# Designed, Manufactured, and Evaluation of a Solid Waste Sorting Prototype for a Selected Academic Institution in Ghana: A Case study.

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Abstract: Solid waste management is a term used for the process of collecting and treating solid waste. Solid waste management has become one of the main issues all over the country with the location of landfills becoming increasingly difficult. This project seeks to design, fabricate and test waste sorting machines into organic and inorganic components for reuse in bioenergy technology and it also aims at developing a workable cost-effective solid waste sorting prototype for waste-to energy generation for a selected academic institution in Ghana. The result in test 1 indicated that the ratios of the light fraction of wastes in the waste stream were evaluated and the results were 0.91 with a time of 1.83 min, 1.30 with a corresponding time of 2.72 min and 1.65 kg with a time of 3.66 min respectively. This shows that the ratio of the light fraction of waste increases as time increases. Again when ferrous metallic materials were not found in the solid waste, 3kg of ferrous metallic materials was introduced into the waste dump. In addition, the result in test 2 indicated that the ratios of the light fraction of wastes in the waste stream were evaluated and the results were 1.65 kg with a time of 2.8 min, 1.85 kg with a time of 3.73 min and 2.08 kg with a time of 4.8 min respectively. The results indicated that the total mass of the solid waste increases with respect to time. The metallic fraction of solid waste of the test for two (2) results indicated 0.25 kg, 0.45 kg and 0.95 kg as the time increases.

Keywords: solid waste management, organic component, landfills, ferrous metallic and waste sorting machine

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## 1. Introduction

Wastes are frequently thought of as societally produced materials that are unfit for further beneficial use and are intended to be abandoned, burned, recycled in specific ways, or deemed to be fundamentally waste-like [1, 2]. Due to the extremely diverse nature of the waste material in terms of composition and physical features, covering a wide range of bulk densities and moisture levels, resulting in a large range of heating values, some solid wastes are more challenging to burn [3, 4]. One of the biggest problems in organizations and communities around the world today is waste management. What a Waste: A Global Review of Solid Waste Management, a 2012 World Bank report on the situation of solid waste [5, 6]. According to the report, urban dwellers would produce much more rubbish between now and 2025 [7, 8]. According to the estimate, by 2025, there will be 2.2 billion tons of municipal solid waste (MSW), up from the current level of 1.3 billion tons annually. The majority of this growth would be caused by the fast expanding cities in emerging nations. 4.8 million metric tons of solid garbage are produced annually in Ghana, which has a population of roughly 29 million [9]. During a presentation at the UN conference on creating partnerships for achieving zero waste, Zoom-lion Ghana Limited made this very evident [10, 11]. The talk additionally emphasized how garbage in Ghana is becoming more complex and abundant [12]. The need for society to manage this trash more skillfully must be addressed [13]. However, a lot of Western towns and institutions have also struggled with this issue in the past (and some undoubtedly still do). Solid waste collection, treatment, and disposal are particularly difficult in cities in underdeveloped countries [14, 15]. Recent studies show that the trash industry is responsible for around one-fifth of all anthropogenic methane emissions, and that methane's contribution to climate change is about equal to that of carbon dioxide [16]. Emissions from the waste sector have been rising consistently worldwide and are predicted to continue rising in the next decades, particularly in emerging nations like Ghana. This led the Clean Development Mechanism (CDM) to include waste management as one of the sectors for greenhouse gas reduction [17]. Due to this, one important technique used in industrialized nations to effectively recover waste resources and encourage access to resources from which value may be added is waste separation [18]. When waste materials are taken out of the waste stream, the need for virgin resources is also decreased [19, 20]. Studies highlight the crucial responsibilities that colleges can play in supporting socially responsible programs [21, 22. One of the many environmental issues that must be addressed is the issue relating to the growing amounts of solid waste in our institutions and urban areas, which must be managed effectively and sustainably. Academic institutions have the capacity to put into practice sustainable development strategies that could be incorporated into their academic programs [23, 24]. Large institutions by their very nature produce greater waste since they have a single decision-making entity and a huge population. The idea of recycling as a waste management alternative to landfill disposal appears to be supported by more states as well as academic institutions, particularly in the developed world. Some local policies are even being implemented to provide recycling services to households [25, 26]. Recycling then becomes a financially sound substitute for trash disposal [27]. But to address the current and ongoing issue of waste management at our institutions, a comprehensive plan is needed [28]. In comparison to manual waste sorting, mechanically controlled machines move through waste sorting far more quickly and recover more materials per unit of time [29]. These machines sort the garbage using a variety of processes in a planned or specified order. They are connected by conveyors and make use of the physical and chemical characteristics of the waste to separate the solid waste into its many components.

