Design of mechanized buggy for the removal of solid wastes from drainages

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Abstract. Drain Buggy is a concept that is to replace the manual scavenging work in the drainages and to protect from environmental hazards by removing waste from the drainage system. If the wastes are not removed properly, then waste gets settled in large amounts in the drainage system and cause blockages. Difficulty in cleaning the drainages can be minimized by the implementation of proposed mechanized buggy. This mechanical cleaning equipment can be used to clean and control the drainages and its level in several parts of the country to avoid water floods. This work comprises of design and development of the components of Drain cleaner consists of a hand wheel, a chain, driver, bucket and frame. The solid waste from the drain is lifted by the bucket which is connected to the chain. The cleaner can be placed across the drain and the chain is attached to the gears driven by motor. So, when the motor is powered it runs the chain, connected to the bucket, start to circulate the bucket to collect the waste. Geared DC motor is selected and can be used in this application. The waste collected in the bucket is stored in the waste storage tank. Thus, the threat of infectious diseases caused is reduced compared to the direct contact with the sewage water.

Keywords: Buggy, Sustainability, waste management, Design

1. Introduction

Solid waste management is one of the major problems faced by the many of the developing and undeveloped countries. It causes several health problems especially to cleaning workers and the community will get expose to infectious diseases as well. The waste water from homes, business industries, commercial activities and institutions flows to the waste water treatment plant for treating wastewater. It was formulated by engineering a network of pipes. The biggest impact of cleaning the chemical wastes can cause diseases like anaemia, jaundice, and carbon monoxide poisoning. It plays a challenging issue for the manual scavengers who worked as municipality worker. A drainage ditch is a narrow channel that is dug at the side of a road or field to carry away the water. Drainage pipes are used for the disposal of sewage and unfortunately sometimes there may be loss of human life while cleaning the blockages in the drainage pipes. The Drain Buggy therefore helps to collect the plastic solid waste in a more easy and efficient manner. A method was proposed to produce biochar via pyrolysis (Between 350 and 450°F) and to apply at a rate of 10 and 15 % on food waste compost bioreactors [1]. It was observed that biochar generated from lawn waste has a positive effect on food waste manure. A better efficient and environmentally friendly method was provided for separation of ABS and PVC mixtures [2]. A prediction model combined with numerical desirability was used to determine the customized conditions. Thus, the proposed method can help to improve the recycling quality of waste plastics for mechanical recycling, promote cleaner and sustainable
disposal of waste plastics, and solve environmental and resource problems associated with waste plastics.

Municipal solid waste logistics management (MSWM) is necessary to care of growing stream of waste and the need to reuse non-renewable resources. The provision of analysis of current MSW management practices and identification of key issues from waste management and reverse logistics are done using a 3-step approach [3]. The study of implementing formal collection and recycling systems of solid waste through the proposal of Global reverse supply chain (GRSC). Investigating and optimizing of robust model design of GRSC with the application of Mixed integer linear programming (MILP). The proposed MILP model shall mitigate waste management problems and control the uncertainties [4]. Solid waste management is one of the challenging issues in cities [5]. This has become a pollution problem due to the accumulation of solid waste in large quantities. For that, an assessment of the Current Situation of Municipal Solid Waste Management (MSWM) was conducted in 59 major cities in India.

The environmental impact of the organic waste management systems introduced in Umbria (Italy) in order to obtain useful information for strategic improvement and optimization decisions. The two most prevalent scenarios were analyzed: collection by sources, followed by production of organic fertilizer and undifferentiated collection, followed by mechanical and biological treatment and disposal of the bio stabilized material in landfills [6]. The hydrodynamic modeling of percolation and dewatering cycles associated with the anaerobic digestion and fermentation of household waste (HSW) in leaching bed reactors. The model was studied for characterization of water distribution and hydrodynamics characteristics of the beds [7]. Solid waste of Kerbala municipalities was classified on the basis of weight % and its analysis was carried out in [9] and identified that most of them are recyclable. The challenges faced while collecting plastic waste was discussed and also reported about its reusability and recyclability [10]. A direct drain water heat recovery system was introduced in [11] for commercial kitchens. Increase in amount of solid wastes in several cities paved the way for the emission of green house gases in urban localities [12]. Unscientific disposal of municipal solid wastes may lead to emission of green house gases. Generation, composition and need of proper disposal was discussed in [8, 13].

