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Design and construction of a mechanical waste compactor

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ABSTRACT

The absence of adequate waste management policies is a challenge faced in our great nation Nigeria. There are problems associated with the segregation of wastes into the various matter forms. Considering the fact that solid wastes have a higher volume when compared with liquid and gaseous wastes, there is a dire need to reduce the volume of wastes. Hence, this research is aimed at the fabrication of a mechanical waste compactor which compact papers, plastic, and Aluminum cans to reduced size in order to ensure ease of conveyance for recycling. The compactor was fabricated with several parts with the chief being mild steel, rack and pinion, wheel, bearing and shaft. The principle of operation is based on the simple rotary motion of the turning of the operating wheel in anti-clockwise direction which in turn moves the rack and pinion gear in the compaction volume to compress the waste. The compaction volume has an opening for loading the waste and unloading after compaction. The Mechanical waste compactor was able to achieve the performance efficiency of 70% on paper, plastic and aluminum waste compression test results. The mechanical

waste compactor is cheaper compared to a foreign made, being constructed with overall cost of =N=133,900 which is the equivalent of USD372 at the time of construction with materials sourced locally in Nigeria.

Keywords: Compactor, Waste, Mechanical

1. INTRODUCTION

In the world today, there is a continuous rise in waste generation rate and this is often associated with industrial and socioeconomic development. Hence, there is a need for a device which can effectively reduce the size of waste materials in order for more waste to be disposed safely. Waste are unwanted or unusable materials which are discarded after their primary use and are hence considered worthless, defective and of no use. Waste materials exist in the form of the three phases of matter which are solids, liquids and gases.

Waste are substance or objects, which are disposed of or are intended to be disposed of or are required to be disposed of by the provisions of the national law (Basel Convention on the Control of Trans-boundary Movements of Hazardous Wastes and their Disposal).

There are many wastes types defined by modern systems of waste management Municipal waste: This includes usual household waste, commercial waste and demolition waste. Hazardous waste: industrial waste. Biomedical waste: this includes clinical waste from health centers and hospitals

Special Hazardous waste: this includes radioactive waste, explosive waste and electronic waste.

Solid wastes are garbage, refuse, sludge which could be from waste water plant, water supply treatment or air pollution control facility and other discarded materials like solid, liquid, semi-solid, or contained gaseous material resulting from industrial, commercial, mining, agricultural operations and from community activities but does not involve solid or domestic materials in domestic sewage or solid or dissolved materials in domestic sewage, or solid or dissolved materials in irrigation return flows or industrial discharges. In layman setting solid waste can be regarded as discarded or abandoned materials. Common examples of solid wastes include waste tire, scrap metal, latex paints, furniture and toys, garbage, appliances and vehicles, oil and anti-freeze, empty aerosol cans, paint cans, compressed gas cylinders, construction and demolition debris etc.

It is important to sort out waste that still possess valuable raw material such as paper and paperboard, deposit beverage containers, clothing, hazardous waste etc. After the material sorting, it is taking to the plant which makes it possible to retrieve metal parts in mechanical sorting, other forms of compressed wastes are baled and buried in the landfill.

For the purpose of appropriately disposing solid wastes, there is a need for a mechanical waste compactor. A mechanical waste compactor is a device that is used for the purpose of solid material size reduction with the aid of a mechanical action.

2. LITERATURE REVIEW

The waste compactor isn't so demanding in Africa as it is in other parts of the world but visible samples in communities within the state region has made it so obvious that due to the absence of this waste compactors many households have been forced to drop their dirt as trash within the streets thereby causing land pollution, Kehl (1983).

These land pollutions have resulted to hazards on young ones and old people which has posed a major threat in the community. These pollutions have also caused a high number of waste disposal which has led to littering, Kehl (1983).

Most of the waste found on the floor in the community are solid waste like pieces of papers, bottles, cans, metals and others and these materials can be recycled again to produce useful materials and used for land filling, but due to the fact that there is absence of trash compactors people tend to dispose their household waste on the street as it is seen cheaper to them leaving them to neglect the adverse effect it can have on the society later on, Kehl (1983).