This research focuses on the design, construction, and testing of a solid waste sorting prototype that can be used to separate waste into the various (organic and inorganic) components that can be used in bioenergy technology. It also aims to develop a practical, cost-effective solid waste sorting prototype for waste-to-energy generation on the campus of the University of Ghana.

# 2. Materials and Methodology

## 2.1 Design considerations and testing

The objective of the design, analysis and evaluation were considered based on; the sizing of the hopper, the design for the blower, the conveyor belt design for the machine, the design for the v-belt, the design for the bearings, the power requirements for the motor, the shaft design for the machine, the design for the pulley.

## 2.2 Assumptions for Design

The design analysis of the shaft was based on the following assumptions;

- ✓ The amount of solid waste to be carried is 3-5 kg after every cycle
- ✓ The thermo-physical property of the solid waste is negligible
- ✓ Frictional losses in the shaft mechanism are negligible

## 2.3 Flow mechanism of solid waste sorting machine

The solid waste sorting machine consists of a hopper, a conveyor belt, an air blower, a v-belt, a magnetic pulley and a roller conveyor. A motor is used to run the entire machine. The rotational motion of the motor shaft is transmitted to the magnetic roller through the v-belt. This magnetic roller acts as the driver for the machine. Due to the rotation of this magnetic roller, the conveyor belt also rotates and at the same time the steel drum also rotates, but the roller conveyor is driven by the force of waste on it, this obeys Newton's first law of motion. An air blower and an air channel positioned on the conveyor belt separate the lighter waste materials like plastic, polythene, etc. from the waste matrix and are collected in collector bin-1 after the mixed waste matrix has been passed through the hopper. The magnetic pulley is approached at the end of the conveyor belt with the remaining waste matrix. The ferrous material is separated from the trash matrix by magnetic attraction and is collected in bin 2. The remaining trash matrixes are then automatically transported through a roller conveyor to be separated by size. Bottles, paper, wood, and other items of comparatively smaller sizes are filtered via the spaces between the rollers and collected in bin 3, and the final collection of larger-sized wastes takes place in bin 4.

## 2.4 Design of Machine Elements

The design of the individual machine elements has been discussed in detail below.

### 2.4.1. Design of hopper

Hopper is a funnel-shaped structure which is used in the feeding of the waste matrix the material is made lightweight and corrosion-resistant, and the galvanized plate is selected as the material for the hopper as shown in Figure 1.

L1 = top length of hopper = 350 mm
B1 = top breadth of hopper = 350 mm
L2 = bottom length of hopper = 200 mm
B2 = bottom breadth of hopper = 200 mm
Height of hopper = 360mm

The volume of the inlet, $V_b = L_1 \times B_1 \times H$

$= 0.35 \times 0.35 \times 0.36 = 0.044$ m$^3$

The volume of outlet, $V_{sm} = L_2 \times B_2 \times H$

$= 0.20 \times 0.20 \times 0.36 = 0.0144$m$^3$

The volume of the hopper, $V_n = V_b - V_{sm}$

$= 0.044 - 0.0144 = 0.0296$ m$^3$

Discharge of hopper, $M = \rho A\sqrt{\frac{Bg}{1+m}}\ tan\theta$

Where;
M = mass flow rate (kg/s)
$\rho$ = bulk density = 30 kg/m$^3$
G = acceleration due to gravity = 9.81 m/s$^2$
B = outlet size (m)
= 0.20m, but m = 0
For pyramidal type hopper
$\theta$ = mass flow hopper angle (vertically) = 760
A = cross-sectional area of the hopper

Thus, discharge of the hopper, $M = 30 \times (0.20 \times 0.20)\sqrt{\frac{0.20\times 9.981}{1+0}}\ tan76 = 3.366\ kg/s$

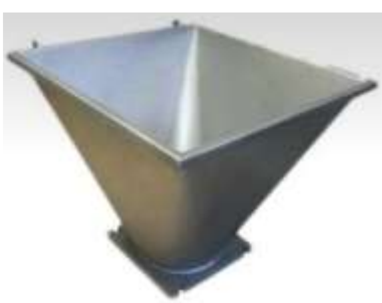

**Fig. 1** The hopper

**2.4.2. Design of Shaft and Conveyor Pulleys**

**Shaft design**

A shaft is a rotating machine element which is used to transmit power from one shaft to another. The power is delivered to the shaft by some tangential force and the resultant torque (or twisting moments) was set up within the shaft and permits the power to be transferred to various machines linked up to the shaft. To transfer the power from one shaft to the various members such as pulleys, gear, sprockets etc., are mounted on it.

