

Design Consideration of a Plastic Shredder in Recycling Processes

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Abstract—Plastic waste management has emerged as one of the greatest challenges facing developing countries. This paper describes the design of various components of a plastic shredder. This machine is widely used in industries and recycling plants. The introduction of plastic shredder machine will promote reduction of post-consumer plastic waste accumulation and serves as a system for wealth creation and empowerment through conversion of waste into economically viable products. In this design research, a 10 kW electric motor with a rotational speed of 500 rpm was chosen to drive the shredder. A pulley size of 400 mm is mounted on the electric motor at a distance of 1000 mm away from the shredder pulley. The shredder rotational speed is 300 rpm.

Keywords—Design, machine, plastic waste, recycling.

I. INTRODUCTION

PLASTICS have been one of man's means of bearing items or contents, widely used by majority in the world. This material is readily used with ease because of its characteristics which include resilience, lightness, resistance to corrosion, and ease of processing [6].

One of many problems facing the world and Nigeria today is the environmental waste control. Likewise, Nigeria also is not excluded from the problem of solid waste. For more than two decades, the amount of plastic waste littering the streets of Nigeria has been of crucial environmental problem. The proper system of plastic waste collection is missing, and the people are not educated as to the problems of plastic waste. Every home in Nigeria generates waste from plastic, ranging from used nylon's, plastic bottles down to big plastic containers like buckets, jerry cans, kegs, and so on. However, the non-biodegradable nature of plastic waste poses a big problem since these wastes can stay longer in our environment causing all sorts of problems.

Biodegradable waste accounts for over 50% of waste generated with other component estimated at different composition in different states. A study by the Basel Convention Coordinating Centre for Africa in 2009 reveals that 70% of all imports were used electronic electrical equipment of which about 30% could be described as e-Waste [4].

Due to the non-biodegradable nature of plastic waste, the way forward for plastic waste disposal is through recycling. Recycling of waste plastic will bring numerous benefits to Nigeria and the world. Recycling of plastic waste is

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environmental friendly as compared to the other ways of disposing it.

Plastics are materials consisting of a wide range of synthetic or semi-synthetic organic solids that are moldable. Plastics are typically organic polymers of high molecular mass and the vast majority of these polymers are based on chains of carbon atoms alone or other substances such as oxygen, sulphur, or nitrogen as well. Plastics are produced by a process called polymerization. This is the process of joining one or more monomers such as ethylene, styrene vinyl chloride together [1].

II. SIGNIFICANCE OF STUDY

The areas of research focus on providing the required information in the construction of a plastic shredder. These areas are: (1) to identify and study the operations of existing outfits; (2) recognize the parts of the machine; and (3) to design and assemble the critical parts of the machine. Although series of research work have been carried out on similar machine in various countries of the world, this paper focuses on improving on the already existing machine

III. PLASTICS AND PLASTIC WASTES RECYCLING PROCESSES

A. What are Plastics

Plastics are materials consisting of a wide range of synthetic or semi-synthetic organic solids that are moldable. Plastics are typically organic polymers of high molecular mass and the vast majority of these polymers are based on chains of carbon atoms alone or other substances such as oxygen, sulphur, or nitrogen as well. Plastics are produced by a process of joining one or more monomers such as ethylene, styrene vinyl chloride together, and this is referred to as polymerization [1].

Polymers are the substances whose molecules have high molar mass and are composed of large number of repeating units called monomers [8]. Polymers occur both in natural and synthetic form. Synthetic polymers commonly called plastics are reproduced commercially on a large scale and have a wide range of properties and uses. The distinguishing characteristics of some plastics occur when the carbon backbone of polymer molecules often bond with smaller side chains consisting of other elements such as chloride, fluorine, nitrogen, and silicon. For example, when chloride atoms substitute hydrogen atoms along the carbon chain, the result is polyvinyl chloride. This is one of the most versatile and widely used plastics in the world [2].

Based on chemical and physical properties, plastics can be divided into two groups; namely thermosetting and








thermoplastics. Thermosettings are plastics that are hardened by chemical cross-linking reaction involving polymer (i.e. it hardens permanently after being heated once). On the other hand, thermoplastics do not undergo chemical change in the molding operation. They may be softened by reheating to the temperature at which they originally became plastics, and hence, they are easily recyclable [2].