Mohlman (1997) worked on the invention of a litter bag for the proper management of waste, it is well known that when travelling in motor vehicles wrappings of edibles and non-edibles are removed and due to civic pride and legal restrictions these may not be thrown from a vehicle and consequently substantial wastes accumulates in the vehicles and creates a problem since some of such articles are likely to fall into the brake or accelerator pedal or other location in which they are physically in the way or they distract the attention of the operator thereby creating hazard. This invention was aimed at reducing the amount of waste stored in dump trucks that causes problems when they are been moved to the dump sites, the invention aimed to solve trash problems and to provide a simple, inexpensive and substantial collection receptacle which could last for a specific period of time and thereby could be discarded after a period of time.

This invention by Mohlman (1997) for the collection of the waste comprises an envelope of a relatively thin semi-transparent waterproof plastic, one end of the envelop is opened and the other end been closed, a relatively wide reinforcing band provided around the margin of the open end of the said envelope providing a double thickness, the band has a general circular opening at opposite disposed portions with reinforced stitching around the said openings with a utility strap having one end attached between the thickness of the material of the reinforcing band at the mouth of the envelope, the strap is provided with longitudinal reinforcing stitch, the envelope is supported and adapted with a projection so that the latter extends through one of the said openings, the strap serves the threefold function of supplemental securing means for carrying the envelope with the strap tied through the opposite opening in the reinforcing band and around the mouth of the envelope for securing the latter in closed positions.

The litter bag is supposedly to be firm to carry a lot of waste but no form of conversion can be done on the waste while in the litter bag, therefore if the litter bags are taken to the dumpsite it still causes littering as there will be no proper source of segregation on the litter waste thereby making all different types of waste to be in a single litter bag, the material used is a plastic which limits its storage to certain objects, when there are sharp objects places in the litter bag it can cause the plastic to pierce and some of the waste may fall off which may still cause littering in the environment.

Other improvements were made on waste management systems. Gladwin (1974) designed a trash compactor. Unlike the litter bag there were much more improvement made on the trash compactor, the trash compactor was designed with an extra improvement to process the waste that were placed into it. Every trash compactor has a design limit, this limit is based on the size of the trash can, the trash can actually come in various shape but Floyd. Gladwin design was aimed at removing any form of compaction complication that might occur when the waste should be compacted.

The trash compactor is in a cabinet format containing in its lower portion a vertically elongated open top receptacle having front and side walls but an open rear which is pivotally connected at its lower end to the cabinet for swinging forwardly outwardly of the cabinet with the rear wall of the receptacle normally closed by the receptacle rear wall. It possesses a horizontal arranged cover having a central opening, fits over the receptacle to hold it in place with the cover being hinged securely to the cabinet for swinging upwardly to thus permit outward swinging of the receptacle. A disposable bag is closely fitted within the receptacle having an upper edge folded over three walls thereof. The design also possesses a downwardly movable ram which is located above the receptacle, compacts the trash contained within the bag with the ram being horizontally to enable it compact the trash contained within a second receptacle and bag positioned within the cabinet alongside the first receptacle, Galdwin (1974).

The invention is made to provide a small size, light weight and compacting apparatus for trash compression and can find usefulness in basically restaurants, homes, small apartments and cafeterias where waste quantity is practicable small of which when compressed can produce small and light weight bales of trash which can be easily handled manually for removal of conventional garbage pick-up trucks and the likes, this design provides a trash baler in the form of small cabinet containing one or more receptacles in its lower portion, it has receptacles mounted on a forwardly swinging panel, so that the receptacles and the panel can be swung forwardly and outward for manual and easy removal of the compressed trash from the disposable bag. The design contemplates utilizing a single ram member such as a hydraulic or pneumatically operated cylinder having a ram member secured to its downward movable piston, with the ram member been positioned above one or another of the receptacle, where more than one or more receptacle is used thereby reducing considerable expense and the weight and ease of operation of the device.

3. MATERIALS AND METHOD

In order to effectively design and construct the mechanical waste compactor which can effectively compact wastes like aluminum, plastics and paper, the following engineering design approach was adopted.

1. Review of existing literatures
2. Design concept development
3. Selection of design concept.
4. Design calculations.
5. Design and simulation of the selected concept using a computer aided design software
6. Selection of materials.
7. Fabrication of the waste compactor.
8. Finishing.
9. Testing

Design calculation

The compactor to be fabricated is a multi-purpose compactor i.e. compacts aluminum, plastic and paper.