**Design of pulleys**

The diameter of the conveyor magnet pulley drum is chosen to be D = 71mm

The translation speed of the conveyor belt is $N = \frac{60V}{\pi D} = \frac{60\times 0.6}{3.142\times 0.071} = 161.397rpm$

The full-thickness longitudinal tensile strength is selected to have a value of 140KN/m for a belt of 350mm width, and then the tensile (peripheral) force, F in the belt is

$F = 140\ x\ 0.35 = 49KN$

For the material subjected to uncertain stresses and load, the factor of safety must have a value from 9 to 12. So considering the factor of safety to have a value of 10

Thus, allowable tensile force falls on the conveying belt.

$$Fall = \frac{F}{F_f} = \frac{49}{10} = 4.9N$$

Torque (T) produce by this force around the pulley of diameter 71mm is

$$T = Fall \times distance$$

$$4.9 \times \frac{0.071}{2} = 0.174\ KN - m$$

The power to be delivered to the conveyor belt through the pulley is

$$P = Fall\ x\ V$$

$$= 4.9 \times 0.6$$

$$= 2.94\ kW$$

The diameter of the shaft to drive the conveyor belt is established as

$$d = \sqrt[3]{\frac{16 \times T \times N}{\pi \times \tau}}$$

Where T, is the torque produced around the pulley = $0.174\ KN - m$

N is the factor of safety which has a value range from 1.25 to 2 and considering the value to be 1.5

$\tau$, is the maximum allowable shear stress taken to have a value of 55 MN/m2 for commercial steel shafting

Thus $d = \sqrt[3]{\frac{16\times0.174\times10^3\times1.5}{3.142\times55\times10^6}} = 0.0289 = 28.9\ mm$

Selecting the standard value of diameter, d = 30 mm

**Fig. 2** magnetic drum

Let $T_1$ = carrying side belt tension,
T2 = return side belt tension
But $T_1 = T_E\ \left[\frac{\varepsilon}{\mu\pi-1} + 1\right]$
Where, $\varepsilon$ = drive coefficient = 1.66
Since the diameter of both the pulley drive is the same.
Thus, $\theta$ = angle of wrap = $180° = 18 \times \frac{\pi}{180} = 3.1415\ rad$
u = coefficient of friction between the drive pulley and belt = 0.35

Hence $T_1 = 20\ \left[\frac{166}{0.35\times3.142-1} + 1\right] = 36.5772\ kW$

$T2\ = T1 - TE$
$=\ 36.5772 - 20\ =\ 16.577\ kW$

**2.4.4. Selection of motor:**
The helical worm gear motor type is selected considering the availability of the product in the market.
Power = 3.5 kW
Output Speed (N) = 300 rpm, (5:1 of 1500rpm)
Diameter of the motor shaft, dm = 20 mm

**Fig. 3** Helical worm gear motor

**2.5 Fabrication of Waste Sorting Machine**
The fabrication of the waste sorting machine began with the cutting of two inches of pipe and machining the internal diameter to a bearing size which the bearings are fixed and the rollers were made. The centre lathe machine was used in machining the pipes the required dimensions were set and the machining was carefully controlled to avoid manufacturing errors. Figure 4.9 shows the rollers being machined cutting of machine members at the mechanical engineering laboratory. After machining the rollers and other components like the magnetic drum and pulleys, the fabrication continued with the hopper, guide and stand on which the whole setup would be mounted. This involved the cutting of metal sheets, angle iron and flat bars into the required shape and then permanently joining them together by welding. The rollers were then placed into positions with the aid of bolts and nuts to the stand. This made it possible to mount the bearings needed to hold the magnetic drum and the supporting drum into a position in which the belt was also mounted and tensioned screw is also welded and the supporting drum was firmly on the stand, the fan/blower is then mounted and well positioned on the belt then the hopper was mounted to the setup via a permanent weld. The whole setup was brought together after the hopper was constructed to be positioned on the belt; the prime mover was mounted beneath the belt. A switch was added to control the prime mover and the fan/blower and the machine was finally assembled.

