Design and Development of Waste Sorting Machine

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Abstract
Nigeria is yet to develop a comprehensive scheme which is required to solve the current and persisting problem of waste management in the country. Whereas the crude methods of sorting wastes practiced may be efficient, it wastes useful time; hence the need for a mechanized sorting machine. An attempt has been made to develop a waste sorting machine, which is conceptualized to sort wastes into light materials, ferrous metals and other heavy materials. The machine is designed with the major components being the fan, the belt conveyor and the magnet. Tests carried out on the machine successfully classified wastes into light materials and heavy materials with inability to sort ferrous metals. Samples of wastes tested weighed 1.15kg and 3.53kg. The wastes consisted of an average of 32% of light materials and the time to sort the waste was 65 minutes per unit mass. This machine separates light materials such as paper, nylon, textile and heavy materials similar to nylon, ferrous and non ferrous metal, glass and paper sorted by the machine developed by Falayi et al. (2007) and the machine designed by Adzimah and Anthony (2009).

Keywords: waste management, materials, development, sorting, machine

INTRODUCTION
The combined solid and liquid waste from residential, commercial, and industrial sources are referred to as municipal wastes and are often perceived as materials generated in urban areas which are unsuitable for further beneficial use, and intended to be discarded, incinerated, recycled in certain ways or considered inherently waste-like (Pankratz, 2001; Cheremisinoff and Graffia, 1995). Solid wastes are more difficult to burn due to the highly variable nature of the waste material in terms of composition and physical characteristics, spanning a wide range of bulk densities and moisture contents, resulting in a wide range heating values (Lee and Lin, 2000). Waste management basically involves the collection, transport, processing, recycling or disposal of waste materials, and is also carried out to recover materials from the waste. Waste management methods vary widely between areas for many reasons, including type of waste material, nearby land uses, and the area available (Anderson et al., 2001).

Municipal Solid Waste Sorting is a method of waste management. In its crude form it is done by scavengers on refuse dumps and in its most advanced form by computer guided machines in a plant. It is a process in which the wastes are separated into their various constituents which are paper and cardboards, metals, textiles, vegetable matter, plastics/rubbers. These constituents can then be further processed to produce other finished goods such as refuse derived fuel, fertilizer or as a land filling agent (Anderson et al., 2001; Bamgboye and Ojolo, 2004). The sorting machine sorts waste by utilizing the physical and/or chemical properties of the waste. To effect the sorting of the wastes, processes like magnetic separation, air classification, density separation, etc, are used with different levels of sophistication introduced in their operation (Dubanowitz, 2000). Mechanical waste sorting is the process of using machines to sort wastes into their various components. These machines use various mechanisms in a prescribed or predetermined sequence, to sort the waste while being interconnected by conveyors. Modern material recovery facilities (MRFs) usually make use of electronics like colour sensors, seismic sensors, eddy current separators, and other means with the main purpose of improving the sorting efficiency (Anderson et al., 2001). With mechanical waste sorting greater quantities of waste derived fuel can be extracted from the waste stream. These high energy components of the waste stream can be incinerated to produce energy to power electricity generating plants. Also, the putrescible vegetable matter obtained from the sorting process can be used to generate biogas or syngas which can also be used to generate electricity in addition to natural gas as integration to an existing gas power plant (Last, 2010).

SINTEF (2007) reports that systems have been developed that can sort any combination of common domestic plastic waste and beverage cartons. The
largest machines can currently handle ten tons of waste per hour on a conveyor belt that is 2.8 meters wide, with a speed of 2.5 m/s. When the machines sort bottles, the selected plastic fraction is 97% pure and 95% of the desired packaging type is picked up from the conveyor. It is reported also that more than 800 sorting units have been delivered to recycling facilities in Europe, Japan, Korea, Australia and the United States. Falayi et al. (2007) have also developed a small scale municipal waste sorter which 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. Wahab et al. (2006) reviewed the state of-the-art technologies that have been deployed by some of the recycling facilities and proposed the design and development of a cost effective prototype automated system for sorting plastic recyclables.

A comprehensive scheme is required to solve the current and persisting problem of waste management in Nigeria. Not being properly treated or cared about, the wastes dumped on landfills in metropolises pose not only environmental threats, but also a high health risk. With the introduction of the mechanically operated machines, waste sorting proceeds at a much faster rate and more materials can be recovered per unit time than the manual waste sorting. This work aims at developing a municipal solid waste sorting machine that could be useful in solving the waste management crisis in Nigeria.

MATERIALS AND METHODS
The waste sorting machine consists of a hopper through which the waste is fed through; a fan and air channel through which the light weight materials are separated from the waste matrix; a belt conveyor which carries the left waste towards a magnet-fitted shaft/pulley which separates ferrous metals and also chambers into which the separated components of the wastes fall. The machine is shown in figure 1.

