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Development of Small Scale Municipal Waste Sorter

F.R. Falayi, B.O. Adetuyi and A. Adesina
Department of Agricultural Engineering, The Federal University of Technology,
Akure, Ondo State, Nigeria

Abstract: The ever increasing generation of municipal wastes and the need for sorting to different categories for efficient recycling can not be over emphasized. The improvement of the environmental quality and enhancing proper waste disposal in a developing country like Nigeria, a prototype municipal waste sorting machine was designed and constructed with locally available and affordable materials. The total cost of the machine was estimated to be about N 80,000 or $615 which is considered affordable. The testing and performance evaluation of the machine was carried out. The machine was able to sort municipal wastes including nylon, ferrous and non ferrous metal, glass and paper. The performance efficiency of the machine was estimated to be 77.3%. The efficiency of the machine varied with fan speed and the highest functional efficiency was recorded at a speed of 1200 rpm. It was concluded that the machine is an efficient sorter of municipal wastes and recommended for sorting municipal waste to enhance recycling in developing countries.

Key words: Waste, sorter, efficiency, recycling, magnetic, rollers

INTRODUCTION

The term solid wastes are all-inclusive and encompass all sources which may be residential, commercial, industrial, agricultural and open areas. Wastes that are discharged may be of significant value in another setting, but they are of little or no value to the possessor who wants to dispose them. The term municipal normally is assumed to include both the residential and commercial solid wastes generated in the community. Sorting, collection and transportation of waste for recycling or treatment are essential steps in waste management. Municipal solid waste can be sorted at source by waste fractions at on-site and regional collection points, which usually consist of 200 or 600 L plastic bins. In large agglomerations, organic waste is collected in a separate bin and miscellaneous municipal waste in one single bin if not further sorted into energy and landfill fractions.

The very basic idea and technology needed to sort municipal waste has been in existence for long. Improvement on it has been the focus of study of many researchers to produce perfect sorting of municipal waste. In recovery of municipal waste, as an example, separation operations have been devised to recover valuable resources from the mixed solid waste delivered to transfer stations or solid waste processing plants. The operations include size reduction and density separation by air classifiers. Further separation may include magnetic devices to pull out iron, eddy-current separators for aluminium and screens for glass. Flotation, inertial separation and other metallurgical industry unit operation may also be used. The selection of any recovery process is a function of economics-cost of separation versus value of the recovered material products.

Justification of study: One of the major problems of urbanization is rapid generation of wastes and majority of the components of the waste are non biodegradable. He composition of this waste are mainly bulky African food remains, nylon or polythene bags, papers, plastics, leather materials and metals. These various waste materials can be converted to useful purpose if adequate sorting can be carried out. The effect of indiscriminate dumping of waste is numerous. Indiscriminate dumping of wastes in public places is a common sight in Nigeria cities which is posing serious health hazard.

Improper management of waste constitutes eyesores as well as leads to the release of nasty smell, which pollutes the oxygen, we breathe. The filthy nature of waste dumps affects the aesthetic beauty of a city and adds a negative feature to a city and adds a negative feature to the overall landscape (Oluka, 2001). The composition of waste generated will dictate the method of

Corresponding Author: F.R. Falayi, Department of Agricultural Engineering, The Federal University of Technology, Akure, Ondo State, Nigeria

disposal hence waste items need to be properly sorted to enhance proper disposal. A properly sorted waste will go along way to reduce the cost of recycling.

MATERIALS AND METHODS

Design considerations: The following design considerations were made when designing the waste sorting machine.

- The equipment should be affordable.
- The equipment should be made with readily available material.
- It should replace manual method of sorting waste.
- The equipment should be able to sort to three categories of solid wastes.
- The component parts must be easily replaceable in case of any damage or failure.
- The operation of the machine must not be difficult to understand.

Design of machine elements: All equations used for the design of machine elements were from PSG Design Data (1983).

Design of V-Belt
Belt selection and power requirement:

- The selected type of belt is A
- The maximum sped of belt was calculated using the equation:

$$= \frac{\pi d\, n}{60} \quad (1)$$

Where:
d = Pulley diameter.
n = Electric motor speed.

Equivalent Pitch diameter, de = Pitch diameter of the Smaller pulley X the smaller diameter factor:

$$(dp \times Fb) \quad (2)$$

The maximum power, of the V-belt (P), (A-type) was calculated using:

$$P = \left(0.455^{-0.09} - \frac{19.62}{d_e} - 0.765 \times 10^{-4}\, S^2\right) S \quad (3)$$

Where:
S = Belt speed.
d_e = Equivalent pitch diameter.