## 3. Testing and Result

The machine was tested with the aid of a stopwatch and a scale. The stopwatch was used in measuring the time in seconds it took the machine to complete the sorting cycle from the activation of the motor to the complete exit of the solid waste. Figure 4 shows the results of the solid waste test. Samples of 2, 3, and 4 kg of dried municipal solid waste obtained from the waste dump were used to test the performance of the machine. Tests on each sample weight were repeated three times (tests 1,2 and 3). These were respectively gradually fed into the machine for sorting and the time taken for the sorting was measured with a stopwatch in a minute. At the end of each operation, the average masses of the sorted wastes were recorded as 2, 3 and 4 kg. The ratios of the light fraction of wastes in the waste stream were evaluated and the results were 0.91 with a time of 1.83 min, 1.30 with a corresponding time of 2.72 min and 1.65 kg with a time of 3.66 min respectively. This shows that the ratio of the light fraction of waste increases as time increases. Again when ferrous metallic materials were not found in the solid waste, 3kg of ferrous metallic materials was introduced into the waste dump. This was also done to determine the machine's capability of sorting metallic (both ferrous and nonferrous metals), plastics and paper materials. Again, since plastic won't decay, this substance might be recycled for further use. In essence, the waste sorting machine separates the plastic from other elements like paper and metal. The metallic fraction of solid waste of test one (1) results indicated 0 (zero) kg throughout as shown in Figure 4.

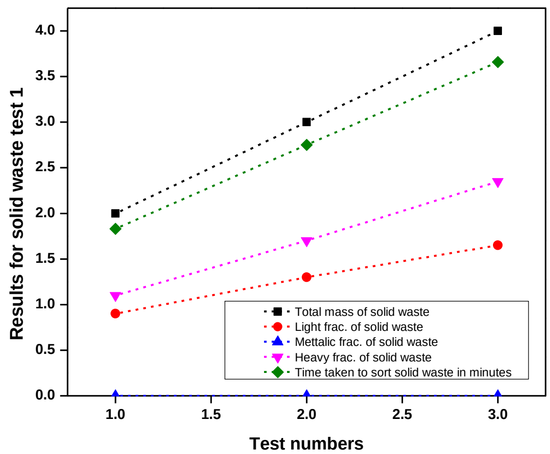


**Fig. 4** Results for solid waste test 1

Figure 5 shows the results of solid waste test 2. Samples were 3, 4, and 5 kg of the dried municipal solid waste containing the added ferrous metallic materials obtained from the waste dump and also used to test the performance of the machine, using the same procedure. The ratios of the light fraction of wastes in the waste stream were evaluated and the results were 1.65 kg with a time of 2.8 min, 1.85 kg with a time of 3.73 min and 2.08 kg with a time of 4.8 min respectively. The results indicated that the total mass of the solid waste increases with respect to time. The metallic fraction of solid waste of the test for two (2) results indicated 0.25 kg, 0.45 kg and 0.95 kg as the time increases as shown in Figure 5.

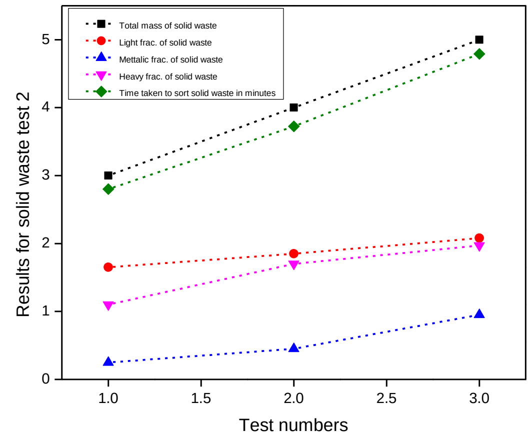


**Fig. 5** Results for solid waste test 2

## 4. Conclusion

The management of solid waste has become one of the issues of great concern in most developing countries like Ghana. The need for concerted efforts to manage these solid wastes cannot be over-emphasized. This study was based on the design of an institutional solid waste sorting device that can lessen human effort in waste sorting and separate waste disposal into various components that can be used for producing electricity, recycling, or other beneficial uses. The system was assembled and tested. The result in test one indicated that the ratios of the light fraction of wastes in the waste stream were evaluated and the results were 0.91 with a time of 1.83 min, 1.30 with a corresponding time of 2.72 min and 1.65 kg with a time of 3.66 min respectively. This shows that the ratio of the light fraction of waste increases as time increases. Again when ferrous metallic materials were not found in the solid waste, 3kg of ferrous metallic materials was introduced into the waste dump. In addition, the result in test 2 indicated that the ratios of the light fraction of wastes in the waste stream were evaluated and the results were 1.65 kg with a time of 2.8 min, 1.85 kg with a time of 3.73 min and 2.08 kg with a time of 4.8 min respectively. The results indicated that as time increases, the masses of the solid waste also increased. The metallic fraction of solid waste of the test for two (2) results indicated 0.25 kg, 0.45 kg and 0.95 kg as the time increases.

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