A study of the constraints to Residential solid waste management in Benin Metropolis, Nigeria. *Journal of Emerging Trends in Engineering and Applied Sciences,* 3 (1), pp. 103-107.

United Nation Environment Programme (UNEP) (2009). *Converting waste plastics into a resource*. Division of Technology, Industry and Economics International Environmental Technology centre, Osaka/Shiga, Japan, pp. 1

Khurmi, R.S. and Gupta, J.K. (2005). *A Textbook of Machine Design.* 1st multicloured edition, Eurasia Publication Press Inc. New – Delhi, pp. 715-758.

Rattan, S.S. (2009). *Theory of Machines*. McGraw Hill Educational Private Limited. New Delhi, pp. 296-304.