Selection of drive pulley speed: The driven pulley diameter was determined using the equation:

$$n_1\, d_1 = n_2\, d_2 \quad (4)$$

Where:
n_1 = Electric motor speed.
d_1 = Electric motor pulley diameter.
n_2 = Speed of driven pulley.
d_2 = Diameter of driven pulley.

Determination of centre distance of the pulleys and nominal length of belt: The centre distance of the pulleys was calculated using the equation:

$$C = C/D \times D \quad (5)$$

Where:
C = Centre distance.
C/D = Ratio of center distance to diameter of larger pulley.
D = Diameter of larger pulley.

Centre distance minimum, C_{min} was calculated using:

$$C_{min} = 0.55\,(D + d) + T \quad (6)$$

and Centre distance maximum:

$$C_{max} = 2\,(D + d) \quad (7)$$

Where:
T = Nominal belt thickness,
D = Larger pulley diameter,
d = Smaller pulley diameter

Nominal pitch length of belt was calculated using the equation:

$$L = 2C + \frac{\pi}{2}(D + d) + \left(\frac{D - d}{4C}\right)^2 \quad (8)$$

The closest nominal pitch length to the calculated value of L, from the table is 823mm.

Actual value of center distance is given by the formula:

$$C = A\sqrt{A^2 - B} \quad (9)$$

Where:

$$A = \frac{L}{4} - \pi\left(\frac{D + d}{8}\right) \quad (10)$$

$$B = \left(\frac{D - d}{8}\right)^2 \quad (11)$$

Arc of contact was determined using:

$$2 \cos^{-1} \frac{D - d}{2C} \quad (12)$$

Determination of the number of belts, N: The number of belts to be used was determined using the equation:

$$N = \frac{P \times F_a}{KW \times F_c \times Fd} \quad (13)$$

Where:
P = Drive power, KW.
Fa = Correction factor according to service.
KW = Rating of the V-belt.
F_c = Correction factor for length.
F_d = Correction factor for arc of contact.

Determination of centrifugal force: The centrifugal force, T_c in V-belt was got from the equation:

$$T_c = Mv^2 \quad (14)$$

Where:
M = Belt mass per unit length.
V = Belt velocity.
T_c = 0.0941×12.82^2.
T_c = 15.46N.

$$\frac{T_1 - T_c}{T_2 - T_c} = R$$
$$T_1 - T_2 = P/V \quad (15)$$

Where:
T2 = Tension of belt in slack slide.
T_1 = Tension of belt in tight side.
T_c = Centrifugal force.
R = Exp (μ α cosec θ/2).

Determination of power required driving the shaft: Power required to drive shaft was calculated using:

$$P = \frac{2\pi nT}{60} \quad (16)$$

Where:
T = Torque.
n = Revolution per minute of shaft.

The centrifugal force, F_c in V-belt is 15.46N as calculated in equation:

$$\frac{T_3 - T_c}{T_4 - T_c} = R \quad (17)$$

$$T_3 - T_4 = P/v \quad (18)$$

Where:
T_3 = Kension of belt in tight side.
T_4 = Kension of belt in slack side.
V = Kpeed of belt.
T_c = Kentrifugal force.
P = Kower transmitted.
R = Exp (N α coscc θ/2).

Design of shaft : The shaft diameter was obtained fom the equation:

$$d^3 = \frac{16}{\pi S_s}\sqrt{(K_B\ M_B)^2 + (K_T\ M_T)^2} \quad (19)$$

Where:
d = Diameter of shaft.
S_s = Allowable shear stress.
K_B = Fatigue factor applied to bending moment.
K_T = Fatigue factor applied to torsional moment.
M_B = Maximum bending moment.
M_T = Maximum torsional moment.

Design of centrifugal fan: The centrifugal fan was designed from the following known data,

- The depth of air stream, D = 10cm
- The width over which air (W) is required is = 35cm
- Dallavale (1978) recommended an air velocity of 25.50m s^{-1} for lead dust,
- The selected fan speed, n = 3,264 rpm
- Actual air flow rate Q_n = VDW
- The theoretical air flow rate, (20)

$$Q_t = \pi d_1 b_1 v_1 = \pi d_2 b_2 v_2 \quad (21)$$

Where, b_1 and b_2 are the width of blades at diameter d_1 and d_2 of the impeller and v_1 and v_2 are tangential components of absolute velocities, V_2 can be approximated as 20% of peripheral velocity of the impeller tip (Joshi, 1981).

