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Design and Fabrication of a Solid Waste Sorting Machine

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Abstract: *Management of solid waste is essential to our health and environmental protection. Separation of the wastes in order to reduce, re-use, recycle, and recover energy from them or to process them for further use, is key to the proper management of the waste. Minna, the capital city of Niger State, Nigeria is on daily basis experiencing continuous growth which contributes enormously to the generation of different types of solid wastes that are dumped together. In order to sort the solid wastes, a sorting machine was designed and fabricated. The machine was designed with the major components being the fast-moving conveyor, slow moving conveyor, shafts, electric motor and fan. When performance evaluation was carried out on the solid waste sorting machine, it was able to sort 2, 3, 4, 6 kg of municipal solid waste into light fractions of 0.90, 1.30, 1.65, 2.45 kg and heavy fractions of 1.10, 1.70, 2.35, 3.55kg in 109.8, 165,219.6 and 330 seconds respectively. The solid waste sorting machine was also able to sort 3, 4, 5, 6 kg of municipal waste into light fractions of 1.65, 1.85, 2.08, 2.15 kg, ferrous metallic fractions of 0.25, 0.45, 0.95, 1.15 kg and heavy fractions of 1.10, 1.70, 1.97, 2.70kg in 168, 223.5, 287.5, 341.20 seconds respectively. The cost of materials and fabrication of the machine was one hundred and fifty-four thousand, nine hundred and eighty naira (₦154,980.00) only.*

Keywords: *Conveyor, Minna, solid waste, sorting machine, waste.*

1.INTRODUCTION

Waste generation and disposal is naturally part of any developing and industrial society. The problem of solid waste is therefore a universal one as waste exists in every society and the wastes from both commercial and domestic sources are considerably growing every day in Nigeria. The quantity and rate of the generation of solid wastes within any city is dependent on the population, level of industrialization, socio-economic status of inhabitants as well as the kind of undertakings being the dominant [1]. An unkempt surrounding affects the living standard, health status of the inhabitants and thus the quality of their lives. It is in view of this, that solid waste management efforts which were initially directed at just the removal of waste from the urban centres and subsequent destruction of such waste later has its attention shifted to utilization of waste, waste reduction, re-use recycling, management of hazardous substances and prevention of pollution resulting from waste disposal. Solid wastes not properly handled and disposed into open spaces poses danger to human health as well as the environment. Waste management is concerned with the generation, prevention, monitoring, characterization, treatment, reuse and residual disposition of solid wastes [2]. This means that waste management consists of the whole set of activities related to the handling, treating, disposing or recycling the waste materials. Waste generation increasing beyond the acceptable levels led to the changes in the framework directives and policies which formulated waste management hierarchy. In waste management hierarchy, the waste should follow “reduce, reuse, recycle and recover energy” before it is dumped into the landfill [3].

Minna, the capital city of Niger state, Nigeria is on daily basis experiencing continuous growth that adds enormously in generating liquid and solid wastes. The amount of solid wastes generated per year is about 1893 tons (1,893,000kg) [4]. Information from Niger State Environmental Protection Agency (NISEPA) and subsequent survey of the only government approved dump site shown in Plate1. The composition of solid waste in Minna consists of paper, pieces of clothes or textile materials, polythene materials, paper tissue, plastics which are the light fractions of the solid waste, scrapped tyres, wood, pieces of bottles and glassware which are the heavy fractions of the solid waste. More so, metallic objects, which are the ferrous metallic fraction of the solid wastes. These wastes therefore need to be separated in order to be able to re-use, recycle, reduce renew them or use as fuel in case of the light fractions. This will also go a long way in sanitizing the city of filth and also reduce if not eliminate the environmental hazards to the people through land and air pollution and most significantly contamination of water.

