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Research Article

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Development of a Waste Plastic Shredding Machine

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Abstract

Plastic is one of the most common used materials in the world today, but, they cause serious environmental pollution and exhaustion of landfill space. The recycling of waste plastic recovers the material, which can be used to make new plastic products such as containers, plastic lumbers and particle boards. For this to happen, the waste plastic will first be shred into small bits making it ready for transportation and further processing. This necessitated the development of a plastic shredder to recycle the waste plastic found in Federal University of Technology, Akure (FUTA), Ondo State, Nigeria environments. The shredder has the feeding unit, the shredding unit, power transmission unit and the machine frame. The performance of the machine was evaluated and test results showed that there was a correlation between the machine speed with a regression < 1 and there was a linear relationship with all variable parameters (The Shredding time (T), the Specific Mechanical Energy (SME), Throughput (TP) and Recovery Efficiency (RE)) and the variable operation speeds (1806.7 rpm, 1290.5 rpm and 1003.7 rpm). The throughput of the machine is 27.3 kg/hr and the efficiency is 53% for all type of plastic and 95% for Polyvinylchloride type of plastic. The machine is user friendly and the cost of producing one unit of the machine as at the time of fabrication was estimated to be One Hundred and Forty Thousand, Seven Hundred and Fifty Naira (N 140, 750:00k) only making it affordable to acquire for small and medium scale entrepreneurs in waste plastic recycling business.

Keywords: Development; Plastic; Shredding; Machine; Waste

Introduction

Plastic have become an essential part of our day to day life since their introduction over hundred years ago [1]. It is one of the most commonly used materials in the world today [2]. They come in five major categories; the Polyethylene terephthalate (PET), the High density polyethylene (HDPE), the Polyvinylchloride (PVC), the Polypropylene (PP) and the Low density polyethylene (LDPE). The huge quantities of these plastic categories currently being marketed will ultimately find their way to the waste dump sites [3]. This is creating waste products problems due to its high amount of waste generated, non-biodegradability and the fastest depletion of natural resources regarding its short life cycle, therefore increased amount of material utilized in its production, and waste generated [4]. Plastic bottles make up approximately 11% of the content landfills, causing serious environmental consequences [5]. The plastic waste globally constitutes more than 60% of the total global municipal solid waste (MSW), 22% were recovered and 78% disposed [6]. In United States, the waste of plastics in 2005 was calculated as 11.8% of the 246 million tons of MSW generated [7]. Some states in the US like Michigan have a recycling rate that is close to 100% and in Brazil, some potential in recycling have been raised where around 15% of all plastics consumed are recycled and returned to industry [8]. Locally in Nigeria and for Nigerian cities and towns, different researches have been carried out on the challenges of solid wastes in Nigeria and Africa generally, but works on plastic wastes in Nigerian cities and towns are still limited [9]. Developing countries like Nigeria have to import virgin plastic at high cost because recycling activities are usually low in these countries [10]. Machinery available for recycling activities in these countries are usually of very high cost and bulky and as such, recycling activities are restricted by these challenges in these countries. Therefore, to overcome these challenges, it was necessary to develop a low cost waste plastic shredding machine using available local materials that can easily be operated without much skill for low and medium income earner. This will prepare the recycled plastic for the production of new products in Nigeria.

Plastic recycling or reprocessing is usually referred to as the process by which plastic waste material that would otherwise become solid waste are collected, separated, processed and returned to use [11]. Waste plastic shredder is a machine that reduces used plastic bottles to smaller particle sizes to enhance its portability, easiness and readiness for use into another new product. The design principle of this machine was got from the ancient tradition method of using scissors to cut materials into reduced form and scratching used by rabbits when digging or tearing. These two traditional methods were applied in the design of the machine by fabricating cutting blades to cut the waste plastic while some of the cutting blades have sharp curved edges to draw-in the plastic into the cutting blades teeth. The waste plastic shredder comprises of four major components, namely; the feeding unit, the shredding unit, the power unit and the machine frame. The machine can be powered by electric motor of 10 Hp.