Power input to the fan shaft was determined using the equation

$$P = \frac{Q_t P_t}{\text{Efficiency}} \quad (22)$$

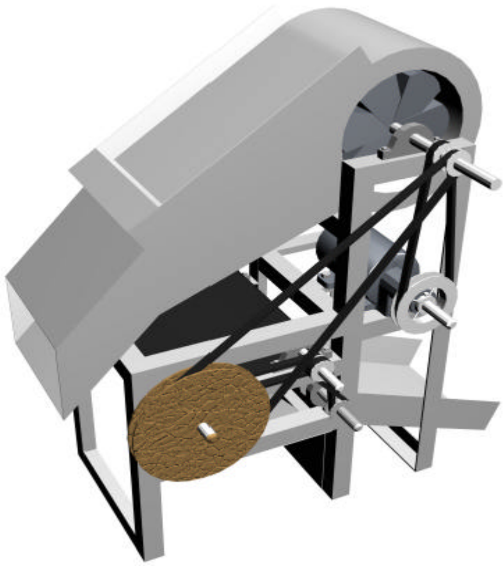

Fig. 1: The waste sorter

According to PSG Design Data (1983), Mechanical efficiency of fan is 40-80%.

Design of horizontal conveyor: The horizontal conveyor was designed using the following previously calculated values

- Density of material conveyed 2700-7992kgm^{-3} Conveyor length C, 40cm (centre to centre distance of the belt).
- Inclination of belt conveyor O°.
- Coefficient of friction between belt and pulley, F = 0.02
- Width of belt = 35cm
- Point driven = head driven

Determination of magnetic field strength of magnetic roller: Te magnetic Flux density (B) was calculated using the equation:

$$= \frac{\theta}{A}$$

wb m^{-2} or Tesla (T),

Where,

θ = Flux per unit pole,

A = Cross sectional area,

For a unit flux of 1Wb radiated out by a unit pole falls normally on a surface of $4\pi r^2$ (m^2), hence, Flux Density:

$$B = \frac{1}{4\pi r^2} \quad (24)$$

Where:

r = radius of the magnetic roller:

$$\text{Absolute permeability } \mu = B/H \text{ in Henry/meter} \quad (25)$$

H = Magnetic field strength, ampere/meter,

Also:

$$\text{Absolute permeability, } \mu = \mu_o \mu_r \quad (26)$$

Where:

μ_o = Ermeability of free space = $4\pi \times 10^{-7}$ H m^{-1} according to Bolton (1980).

μ_r = Relative permeability of material. It is dimensionless.

For ferro-magnetic substance like iron nickel, cobalt and alloys such as nickel-iron Nr is for greater than then unity. According to Bolton (1990) μ_r for nickel iron is 100,000.

Therefore, from Eq. 25 and 26

$$\mu_o \mu_r = B/H$$

$$H = B/\mu_o \mu_r$$

Magnetic field strength, H = 4.502×10^{-4} amp m^{-1}.

Machine description: The municipal waste sorter is as shown in Fig 1. It consists of a hopper though which the waste will be deposited. The waste materials move by gravity and pass though the blower which blows off lighter waste materials like papers and nylon into a collecting tray outlet. Ferrous and non ferrous metals in the waste are collected on the rolling belt conveyor and pass through a magnetic roller. The ferrous metals are attracted to the magnetic roller while the non ferrous metals are thrown and collected in an outlet. The ferrous metals are scraped from the rollers with a wooden scraper into another outlet.

Performance test evaluation: A performance evaluation of the machine was carried out to determine the efficiency of separation to three categories of waste. The tests were performed at different fan's speeds and at constant speed of magnetic roller (1440 rpm).

To determine the performance of the machine with respect to aforementioned parameters, the following records were taken from the sorting trials:

Weight of magnetic material (ferrous metal), W_1
Weight of non magnetic material (non ferrous metal and broken glass), W_2
Weight of nylon and paper material, W
Weight of the whole material fed into the collecting tray ($W_1 + W_2 + W$), F
Weight of material collected via the air duct, U
Weight of material not blown off by the air stream in the air duct (i.e. weight of material conveyed to the magnetic roller), F_1
Weight of material collected at chute 1 (i.e. chute for magnetic material) U_1
Weight of nylon and paper material collected via air duct after feeding U_n
Weight of magnetic material collected at chute 1 after feeding U_m
Weight of material collected at chute 2 (chute for non-magnetic) U_2
Weight fraction of nylon material recovered at the air duct W_u
Weight fraction of magnetic material recovered at chute 1 W_u
Weight fraction of nylon material in the feed W_f
Weight fraction of magnetic material not blown off by air stream, but conveyed to the magnetic roller W_{f1}

RESULTS AND DISCUSSION

According to Foust (1960) efficiency of separation can be evaluated in terms of percentage recovery.
Recovery (%):

$$\frac{UW_u}{FW_f} \qquad (27)$$

Where:

U = Weight of material collected.
F = Weight of material fed.
W_u = Weight fraction of material desired in the product collected.
W_f = Weight fraction of material of desired size in the feed.