Plate I: Minna solid waste dump site

In recent times, there are emphases on the waste sorting, before recycling and re-using; including other practices which help to reduce waste management costs are also used. It is in view of the above that several researchers [5-10] embarked on the development of different types of waste sorting machine. The waste management agency in Niger State lacks waste sorting machine. So the solid waste generated in Minna are only collected and dumped in the designated dump site by the Waste Management Agency. It is only scavengers from the community and other places that sort these wastes in a crude form, by hand picking, that is tedious and ineffective. Besides, the scavengers are prone to health hazard when sorting the waste. So, design and fabrication of a solid waste sorting machine was carried out in this research work, in order to circumvent the problems associated with the sorting of the waste by scavengers and provide the government with a waste sorting machine. More so, in order to reduce, utilize and in a nutshell, enhance management of solid waste generated in Minna, the capital city of Niger state.

2.MATERIALS AND METHOD

2.1 Design Theory and calculations

The following parts were considered for the design of solid waste sorting machine

- Fast moving conveyor
- Slow moving conveyor
- Shafts
- Electric motor and
- Fan

2.2 Design Specifications for Slow Moving Conveyor

The following are the design specifications for the slow moving horizontal flat conveyor where the ferrous metals are separated from the waste stream and the remaining waste fed onto the fast moving conveyor.

- In order to accommodate a reasonable quantity of waste per unit time, a belt width of $500mm$ is considered.
- To avoid spilling off of the waste from the conveyor belt during operation, the dimensions considered for the outlet and inlets of the upper hopper are respectively $400\ mm \times 400\ mm\ and\ 300\ mm \times 300\ mm$,

Giving a clearance of 100mm on both edges of the belt.

- The recommended minimum pulley (conveyor drum) diameter for type C that is being used in this design is 200mm [11]. So 210mm was considered for the diameter of the conveyor drum.
- The maximum density of medium waste material to be conveyed is 514 kg/m^3
- The maximum lump size of waste material that can be conveyed by a belt width of 500 mm is 175 mm [11].
- Solid waste deposit is a mixture of different materials and the angle of repose of the constituent materials differs. It ranges between 22^0 for alumina, [11] a non-ferrous metal and 35^0 for sawdust, [11] which is a biomass waste. So the angle of repose of garbage which constitutes a mixture of different materials is taken or assumed to be 25^0.
- To enable manual sorting of reasonably large waste to be carried out on the slow moving conveyor belt, a low speed of 0.3m/sec is considered for the slow moving conveyor belt. In this process, the sorters will remove items that could damage equipment or that are of value.
- A length of 1m is considered for the slow moving conveyor belt.

2.3 Capacity of the Slow Moving Conveyor

In[11], $Conveyor\ belt\ capacity = 3.6 \times A \times \rho \times V\ t/hr$ **(1)**

Where A= Load cross sectional area perpendicular to the belt of load on the belt (m^2).

ρ = Approximate density of material conveyed (kg/m^3)

V = Belt speed (m/sec)

In [12] stated by [13], $A = 0.16 \times B^2 \times C \times \tan\theta$ (2)

and also $\theta = 0.35 \times angle\ of\ repose$ (3)

Hence $A = 0.16 \times 0.5^2 \times 1 \times \tan 8.75 m^2 = 0.006156 m^2$

Conveyor belt capacity $= 3.6 \times 0.006156 \times 514 \times 0.3 \times 1000 kg/hr = 3420 kg/hr$

2.4 Power Required for Driving the Slow Moving Conveyor

The power requirement for belt conveyor is given by [11] as

$$Power = \frac{\{F_c(L+tf)(C+3.6QS)\}}{367} \pm \frac{CH}{367} kW \quad (4)$$

Where Fc = Equipment friction factor.

L = Horizontal centre to centre distance.

tf = Terminal friction constant in metres

C = Capacity in tonnes/hr

Q = Mass of moving parts expressed in kilograms per metre of centre to centre distance

S= Belt speed

H = Net change in elevation.