Design of the Belt Conveyor
The design of the belt conveyor is specifically for the flat idler type. The cross-sectional area of load on the belt, or load stream area, is estimated using

\[ A = 0.16B^2 \tan(\frac{\psi}{2}) \]  

(Singh, 2000)  

(1)

Where, \( B \) = the width of the belt which is selected to have a value of 200 mm.
\( C \) = a constant with a value between 0.85 and 1.00. A value of 1.00 is selected.
\( \psi \) = static angle of repose of load (Singh, 2000)

The municipal solid waste is considered to have the characteristic of refuse which include sluggishness regarding flowability, abrasive, and very light and fluffy – meaning it may be wind-swept. Hence, the static angle of repose is given as 40\(^\circ\) and upward. A value of 45\(^\circ\) is selected. Thus,

\[ \psi = 0.35 \times 45^\circ = 15.75^\circ \]

Therefore, the cross sectional area of load on the belt is

\[ A = 0.16 \times 0.2^2 \times 1 \times \tan(15.75) = 0.0018 \text{m}^2 \]

The capacity of the conveyor is estimated using

\[ Q = \frac{3600A\nu\gamma}{\rho g} \]  

(Singh, 2000)  

(2)

Where
\( \nu \) = conveying speed which should range from 0.5 to 0.8 m/s. A speed of 0.6m/s is selected;
\( \gamma \) = specific weight of the load in kN/m\(^3\) = \( \rho g \);
\( \rho \) = density in kg/m\(^3\);
\( g \) = acceleration due to gravity = 9.81 m/s\(^2\).

Refuse has an average density of about 160 to 320 kg/m\(^3\). Hristovski et al. (2007) also found that the densities of the uncompacted and compacted solid wastes are approximately 140.5kg/m\(^3\) and 223kg/m\(^3\) respectively. A value of 300 kg/m\(^3\) is, however, selected for the design. Therefore, the specific weight of the municipal waste is

\[ \gamma = 300 \times 9.81 = 2943 \text{N/m}^2 = 2.94 \text{KN/m}^3 \]

Hence, the capacity of the conveyor is

\[ Q = \frac{3600 \times 0.0018 \times 0.6 \times 2.94 = 11.43 \text{ kN/hr}}{\rho g} \]

The nominal volume capacity is estimated using (Singh, 2000):

\[ V = \frac{3600 \times \text{Load stream area} \times \text{Belt speed}}{\gamma} \]

(3)

Design for Conveyor Pulleys, and Shafts
For the belt width selected, the diameter of conveyor pulley drum, \( D \), has been selected to be 100mm and to have a face width of about 300mm such that an edge clearance of about 50mm is allowed. The driven shaft on which the conveyor pulley drum is mounted carries a magnet of about 3kg which has been made to act at the centre of rotation. The rotational speed of the pulley, hence the speed of the shaft, which brings about the selected translational speed of the conveyor belt, is evaluated as
\[ N = \frac{60 \times \omega}{\pi} = \frac{60 \times 0.6}{\pi 	imes 0.1} = 114.6 \text{ rpm} \]  
(4)

The full thickness longitudinal tensile strength is selected as 160 kN/m width (Singh, 2000). For a belt width of 200mm, the tensile force in the belt is

\[ F = 160 \times 0.2 = 32 \text{kN} \]

Taking factor of safety of 4 for the material subject to uncertain stresses and load, the allowable or working tension, \( F_{\text{at}} \), on the conveying belt is 8kN. The torque produced by this force around the pulley of diameter 100mm is

\[ T = 3 \times \frac{0.1}{2} = 0.4 \text{kNm} \]

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

\[ P = F_{\text{at}} v - 3 \times 0.6 - 4.6 \text{ kW} \]  
(5)

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

\[ d = \left( \frac{16 \pi n}{\tau} \right)^{1/2} \]  
(6)

Where \( \tau \) is the maximum allowable shear stress, taken as 55MN/m² for commercial steel shafting (Sharma and Aggarwal, 2010). Hence,

\[ d = \left( \frac{16 \times 400}{\pi \times 55 \times 10^5} \right)^{1/2} = 0.0333 \text{m} \]

The shaft diameter selected is thus 35mm for the driver and driven shafts.