Volume of compactor (V_c)

Since the compactor is a cube like structure, the volume of the compactor will be given by applying the formula below;

$$Vc = L \, x \, b \, x \, h \quad (1)$$

Where l, b, h represents the length, breadth and height of the compactor respectively.
Let l, b and h be 480mm,480mm and 660mm respectively.

$$V_c = 0.48 \, x \, 0.48 \, x \, 0.66 = 0.1521 m^3$$

Mass of waste (M_w)

$$M_w = \rho_a \, x \, V_c \quad (2)$$

Where ρ_a is the density of aluminium i.e. when aluminium as the waste to be compacted

Table 1 Aluminium material properties (Charles, John, and Eshun, 2016)

Density of aluminium (ρ_a)	Compressive property (E)	Ultimate strength (σ_{ut})
2700kg/m^3	70Gpa	310Mpa

Hence,

$$M_w = 2700 \, x \, 0.1521 = 410.67 kg$$

Force exerted by the waste on the compactor (F_W)

$$F_W = M_w \, x \, g \quad (3)$$

Where g is the acceleration due to gravity i.e. 9.81m/s^2

$$F_W = 410.67 \, x \, 9.81 = 4.03 KN$$

When paper is considered, mass of waste will be,

$$M_w = \rho_p \, x \, V_c \quad (4)$$

Table 2 Paper properties(Charles, John, and Eshun, 2016).

Density of paper (ρ_p)	Compressive property (E)	Ultimate strength (σ_{ut})
250-1500kg/m^3	2-4Pa	150-475Mpa

Picking the density of the paper to be 750 kg/m^3

$$M_w = 750 \, x \, 0.1521 = 114.08 kg$$

Force exerted on compactor by waste (F_W)

$$F_W = M_w \, x \, g$$

Where g is the acceleration due to gravity i.e. 9.81m/s^2

$$F_W = 114.08 \, x \, 9{,}81 = 1119.08 N$$
$$F_W = 1.12 KN$$

When the waste considered is polyethylene terephthalate bottles i.e. plastics

Table 3 Polyethylene terephthalate bottle properties(Charles, John, and Eshun, 2016).

Density of plastic bottle (ρ_{pb})	Compressive property (E)	Ultimate strength (σ_{ut})
1370kg/m^3	4GPa	100Mpa

Mass of waste becomes

$M_w = \rho_{pb}\ x\ V_c$

$M_w = 1370\ x\ 0.1521 = 208.38kg$

Then

$F_W = 208.39\ x\ 9.81 = 2044.18N$

$F_W = 2.04KN$

Weight of piston

$W_{Pi} = M_{pi}\ x\ V_{pi}$

Where M_{pi}, V_{pi} are the mass and volume of the piston respectively.

Hence,

$$V_{pi} = \frac{\pi d_{pi}{}^2 h}{4} \quad (5)$$

Let $d_{pi} = 60mm$

$$V_{pi} = \frac{\pi\ x\ 60^2 x\ 100}{4} = 2.8278\ x\ 10^{-4} m^3$$

Mass of piston (M_{pi})

$$M_{pi} = \rho_{pi}\ x\ V_{pi} \quad (6)$$

The piston used is made from mild steel.

Hence, the density of the piston is equal to the density of mild steel.

$\rho_{pi} = 7850kg/m^3$

$M_{pi} = 7850\ x\ 2.8278\ x10^{-4} = 2.22kg$

Weight or force exerted by the piston (W_{pi})

$W_{pi} = 2.22\ x\ 9.81 = 21.78N$

Volume of piston plate (V_{pp})

$V_{pp} = l\ x\ b\ x\ h$

$V_{pp} = 0.43\ x\ 0.43\ x\ 10 = 1.849\ x\ 10^{-3} m^3$

Mass of piston plate (M_{pp})

$M_{pp} = \rho_{pp}\ x\ V_{pp}$

Piston plate is made from mild steel. Hence,

$\rho_{pp} = 7850kg/m^3$

$M_{pp} = 7850\ x\ 1.849\ x\ 10^{-3} = 14.515kg$

Weight of piston plate (W_{pp})

$W_{pp} = M_{pp}\ x\ g$

$W_{pp} = 14.515\ x\ 9.81 = 142.39N$

Therefore, total weight = 21.78 + 142.39 = 164.17N

Assuming the average power of an adult human being to be 75W, we can calculate the speed of rotation of the gear.

$$P = F_t \, x \, V_l \tag{7}$$

Where P,F_t, V_l represents the power, total force and linear velocity respectively.

$$V_l = \frac{75}{164.19} = 0.4568 m/s$$

$$\omega_g = \frac{V_l}{r} \tag{8}$$

Where ω_g, r represents the angular velocity of the gear and the pitch radius of the gear respectively.

$$\omega_g = \frac{0.4568}{0.8} = 0.571 rad/s$$

Velocity ratio = $\frac{N_1}{N_2}$ (9)

The speed of the pinion is four time the speed of the gear.