For short distance conveyors using belt quality, it is often convenient to use an average equipment friction factor of

0.0225 for horizontal conveyors while the terminal friction for horizontal conveyors up to 300m centre is 60m and the valve of Q is taken as 18kg/m. [11] Hence Power

$$(\mathrm{P}) = \frac{\{0.0225(61)(22.86)\}}{367} \pm \frac{0}{367} kW \; = 0.855kW$$

2.5 Power Required by Motor

Motor power required is given by the relation

$$P_m = \frac{P}{\eta} \qquad (5)$$

where P_m = Motor Power required
P = Conveyor Power required
η = Motor efficiency
Efficiency which is the ratio of useful work to energy expended is taken to be 85%,

$$P_m = \frac{0.0855}{0.85} kW \; = 101 Watts$$

The speed of the electric motor used from manufacturers rating is $1400rpm$. The diameter of the electric motor shaft is 25 mm. The diameter of the driving pulley on the motor shaft is 40mm
In [14],the output of the driving pulley

$$(V) = \frac{\pi DN}{60} \qquad (6)$$

Where $D = Pulley\ diameter\ (0.04m)$
$N = 1400rpm$

Hence $V = \frac{\pi \times 0.04 \times 1400}{60} m/s$ = 2.93 m/s

2.5 Shaft Design

Shaft design is the determination of the correct shaft diameter that will ensure satisfactory rigidity and strength when the shaft is transmitting motion under different operating and load conditions.

2.6 Fast Moving Conveyor Shaft

Motor power selected $= 1\ Horse\ power = 746W$
X and Y are pulley belts mounted on the pulley.

Net torque ,$(T) = (T_2 - T_1)R$ (7)

Also Power (P) $transmitted = T \times \omega$ (8)

Hence power P = $(T_2 - T_1)$ R x $\frac{2\pi N}{60}$

Where $T_2 = Tension\ on\ the\ tight\ side\ of\ the\ belt$
$T_1 = Tension\ on\ the\ slack\ side\ of\ the\ belt$
$R = Radius\ of\ the\ driven\ pulley$
$N = Revolutions\ per\ minute$

From equation 8, $Torque = \frac{Power}{\omega}$

$$= \frac{746 \times 60}{2\pi N}$$

Speed of the fast moving conveyor $= 238.9rpm$

Therefore torque $= \frac{746 \times 60}{2\pi \times 238.9} Nm \; = 29.82Nm$

Figure 1: Reaction at the Bearings of Fast Moving Conveyor Shaft.

Bending moment about $A = 206.18 \times 0.0675Nm = 13.92Nm$

Bending moment about $B = 51.09 \times 0.5675Nm \; = 28.99Nm$

Therefore, $\max imum\ bending\ moment = 28.99Nm$

American Society of Mechanical Engineers (ASME) code for commercial steel shafting gave allowable shear stress (τ) for shafts with key way as 40 MPa and diameter of shaft

$$d = \sqrt[3]{\frac{16}{\pi\tau}\sqrt{(C_{bm} \times M_b)^2 + (C_t \times M_t)^2}} \qquad (9)$$

Where $d = Shaft\ diameter$
τ = maximum allowable shear stress
C_{bm} = Bending factor (Combined shock and fatigue factor for bending, K_b).
C_t = Torsion factor (Combined shock and fatigue factor for torsion, K_t)
$M_t = Torque$
$M_b = Bending\ moment$

C_{bm} or K_b and C_t or K_t for gradually applied load on rotating shafts is given as 1.5 and 1.0 respectively [15].

Hence $d = \sqrt[3]{\frac{16 \times 1000}{40\pi}\sqrt{(1.5 \times 28.99)^2 + (1.0 \times 29.82)^2}}\ mm$