**Design for Fan/Air Flow**

Air is forced through a cylindrical channel, 178mm diameter, by a fan to separate light weight materials from the waste. The force (or pressure) delivered by the stream of flow should be overcome the weight of the light weight material to ensure that the material is moved by the stream away from heavier materials. The average mass per unit area of light materials is assumed to be 400g/m² based on the maximum weight of paper (Micro Format, 2008; Packetizer, 2010). The weight of the material is thus

\[ W = (mA)g \]  
(7)

Where, \( m \) is the mass per unit area of the material, \( A \) is taken to be the cross sectional area of the channel and \( g \) is the acceleration due to gravity. Hence,

\[ W = 0.6 \times \pi \times (0.178)^2/4 \times 9.8 = 0.1N \]

The force of the air required to be delivered by the fan should thus be greater than 0.1N. Using the rate of momentum change, assuming an initial velocity of zero in the direction of flow,

\[ F = \frac{\Delta m}{\Delta t} = \rho A \Delta v \]  
(8)

Where, \( v \) is the required velocity of the air stream. To evaluate the minimum required velocity of air flow,

\[ v = \left[ \frac{F}{\rho A} \right]^{1/2} \]  
(Sharma and Aggarwal, 2010)  
(9)

Where \( \rho \) is the density of air assumed to be 1.225 kg/m³, \( F \) is assumed equal to the weight of the light weight material.

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**TESTS ON THE WASTE SORTING MACHINE**

The waste used to test the machine was a sample obtained from a waste dump on the premises of the University of Lagos. It composed of putrescible materials, leaves, paper, plastics, nylon, metals, and ceramics, building materials such as concrete, wood, cork, and other materials. Hence, it had the characteristics of a typical municipal mixed waste stream. Waste samples with masses of 1.15kg and 3.53 kg were used during the test. The masses of the materials that were sorted at each level were obtained and the ratios of those masses to the initial masses of the mixed waste were evaluated. The average of these ratios was then calculated to know the relative composition of two types of waste in the waste stream. This was done for three replicates.

**RESULTS AND DISCUSSIONS**

When the conveyor was operated, the fan was able to separate light materials from the waste stream. However, ferrous metals could not be separated from the rest of the stream. Hence, the waste stream was classified into light materials and heavy materials based on the sorting capability of the machine. The inability to separate ferrous metals may be due to the insufficient magnetic pull of the magnet or may be due to the speed of the conveyor belt. The results obtained from the tests on the machine are presented in Tables 1 and 2.
Table 1: Table of results obtained from testing of machine for mass of 1.15kg

<table>
<thead>
<tr>
<th>Test</th>
<th>Total mass</th>
<th>Mass of light materials</th>
<th>Mass of heavy materials</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.15</td>
<td>0.42</td>
<td>0.73</td>
</tr>
<tr>
<td>2</td>
<td>1.15</td>
<td>0.44</td>
<td>0.71</td>
</tr>
<tr>
<td>3</td>
<td>1.15</td>
<td>0.41</td>
<td>0.74</td>
</tr>
<tr>
<td>4</td>
<td>1.15</td>
<td>0.43</td>
<td>0.72</td>
</tr>
</tbody>
</table>

Table 2: Table of results obtained from testing of machine for total mass of 3.53kg

<table>
<thead>
<tr>
<th>Test</th>
<th>Total mass</th>
<th>Mass of light materials</th>
<th>Mass of heavy materials</th>
<th>Time (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3.53</td>
<td>1.13</td>
<td>2.4</td>
<td>3.88</td>
</tr>
<tr>
<td>2</td>
<td>3.53</td>
<td>1.15</td>
<td>2.38</td>
<td>3.65</td>
</tr>
<tr>
<td>3</td>
<td>3.53</td>
<td>1.18</td>
<td>2.35</td>
<td>3.96</td>
</tr>
<tr>
<td>4</td>
<td>3.53</td>
<td>1.12</td>
<td>2.41</td>
<td>3.62</td>
</tr>
</tbody>
</table>

From the results obtained, it was observed that the percentage of light materials found in the waste with total mass of 1.15kg was about 37% but was observed to be 32% when the total mass of the waste was increased to 3.53kg. The tests conducted implied that the variation of the composition of the different samples of wastes was not very significant.

An average time of 3min 47secs was required to sort 3.53kg of waste which contains about 32% of light materials. This puts the time required to separate a unit mass of waste of the same composition at about 65 seconds. With respect to other crude forms of separation, the machine could be improved to reduce the time needed to have the separation done more efficiently.

Although, the times recorded for the separation for each sample were close, the relationship of the time of separation with the mass of waste components generally shows an increasing time relationship with increased mass of light materials. This may be due to light materials requiring more separation time when the quantity is increased. Considering the waste to be homogenous, it may be deduced that the longer it took to separate the waste the more efficiently it separated out the light materials from the mixed stream of waste.

**CONCLUSIONS**

A waste sorting machine has been developed which have been able to sort wastes from the University of Lagos into light weight and heavy materials. It was observed that wastes consist of approximately 32% of light materials which were separated by the means of a fan blowing through a channel. The machine needs modifications of the magnetic end to efficiently separate ferrous metals from other metals. The machine can be manufactured at a well equipped mechanical workshop, using locally sourced materials and at a good price.

**REFERENCES**