The purpose of this work was to design a mechanized drain buggy for the removal of solid wastes from drainages and thereby initiating a mission for a better and clean locality in our country.

2. Components of the machine

The main components of “Drain Buggy” have been developed. They are:

A. DC Motor
B. Sprockets
C. Chain Drivers
D. Shaft
E. Bucket
F. Waste compartment

A sprocket or sprocket wheel is a profiled wheel with teeth, or cogs, that mesh with a chain; track or other perforated or indented material. The name “sprocket” applies generally to any wheel upon which radial projections engage a chain passing over it. It is distinguished from a gear in that sprockets are never meshed together directly, and differs from a pulley in that sprockets have teeth and pulleys are smooth. Sprockets are used in bicycles, motorcycles, cars, tracked vehicles, and other machinery to transmit rotary motion between two shafts where gears are unsuitable or to impart linear motion to a track, tape etc.

Chain drive is a way of transmitting mechanical power from one place to another. It is often used to convey power to the wheels of a vehicle, particularly bicycles and motorcycles. It is also used in a wide variety of machines besides vehicles. Most often, the power is conveyed by a roller chain, known as the drive chain or transmission chain, passing over a sprocket gear, with the teeth of the gear meshing with the holes in the links of the chain. The gear is turned on, it pulls the chain putting mechanical force into the system.
3. Working mechanism

Drain buggy consists of 4 wheels which are attached to a frame. This allows the movement of the machine moving outside of the drain. A chain system is used in this. There are hoppers attached to the chain that rotates and it vertically moves downwards. Bevel gears are used for rotating movement of chain where shafts are connected. When the motor runs the shaft connected to bevel rotates and simultaneously the bevel rotates thus driving the chain. The horizontal movement of hopper is used to collect the wastes on sides of drain. This movement is achieved by using a shaft built with grooves.

This horizontal motion can be achieved by the rotation of hand wheel. As the hand wheel is rotated the shaft having grooves attached to chain rotates and the waste can be collected with help of hopper moving left and right. The shaft with grooves is mainly selected as it has a locking system. The vertical movement is similar to horizontal movement, where the hand wheel is rotated the shaft rotates and the chain moves downwards, collects wastes and the solid wastes are dumped into the waste compartment. The waste contains both solid and liquid. The waste compartment is designed in such a manner that at the bottom of compartment there are pores. The waste compartment is detachable. This feature is useful as it is easy for disposal of waste in an effective manner.

As the waste is collected the liquid is drawn back to drain itself and only solid waste is collected. The hoppers are designed and shaped as a frustum. The frustum shape is selected for more capacity and easy collection of waste. The waste and hoppers are designed to maximize the load carrying capacity and rate at which the wastes are collected and disposed. The shafts are made of mild steel as it has a relatively low tensile strength and is cheap. The frame and waste compartment are made of stainless steel as it has high strength, corrosion resistant, ductile. Material for hopper is stainless steel as it can be shaped easily and has high strength for collecting load. The materials for each component are selected depending upon the required strength and load carrying capacity. The supporting structures used in this machine are the frame made of steel and C-shaped section used for vertical movement.

Figure 1 shows the methodology chart. The waste compartment and bucket are designed in such a manner that it can carry maximum of solid waste. The hopper is shaped as frustum as it can carry maximum load in a simple and efficient manner. The motor and transmission devices are selected based on the desired speed at which the chain should rotate and power requirement for the system. All these components are assembled according to the 3D model shown in figure 2, after considering both advantages and disadvantages.