$d = \sqrt[3]{6713.45}\ mm$

d = 18.86 mm

A shaft of diameter 25mm is selected to conform to standard sizes of commercial

2.7 Velocity of Air Required

Applying conservation of momentum equation,

$$F = \rho AV^2 \qquad (10)$$

$F = Weight\ of\ light\ material\ (0.544N)$

Therefore, $0.544 = 1.225 \times 0.8(\frac{\pi \times 0.42^2}{4})V^2$

$V = \sqrt{4.91}m/s$
= 2.22 m/s

2.8 Volumetric Flow Rate of Air Required

In [16], $Volumetric\ flow\ rate\ (Q) = AV$

$$= \frac{0.8\pi \times D^2}{4 \times V} m^3/s = \frac{0.8\pi \times 0.42^2}{4 \times 2.22} m^3/s = 0.25m^3/s$$

2.9 Power Required by Fan

Power required by the fan according to Rajput (2004), is given in[16] as

$$P = \Delta p Q \tag{11}$$

Where (Δp) is the pressure drop in air flow channel estimated to be $0.3817 N/m^2$

$P = 0.3817 \times 0.25 kW = 95.43 kW$

2.10 Power Required by Fan Motor

Power $= \dfrac{95.43}{\eta}$ *watts*

Assuming motor efficiency of 85%,

$$P = \frac{95.43}{0.85} = 112.3W$$

2.11 The materials needed for the fabrication and assembly of the solid waste sorting machine

The materials needed for the fabrication and assembly of the solid waste sorting machine are as follows.

- Gravity fed hopper through which the waste stream is fed onto the slow moving conveyor.
- Slow moving conveyor system.
- Stationary magnetic rotating drum which picks up ferrous metallic waste from the waste stream as the conveyor moves.
- Fast moving conveyor system which receives the remaining waste from the slow moving
- Conveyor after the removal of the metallic fraction.
- Air channel through which air that is enough to separate the light fraction from the waste is supplied.
- A fan with the required power (wattage) to overcome the pressure drop along the air channel.
- Settling chamber that receives the light waste fraction.
- Container that receives the remaining heavy waste fraction.

Based on the design theory and calculations, the solid waste sorting machine was fabricated. The pictorial view, exploded view and orthographic drawings of the solid waste sorting machine are shown Plate II, figures 2 and 3 respectively.