Materials and Methods

Machine description and operation

The waste plastic shredder has four main components; the feeding unit, the shredding unit, the power unit and the machine frame. The feeding unit is made of 16 – gauge galvanized mild steel sheet of 2 mm thick plate and a dimension of 200 mm × 550 mm through which the waste plastic are fed into the shredding unit. The shredding unit is where the waste plastic are been cut into smaller sizes. The unit consists of a shaft, 50 mm length made up of 30 mm mild steel rod and a cylinder of 55 mm length and 200 mm diameter. Attached to

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the shaft are cutters made of 12 mm mild steel having nine serrated teeth welded 2 mm apart. The cylinder equally has same cutters with sharp edges to shred the waste plastic. Underneath the shredding unit is the outlet made of 16-gauge galvanised mild steel of 43 mm × 27 mm dimension. The shredded waste plastic discharge freely from the shredding unit through the outlet. The machine is powered by 10 Hp electric motor with the aid of belt and pulley arrangement which has 110 mm diameter driven pulley and 60 mm driver pulley as shown in Figures 1-3.

Design considerations

Some of the factors considered in the design of the recycled plastic waste shredding machine are safety, power requirement, compactness, ease of operations and overall cost of production. Material selection based on availability, durability, cost and ease of fabrication were also considered.

Design of machine components

Feeding chute capacity:

Volume of the hopper = Area of cross-section of the hopper × width of hopper= ½ (a + b) h × width…(1) [12]

Hopper capacity = 2.1×10^{-2} m^3

Volume of PET bottle (coca cola) in the shredding chamber:

No of bottle to fill the hopper = volume of hopper/ volume of PET bottle

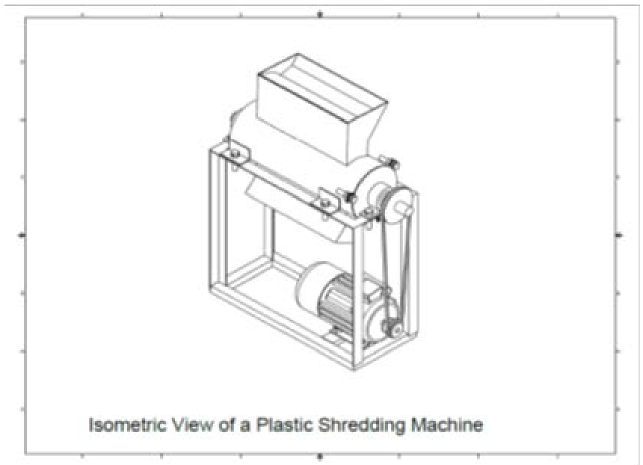

Figure 1: Isometric drawing of the shredding machine.

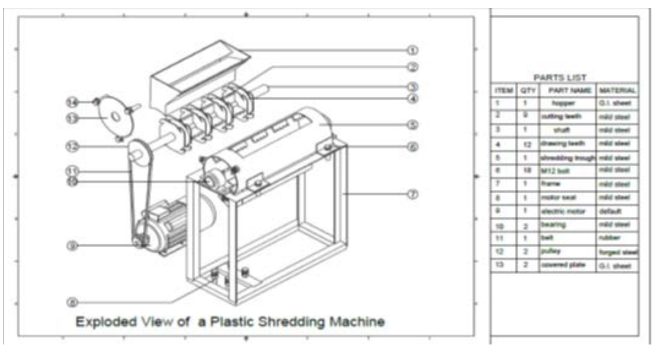

Figure 2: Exploded view of the shredding machine.

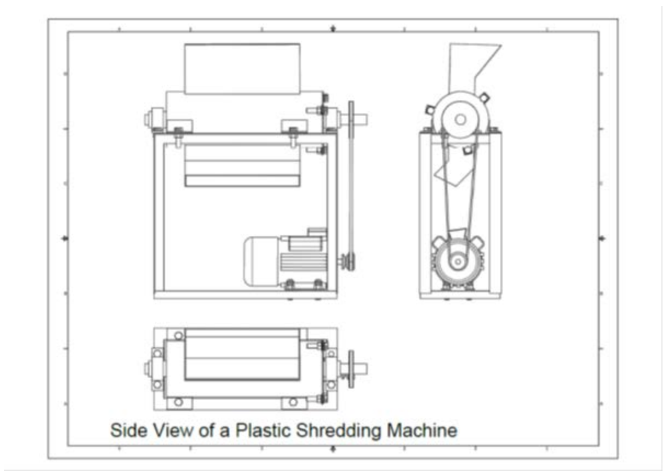

Figure 3: Orthographic drawing of shredding machine.