B. Types of Plastics

Plastic is one of the essential components of numerous products including water bottle and product containers. The need to classify plastics was born because not every kind of plastic is the same. In 1988, the society of the plastic industry (SPI) established a classification system with the aim of helping consumers and recyclers to properly recycle and dispose of each type based on its chemical makeup. This classification by the society will help to properly recycle plastics. Manufacturers are to follow this coding system and place a number or SPI code on each plastic product. This code is usually molded into the bottom of the product.

The seven types of plastics as classified by the Society of the Plastic Industry (SPI) are described in the Table I [1]:

TABLE I
PLASTIC RECYCLING CODE

| Plastic Code | Name of Plastic |
|--|--|
|  PET | Polyethylene Terephthalate (PET) |
|  HDPE | High-Density Polyethylene (HDPE) |
|  PVC | Polyvinyl Chloride (PVC) |
|  LDPE | Low-Density Polyethylene (LDPE) |
|  PP | Polypropylene (PP) |
|  PS | Polystyrene (PS) |
|  Other | Other Plastics (this include polycarbonate and polyactide) |

C. Plastic Waste Recycling Processes

Plastic recycling is the method of recovering waste plastic and reprocessing these materials into usable products. These products could totally vary in form from the original material. Recycling it is one of the adopted methods used in reducing plastic in the waste stream, since plastics are not biodegradable [3].

There is a wide range of products made from recycled plastics; i.e., polyethylene bin liners and carrier bags, plastic bottles, flooring and window frames, video and compact disc

cassette cases and many more.

The plastic recycling processes are referred as the process of collecting plastic waste materials and then separating or sorting and processing them into usable materials again. The methods employed by material recovery systems tend to vary according to the type of plastic being processed, and stages such a plastic collection, sorting, shredding, washing, and pelletizing are performed.

IV. DESCRIPTION AND OPERATION OF PLASTIC SHREDDER

The sorted plastic waste is fed into the shredder hopper to reduce the size into small plastic flakes. In the case of bigger size plastics, it is important to cut the plastic into small sizes before feeding them into the hopper. This is known as the size reduction. The shredder is incorporated with the rotating cutting blade. From the shredder drawing in Fig. 1, the plastic wastes are introduced into the machine through the hopper and the rotary blade inside the shredder, then the plastic is cut into the required flakes size, and these goes through a screen with small holes. The screen holes determine the flakes sizes. The flakes are then collected in a collection bin.

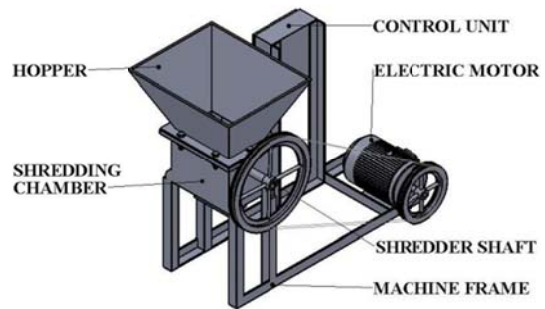


Fig. 1 Isometric View of the Plastic Shredder

The rotary blade is powered by an electric motor. The rotary blade is connected to the electric motor by a v-belt pulley with the pulley of both the rotary blade and the electric motor. Through the transmitted power between the blade and electric motor, the cutting process is initiated on the plastics by the blade, then it takes the sizes of the screen hole in the shredder.

V. DESIGN PROCEDURE

In this research work, each critical parts of the machine will be conceptually set up, and this choice will be based on certain design criteria which will be used to produce a detailed design of the machine.

The quality that makes a good design is based on the development of a good philosophy of design. The following considerations was adopted in this design: (1) minimum vibration level, (2) lower overall cost, (3) machine longer and extended product life, (4) Good and attractive appearance of the machine assembly- color and styling, (5) design for easy manufacturing, (6) design for easy maintenance and assembly (7) design for high efficiency.