Plate II. Fabricated solid waste sorting machine

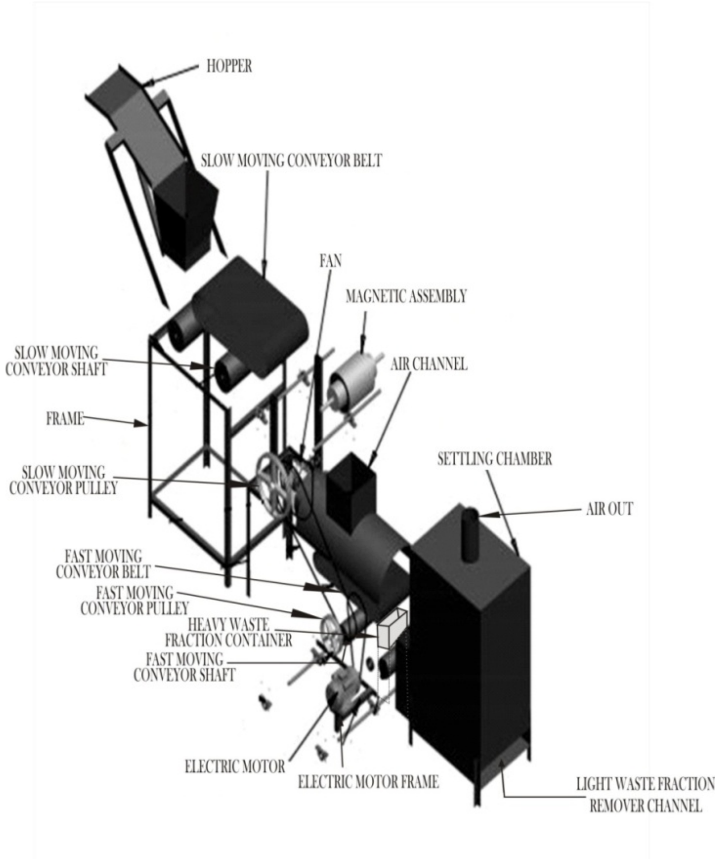

Figure 2. An exploded view of the fabricated solid waste sorting machine

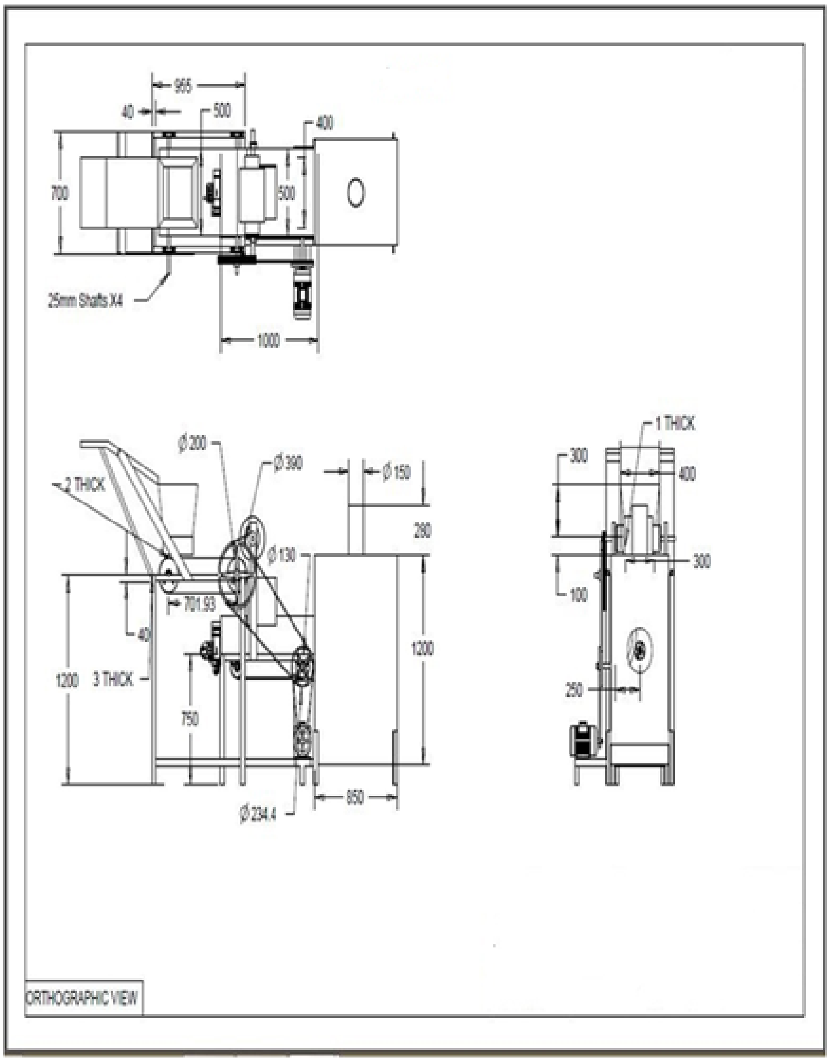

Figure 3. The orthographic drawings of the solid waste sorting machine

2.12 Performance Evaluation

Samples of 2, 3, 4, and 6 kg of dried municipal solid waste obtained from waste dump were used to test the performance of the machine. Tests on each sample weight were replicated three times. These were respectively and gradually fed into the machine for sorting and the time taken for the sorting was measured with a stop watch. At the end of each operation, the average masses of the sorted wastes were recorded. The ratios of the light fraction of wastes in the waste stream were evaluated. When ferrous metallic materials were not found in the solid waste, 3Kg of ferrous metallic materials was introduced into the waste dump. This was done in order to determine the machine's capability of sorting metallic materials. So samples of 3, 4, 5 and 6kg of the dried municipal solid waste containing the added ferrous metallic materials were obtained from the waste dump and also used to test the performance of the machine, using the same procedure.

3. RESULTS AND DISCUSSION

The results of the tests carried out on the solid waste sorting machine are shown in Tables 1 and 2 respectively.