4. Methodology

5. Design of components

To accomplish the objectives for fabricating the buggy a well sorted design phase is important.
5.1 Design of hopper
Hoppers are designed such a way that they can carry bulk material with help of a chain. The hopper used in the system is in the shape of a frustum. This will enable the system to collect more waste material from the drain.

\[ \text{Volume (a hopper)} = \text{Volume of Cuboid} + \text{Volume of prism} = \frac{\text{mass}}{\text{density}} \]

Volume (a hopper) = (lh) + (\frac{1}{2}bh) = \frac{m}{p} \quad (1)

Where, length(l) = 330mm
Breadth(b) = 160mm
Height(h) = 100mm
Density(\rho) = 350 kg/m^3 (Taking Density of bamboo as assumption)

Inclination of hopper, \( \alpha \)
\[ \tan \alpha = \frac{1}{h} \quad (2) \]

5.2 Design of Chain
The chain drive is used for transferring mechanical energy from one location to another. It is often used to express energy the wheels of a vehicle, especially bicycles and motorcycles. It is used in a variety of machinery. The following equation was used to design the chain.

\[ L = L_n \times \pi \quad (3) \]

Average Velocity of chain,
\[ \nu = \frac{\pi DN_1}{60 \times 10^3} \quad (4) \]

Where \( N_1 \) is the full speed of the motor

Velocity ratio,
\[ i = \frac{N_1}{N_2} = \frac{Z_2}{Z_1} \quad (5) \]

Where
\( Z_1 \) is the no. of driving sprocket teeth\n\( Z_2 \) is the no. of driven sprocket teeth

Number of links in the chain, \( L_n \)
\[ L_n = 2 \left( \frac{Z_2}{2} \right) + \left( \frac{Z_2+Z_1}{2} \right) + \frac{\pi}{2} \left( \frac{Z_2-Z_1}{2\pi} \right)^2 \times \frac{p}{a} \quad (6) \]

Centre distance, \( a \)
\[ a = \frac{p}{4} \left[ L_n - \left( \frac{Z_2+Z_1}{2} \right) + \sqrt{L_n - \left( \frac{Z_2+Z_1}{2} \right)^2 - 8 \left( \frac{Z_2-Z_1}{2\pi} \right)^2} \right] \quad (7) \]

Value of 'a' should lie between 30 p to 50 p. So, it is assumed to be 40 p.

Power rating by the chain, kW
\[ \text{Power} = \frac{\text{kW to be transmitted} \times k_s}{k_1 \times k_2} \quad (8) \]

Where \( k_s \) is the service factor and its value is 1.3, \( k_1 \) and \( k_s \) are the multiple strand factor and tooth correction. The value of \( k_1 = 1 \) and \( k_s = 1.11 \)

Factor of safety, \( f_s \)
\[ f_s = \frac{13800}{\text{Chain tension}} \quad (9) \]
Where

\[
\text{Chain tension} = \frac{\text{kW} \times 1000}{v}
\]  
(10)

**Figure 2** Conceptional model

### 5.3 Design of sprocket

The difference between sprocket and pulley is that, sprocket has teeth and pulleys are smooth. The teeth of the sprocket are made to mesh the chain.

**Pitch circle diameter**

\[
D = \frac{p}{2\sin \frac{\alpha}{2}}
\]  
(11)

**Pitch angle, \(\alpha\)**

\[
\alpha = \frac{360}{2\pi}
\]  
(12)

### 5.4 Design of shaft

It is considered as the rotating machine element which is circular in cross section and is used to transmit power from one part of the machine to another part. The following equation was used to design the shaft.