Volume of PET bottle (coca-cola bottle) =

Area × height= $\frac{\pi d^2}{4} \times$ h …(2) [13]

$= 2.1 \times 10^{-2} / 7.7 \times 10^{-4}$

The number of plastic water bottle the hopper will accommodate is 27.

Determination of shaft diameter

$$d^3 = \frac{16}{\pi\tau}\sqrt{(k_b m_b)^2 + (k_t m_t)^2} \; \ldots (3)$$ Hall et al. [14]

Where,

d = diameter of the shaft = 30 mm

= allowable shear stress of metal with key way = 40 × 106 N/m^2

mb = maximum bending moment = 25.61 Nm

mt = torsion moment = 22.3 N

Kb = combined shock and fatigue factor applied to bending moment = 2.0 (sudden loading)

Kt = combined shock and fatigue factor applied to torsional moment = 2.0 (sudden loading)

Performance evaluation procedure

One kilogram (1 kg) each of the four different plastic types (Polyethylene Terephthalate (PET), the High density polyethylene (HDPE), the Polyvinylchloride (PVC) and the Polypropylene (PP) were shredded at varied motor speed of 1,806.7 rpm, 1,290.5 rpm and 1003.7 rpm using 10 Hp three-phase electric motor as the prime mover. The shredded waste plastic, Q, was weighed to determine the quantity of the actual shredded waste plastic before sieving into three different sizes in order to determine their average size and area using Excel 2014. The Shredding time (T), the Specific Mechanical Energy (SME), Throughput (TP) and Recovery Efficiency (RE) of the machine were also determined using the relationship below:

Specific Mechanical Energy = Power (P) × Time (t)

Output mass (Q)

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Throughput (TP)=Output mass of recycled waste plastic (Q)

Time taken for recycling (t)

Recycling Efficiency (RE)= Output mass of recycled waste plastic (Q) × 100

Input mass of waste plastic (I) [10].

Results and Discussion

Results

The results obtained from the machine were presented in Tables 1 to 3 while Figure 4 represent the summary of the average size and percentage number of plastic shredded at three variable speed of the motor.

Discussion

At the machine speed of 1806.7 rpm, the shredder performed optimally when shredding PVC with a result of 53.6% shredding achievement while the average shredded size particle is 5.07 mm^2. It takes the machine 3 mins to shred the bottle with a recovery efficiency of 95% and the specific mechanical energy was minimal at 392 KJ/kg with a throughput of 19 kg/hr. This is followed by HDPE with 48% shredded but with an average particle size of 13 mm^2 when compared to the particle size of 12.23 mm^2 for PET.

At the machine speed of 1290.5 rpm, the shredder still performed optimally when shredding PVC with 52.8% shredding output within 2 mins and an average shredded size particle of 6.29 mm^2. The SME for PET was further reduced by 61% when compared to the speed of 1806.7 rpm while the recovery efficiency was 94% and the throughput increases by over 100% to 238.1 KJ/kg which is This is followed by HDPE and PP

	PET		HDPE		PVC		PP	
S/N	Avg size (mm^2)	% Shreddd	Avg size (mm^2)	% shreddd	Avg size (mm^2)	% Shreddd	Avg size (mm^2)	% shreddd
1	3.71	28.1	1.01	12.5	0.66	13.4	4.48	13.8
2	8.04	24.6	4.53	28.5	1.89	27.8	11.70	27.7
3	12.23	37.3	13.60	48.0	5.07	53.6	18.05	37.0

Table 1: The result of the shredded plastic at 1806.7 rpm.

	PET		HDPE		PVC		PP	
S/N	Avg size (mm^2)	% Shreddd	Avg size (mm^2)	% shreddd	Avg size (mm^2)	% shreddd	Avg size (mm^2)	% shreddd
1	1.07	24.1	0.64	12.6	0.79	14.8	2.12	15.7
2	5.32	27.6	3.25	23.2	1.73	26.7	6.44	30.0
3	10.21	39.4	8.27	48.8	6.29	52.8	14.25	40.0

Table 2: The result of the shredded plastic at 1290.5 rpm.