Table 1: Results obtained from the solid waste sorting machine test

Test S/N	**Total mass of solid waste(kg)**	**Light fractions of solid waste(kg)**	**Ferrous metallic fractions of the solid waste(kg)**	**Heavy fractions of the solid waste(kg)**	**Time taken to sort(Seconds)**
1	2	0.90	0	1.10	109.8
2	3	1.30	0	1.70	165.0
3	4	1.65	0	2.35	219.6
4	6	2.45	0	3.55	330.0

Table 2: Results obtained from the solid waste sorting machine test with the introduction of metallic materials in the waste

Test S/N	Total mass of solid waste(kg)	Light fractions of solid waste(kg)	Ferrous metallic fractions of the solid waste(kg)	Heavy fractions of the solid waste(kg)	Time taken to sort(Seconds)
1	3	1.65	0.25	1.10	168.00
2	4	1.85	0.45	1.70	223.50
3	5	2.08	0.95	1.97	287.50
4	6	2.15	1.15	2.70	341.20

3.1 Discussion

It can be seen from Table 1, that as the sampled weight of dried waste increases, the weights of light fractions and heavy fractions of the solid wastes sorted also increase. It is evident in Table 1, that the solid waste sorting machine was able to sort 2, 3, 4, 6kg of municipal solid waste into light fractions of 0.90, 1.30, 1.65, 2.45kg and heavy fractions of 1.10, 1.70, 2.35, 3.55kg in 109.8, 165,219.6 and 330 seconds respectively from Table1, it is also observed that there is no record of ferrous waste metals sorted neither by the magnetic drum nor among the heavy fraction. This shows that ferrous waste metals are being removed by scavengers at the dump sites which they sell to recycling companies. This machine performs faster than the small scale municipal waste sorter developed in [13], that could sort 1.20, 1.5 and 1.80kg of solid waste in 126, 138 and 135 seconds respectively. Table 2 revealed that as the sampled weight of dried waste increases, the weights of light fractions, ferrous metallic fractions and heavy fractions of the solid wastes sorted also increase. The solid waste sorting machine was also able to sort 3, 4, 5, 6kg of municipal waste into light fractions of 1.65, 1.85, 2.08, 2.15kg, ferrous metallic fractions of 0.25, 0.45, 0.95, 1.15kg and heavy fractions of 1.10, 1.70, 1.97, 2.70kg in 168, 223.5, 287.5, 341.20 seconds respectively, as seen in Table 2.

The cost of materials and fabrication of the machine was one hundred and fifty-four thousand, nine hundred and eighty naira (₦154,980.00) only. This is higher than the cost of small scale waste sorter that was designed and fabricated in [17], which is about eighty thousand naira (₦80,000). The reason can be adduced to the bigger in size and differences in components used as well as rising cost of materials in the country, Nigeria. However, market survey revealed that it is cheaper than the imported ones which is about six hundred and ninty five US dollars(695USD) that is about Two hundred and fifty thousand naira (₦250,000) that can be used on the same scale.

4. CONCLUSION

Management of solid waste has become one of the issues of great concern in most developing countries like Nigeria. The need for concerted efforts to manage these solid wastes cannot be overemphasised. So solid waste sorting machine capable of sorting dried municipal solid waste into light, heavy and ferrous metallic fractions was designed and fabricated. This was done with a view to managing solid waste by recycling and reusing. Based on the result of the performance evaluation, it can be concluded that the waste sorting machine is capable of separating different constituent materials from waste stream thereby minimizing the waste that goes to landfill for final disposal. The sorting machine can be used anywhere for sorting of solid wastes. The uniqueness of the developed solid waste sorting machine is that it consists of two conveyor systems which enhance effective sorting. However, for further improvement on the machine, the distance between the magnetic drum and the belt should be made closer by considering smaller lump size for the design so as to be able to remove any particle size of ferrous metallic materials from the stream of solid waste.

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