Hence,

$$\omega_p = 4 \, x \, \omega_g$$

$$\omega_p = 4 \, x \, 0.571 = 2.284 rad/s$$

Force generated by spindle (F_s)

$$F_s = \frac{T}{r} \tag{10}$$

Where T is the torque of the spindle.

$$T = \frac{P}{\omega_p} \tag{11}$$

$$T = \frac{75}{2.28} = 32.8 Nm$$

$$F_s = \frac{32.8}{0.02} = 1640 N$$

Load transmitted (L_t)

$$L_t = \frac{T}{r} \tag{12}$$

$$L_t = \frac{32.8}{0.06} = 546.7 N$$

Fabrication process

For the fabrication of the mechanical waste compactor, the following steps were adopted.

- Measurement and cutting out of steel plates according to the design values.
- Folding of plates to form the chamber cover and the compacting chamber
- Marking out of the base plate metal in order to ensure the various parts were well positioned.
- Welding of the folded plates to the base plate.
- Drilling of holes in the base plate for pillar re-enforcement.
- Locking of the pillar to the base plate with the aid of fasteners i.e. bolt and nuts.
- Construction of the racking mechanism.
- Welding of the racking mechanism to the compacting plate.
- Welding of a wheel control mechanism which would ensure the reciprocating motion of the racking member
- Finishing

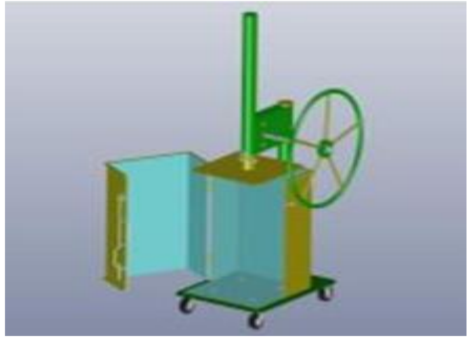

Fig 1: Designed mechanical waste compactor

Fig 2: Fabricated mechanical waste compactor.

Table 4 Bill of Engineering Measurement and Evaluation (BEME)

S/N	MATERIAL	QUANTITY	UNIT COST (₦)	AMOUNT (₦)
1	12mm steel plate (4 by 4)	1	30000	30000
2	3mm steel plate (4 by 4)	1	12000	12000
3	3 inch pipe	1	6000	6000
4	2 inch pipe	1	3500	3500
5	Bearing	2	1000	1000
6	Bearing housing	2	500	500
7	Hinge	1	800	800
8	Rectangular flange	1	3500	3500
9	Bolt and nut	8	600	600
10	Roller	4	3500	3500
11	Shaft (20mm)	1	2500	2500
12	Steering wheel	1	1500	1500
13	Rolled plate	1	2500	2500
14	Paint	1	4000	4000
15	Rack and pinion	1	12000	12000
16	Expert services			50000
			Total	133900

One hundred and thirty three thousand nine hundred naira only.

4. RESULTS AND DISCUSSION

The mechanical waste compactor was successfully achieved and tested.. The sizes of the compacted cans were reduced to about a ratio of one to four of their original size. The compactor was fabricated with several parts with the chief being mild steel, rack and pinion, wheel, bearing and shaft. The principle of operation is based on the simple rotary motion of the turning of the operating wheel in anti-clockwise direction which in turn moves the rack and pinion gear in the compaction volume to compress the waste. The compaction volume has an opening for loading the waste and unloading after compaction. The Mechanical waste compactor was able to achieve the performance efficiency of 70% on paper, plastic and aluminum waste compression test results.

5. CONCLUSION

The project which is aimed at designing and fabricating a mechanical waste compactor was successfully completed and tested in order to ascertain its performance and efficiency. The fabricated compactor ensures there is a reduction in cost through the reduction of energy consumption that is associated with electrically powered waste compactors. In conclusion, if the production of mechanical waste compactors is massively encouraged and commercialize, it would serve as a means of empowerment or employment to the youths of the nation and as well aid the development of our technical and technological knowhow.

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