Rejection = 1 – recovery of undesired material

$$= 1 - \left[\frac{U(1 - W_u)}{F(1 - W_f)}\right] \qquad (28)$$

$$\text{Efficiency} = \text{recovery} \times \text{rejection} \qquad (29)$$

By applying the logic of probability distribution, as used by Derek (1984) the overall efficiency of the machine was evaluated as shown in Fig 2.

$$\text{Efficiency} = \text{P [Recovery 1]} \times \text{[P (Rejection 1} \times \text{Rejection 2)} \times \text{P (Rejection 1} \times \text{Recovery 2)]} \qquad (30)$$

Estimating the efficiency: The weight fraction of nylon material recovered through air duct was estimated from the equation:

$$W_u = \frac{U_n}{W}$$

The weight fraction of magnetic material recovered at chute 1 was calculated from the equation:

$$W_{u1} = \frac{U_m}{W_1}$$

The weight fraction of nylon material in the feed was calculated from:

$$W_f = \frac{W}{F}$$

The weight fraction of magnetic material conveyed to the magnetic roller was calculated from:

$$W_{f1} = \frac{W_1}{F_1}$$

The recovery at separation unit was estimated from:

$$\frac{UW_u}{FW_F}$$

The rejection at separation unit was calculated from:

$$1 - \left(\frac{U(1 - W_{u)}}{F(1 - W_f}\right)$$

From the experimental work, it was observed that at high speed of 3.264 rpm of fan, the efficiency was very low (8.4%), because some of the magnetic and non magnetic materials such as ferrous metal, non ferrous metal and glass were recovered via air duct, this led to low efficiency of separation of unit 2 because of low percentage of magnetic and non magnetic material that reached the separation unit 2 when compared to the percentage of magnetic and non magnetic material in the whole feed.

Furthermore, at 1440 rpm of fan's speed, the functional efficiency increased to 43.3%. Some of the

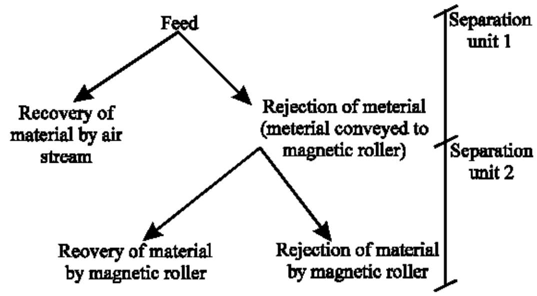

Fig. 2: Probability distribution of efficiency

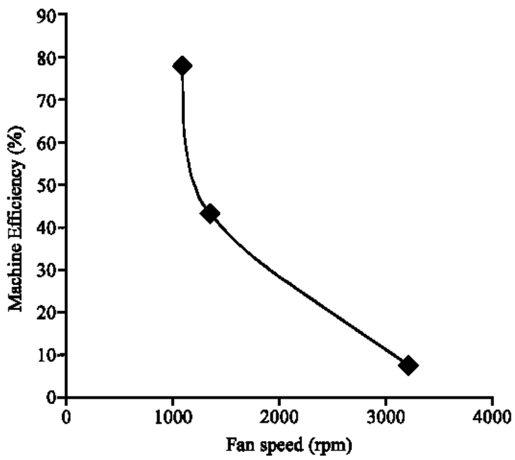

Fig. 3: Relationship between efficiency amd fan speed

magnetic and non magnetic materials were able to reach separation unit 2. At 1200 rpm of fan's speed, the efficiency increased to 77.3%. The relationship between the efficiency and fan's speed is shown in the Fig. 3.

CONCLUSION

The concept of developing small scale municipal waste sorter goes a long way to improving environmental quality and to enhancing proper waste disposal. The sorting machine was designed and constructed with great consideration for locally available and affordable materials in order to minimize cost and to meet up with the design considerations.

The machine efficiency of separation was highest at lowest machine speed of about 1000rpm and recommended for sorting municipal waste in developing countries of Africa.

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