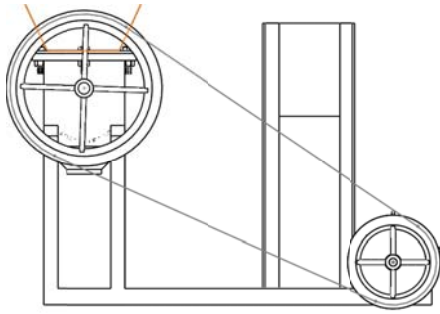


Fig. 2 Shredder Pulley Arrangement

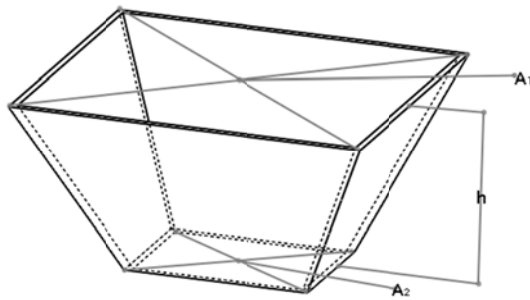


Fig. 3 Frustum of a Pyramid for the Hopper

A. Design of Pulley and Transmission Belt

The choice of a drive is dependent on some parameters, such as the driver power rating, number of belts, the size of the pulley. For this aspect of the research design, an electric motor with a required power rating of 10 kW, which is expected to run at a rotational speed of 500 rpm was chosen. The electric motor bears a pulley size of 400 mm at a distance apart (x) of 1000 mm from the shredder pulley. The shredder is expected to run at a rotational speed of 300 rpm. The belt cross-sectional area (A) and the allowable tensile stress (σ) for the system are 400 mm² and 2 MPa, respectively.

The relationship (1) is used to determine the diameter of the larger pulley [7];

$$\frac{N_1}{N_2} = \frac{d_2}{d_1} \quad (1)$$

where: N_1 = Speed of rotation of the electric motor, N_2 = Speed of rotation of the shredder, d_1 = Diameter of the electric motor pulley, d_2 = Diameter of the shredder pulley.

For an open belt drive [7],

$$\sin \alpha = \frac{r_2 - r_1}{x} = \frac{d_2 - d_1}{2x} \quad (2)$$

The tension acting on the tight side T_1 and slack side T_2 of the belt were determined by using the relationship (3) [7];

$$2.3 \log \left(\frac{T_1}{T_2} \right) = \mu \theta \operatorname{cosec} \beta \quad (3)$$

where β is the groove angle of the pulley, $2\beta = 40^\circ$, and θ is the angle of lap.

Angle of lap on the smaller pulley or driving pulley, θ

$$\theta = 180^\circ - 2\alpha \quad (4)$$

Equation (5) is used in determining the belt speed V;

$$V = \frac{\pi d_1 N_1}{60} \quad (5)$$

The service factor K_s is the product of various factors such as the load factor for variable load with heavy shock loads $K_1=1.5$, the lubrication factor for drop lubrication $K_2=1$, and the rating factor for 8 hours per day $K_3=1$.

$$K_s = K_1 * K_2 * K_3 \quad (6)$$

Power transmitted by belt and the number of belt (N) required can be gotten using (7);

$$P = (T_1 - T_2)V \quad (7)$$

$$N = \frac{\text{total power transmitted}}{\text{power transmitted per belt}} \quad (8)$$

B. Hopper Design

We assume high density polyethylene (HDPE) with a bulk density of 954 kg/m³ as the plastic material [5].

The shape of the hopper, as shown in Fig. 3, describes the volume of the plastic material that can be machined in a single operation. The volume of the hopper V_h can be calculated as;

$$V_h = \frac{h}{3} \times (A_1 + A_2 + \sqrt{A_1 \times A_2}) \quad (9)$$

where V_h = volume of the hopper, A_1 = Area of the upper pyramid base, A_2 = Area of the lower pyramid base, h = height of the frustum pyramid.

$$A = \text{Area of rectangle} = L \times B \quad (10)$$

The weight of the plastic material required to fill up the hopper can be calculated as [9];

$$W_p = V_h \rho_p g \quad (11)$$

where W_p = weight of the plastic, V_h = volume of the hopper, ρ_p = bulk density of the plastic which is 954 kg/m³, g = acceleration due to gravity (9.81 m/s²).