	PET		HDPE		PVC		PP	
S/N	Avg size (mm^2)	% Shreddd	Avg size (mm^2)	% shreddd	Avg size (mm^2)	% shreddd	Avg size (mm^2)	% shreddd
1	0.36	20.1	0.53	13.5	0.93	16.2	0.67	15.1
2	1.89	30.5	2.12	17.4	1.62	25.6	1.18	29.8
3	7.32	41.5	4.58	52.3	7.51	53.3	2.86	40.5

Table 3: The result of the shredded plastic at 1003.7 rpm.

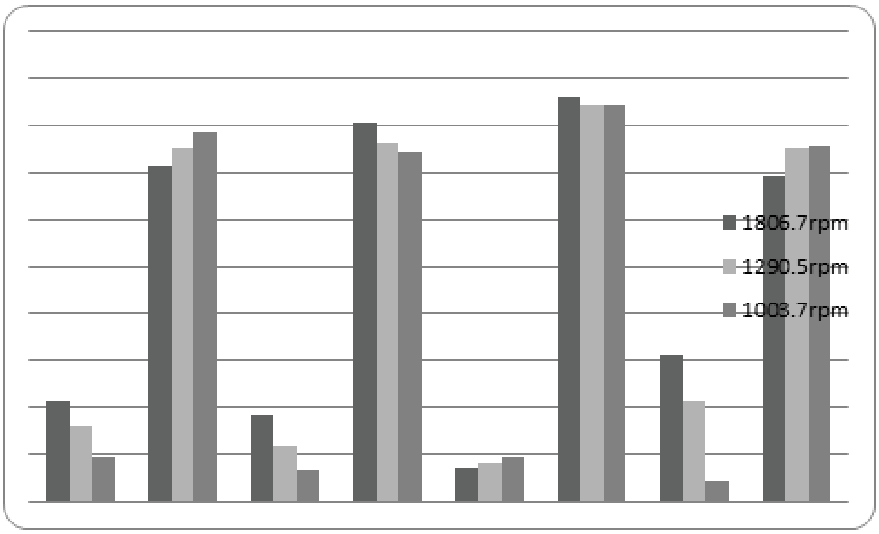

Figure 4: Summary of shredder performance with three speed.

which has a minimal variance for all the parameters measured.

At the machine speed of 1003.7 rpm, 53.3% of PVC plastic was shredded to an average particle size of 7.51 mm^2 within 2 mins. The specific mechanical energy of the machine at this speed and for PVC reduced by 1% when compared to speed 1806.7 rpm while the recovery efficiency was 95% with throuput of 31.67 kg/hr which is 1% higher than the speed at 1290.5 rpm. Again, the machine shredded 52.3% of HDPE with an average particle size of 4.58 mm^2 at this speed within 4 mins with a recovery efficiency of 83%.

Conclusion and Recommendation

There was a correlation between the machine speeds with a regression <1 and there was a linear relationship with all variable parameters and the operating speed. Throughput capacities of the machine at different shaft speed of 1806.7 rpm, 1290.5 rpm, and 1003.7 rpm were 19.00 kg/hr, 31.33 kg/hr, 31.67 kg/hr respectively. The recovery efficiencies were up to 95%, 94% and 95% respectively. The specific mechanical energy was 1077.6 KJ/kg, 1065.7 KJ/kg and 973.0 KJ/kg respectively. The average particle size was 18.05 mm^2, 14.25 mm^2 and 7.51 mm^2 respectively and percentage shredded were 53.6%, 52.8% and 53.3% respectively. The machine therefore has an average Throughput of 27.3 kg/hr, Recovery Efficiency of 95%, Specific Mechanical Energy of 1,039 KJ/kg, Percentage shredded of 53.2% and 95% specifically for PVC type of plastic. The average particle size shred of 13.3 mm^2 and the production cost of the shredding machine is One Hundred and Forty Thousand, Seven Hundred and Fifty Naira (N 140,750:00 k) only.

The results obtained from the waste plastic shredding machine performance further shows that the machine could be very useful in a situation where considerable plastics have to be shredded and also efficient in shredding large sizes. The machine is therefore recommended for use by small and medium scale entrepreneurs working on recycled plastic.

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