The mass of the plastic material to fill the hopper is calculated as;

$$M_p = \rho_p V_h \quad (12)$$

C. Shaft Design

The shafts are cylindrical with circular cross sections and with pulleys and bearings mounted on them. The shaft will be subjected to the functionality torque and bending moments and therefore combined shock and fatigue factors are taken into accounts.

Since the feeding of the plastic material will be suddenly applied load with minor shocks only. Thus, the combined shock and fatigue factor for bending $K_m=2.0$; the combined shock and fatigue factor for torsion $K_t=2.0$.

The shaft and belt tensions are subjected to both bending moment and shear force as a result of the applied loads as shown in Fig. 4.

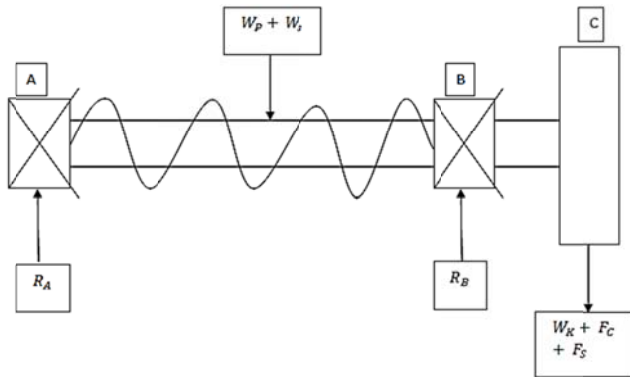


Fig. 4 Free Body Diagram of the Shaft Design

The estimated distribution load W_L , [9];

$$W_L = \frac{W_p}{L} \quad (13)$$

where; W_p = the calculated weight of the plastic material, L = length of the shaft.

Force at point C = $W_k + F_c + F_s$

Force acting on screw = $W_p + W_s$

Taking moment about B; $\sum M_B = 0$

$$R_C * L_{BC} + (W_p + W_s) * \frac{1}{2} L_{AB} = R_A + L_{AB} \quad (14)$$

Taking resultant forces along the vertical direction; $\sum f_y = 0$

$$(W_p + W_s) + (W_k + F_c + F_s) = R_A + R_B \quad (15)$$

The maximum permissible working stress, σ_b , and the maximum allowable shear stress, τ with key way are 84 MPa and 42 MPa respectively.

Since $K_m = 2.0$ and $K_t = 2.0$ as indicated in the Table 5.3, using equivalent twisting moment (T_e) and equivalent bending moment (M_e) to determine the shaft diameter Torque, T [7];

$$T = \frac{P \times 60}{2\pi N} \quad (16)$$

Equivalent twisting moment, T_e [7];

$$T_e = \sqrt{(K_m + M_n)^2 + (K_t + T)^2} \quad (17)$$

$$T_e = \frac{\pi \tau d^3}{16} \quad (18)$$

Equivalent bending moment, M_e [7];

$$M_e = \frac{1}{2}(K_m \times M_B + T_e) \quad (19)$$

$$M_e = \frac{\pi \sigma_b d^3}{32} \quad (20)$$

VI. RESULT SUMMARY

A theoretical evaluation of expected machine capacity is determined by comparing similar values of an existing machine with the calculated value in this design.

A VR60 machine of Untha shredding technology was compared with the plastic shredder, and a 5090.90 kg production capacity was estimated for a period of 8 hours.

This result shows the functionality of the plastic shredder with its application in small-scale production industries.

VII. CONCLUSION

An improved and efficient design of the machine specifically for recycling plastic waste was carried out in this research.

The modifications introduced in the design and operation of the machine, if implemented, will be beneficial and advantageous in the following:

1. Amount of plastic waste in our environment will be reduced through recycling processing.
2. The processing of waste materials will be enhanced to achieve the production of high quality products on relatively large scale for domestic and industrial uses.
3. The national economy will be boosted since adoption of such machines will help in reducing the importation of similar machine, maximize the use of local materials, thereby save cost.
4. Promotion of technology transfer and adoption for the production of recycling machine from small to medium scale level.
5. Recycled plastic waste can serve as raw materials for other machine processes such as kitchenware, trash bag, carpet, roof tiles, and so on.

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