**Power of the motor**

\[
P = \frac{2\pi N_1 T}{60}
\]  
(13)

**Equivalent torque**

\[
T_{\text{equivalent}} = \sqrt{M^2 + T^2} = \frac{\pi d^2 \tau}{16}
\]  
(14)

**Equivalent bending moment**

\[
M_{\text{equivalent}} = \frac{1}{2} \times \left[ M + \sqrt{M^2 + T^2} \right] = \frac{\pi d^4 T_b}{32}
\]

**Maximum shear stress, \(\tau_{\text{max}}\)**

\[
\tau_{\text{max}} = \frac{16}{\pi d^4} \sqrt{(k_b M_b)^2 + (k_f M_f)^2}
\]  
(16)

Where, \(d\) is the diameter of the shaft
\(k_b\) is the shock factor and its value is 1.5
\(M_b\) is the bending moment
\(k_f\) is the fatigue factor and its value is 1

**θ**

\[
\theta = \frac{584 M_1 l}{G d^4}
\]  
(17)
Where $\theta$ is the angle of twist and is assumed to be $3^\circ$ for line shaft, $l$ is the length of the shaft which is taken as 600 mm, and $G$ is the modulus of rigidity and its value is $79300 \text{ N/mm}^2$

$$\tau_{\text{max}} = \frac{0.5S_{yt}}{f_s}$$

Shaft is of plain carbon steel – 30C8. Hence, yield strength $S_{yt} = 400 \text{ N/mm}^2$, & $f_s = 3$

5.5 Design of waste compartment

It is used for collecting waste materials from the drain with the help of hoppers attached to the conveyor. The shape of a frustum shape had been selected for this compartment because it gives us the legitimate shape to scoop the waste from the drain and also gives more area.

5.6 Specifications of the motor

It is the motor that gives the necessary power which gets transmitted from the motor to the gear from there to the chains. All due to this, the hopper gets the its necessary strength to scoop the bulk waste from the channel. Power delivered the hopper helps it to moves in a well specified motion. Motor was selected has Geared DC motor. Since, the speed can be adjusted essentially to any desired outcome. Also, it helps to increase torque and withstand large unusual loads and vibrations.

- Rated current
  - Full load current: 13.4 A, No load current: 2.2 A
- Operating power: 250 W
- Rated speed: 337 rpm
- Rated torque: 8 Nm
- Length of cable: 0.5 m
- Sprocket has 9 teeth
- Weight: 2.35 kg
- Top speed: 15.932 kmph
- Gear ratio is 2:1
- Chain pitch, $p = 12.7$ mm
- Roller diameter = 7.62 mm
- Roller width = 4.06 mm
6. Selection of materials & its characteristics

In this proposed project mainly two materials are used, G.I steel and plain carbon steel. G.I steel are prepared by dipping the steel in a pool of zinc. It is covered by a layer of zinc so as to protect it from rusting (one of the main reasons). It is cost effective and is well suitable for the construction. Due to its high density it can resist low heat exchanges. Carbon steel or plain-carbon steel is a metal alloy. It is a combination of two elements such as iron and carbon. Low carbon steel is the most common and cost-effective material and is malleable and ductile in nature. Medium carbon steel contains carbon more than low carbon steel and balances ductility and strength with good wear resistance.

7. Results & Discussion

Designing manual drain cleaner consists of the following main components such as chain, sprocket, shaft, hopper and waste compartment. Plain carbon steel is used for shaft because it is light weight, cheap and can be cut to create the desired shape easier than any other metal. G.I steel is used for the body of the cleaner. This is because it has high density and hence low heat exchange. Also, it is strong, cheap, resist corrosion, has good weldability and recyclability. Depth and width of the channel is considered to be 0.5 m. This depth and width of the channel was considered so that the model made would be cost effective. Larger the dimensions considered for the channel, the more expensive will be the model that has to be fabricated. A 40 Ah car battery was selected to drive the motor. figure 3 and figure 4 represents the dimensions of the machine and its components used.

- **Sprocket:**
  - Pitch angle, $a = 18.247^\circ$
  - Pitch circle diameter of sprocket, $D = 79.3$ mm

- **Chain:**
  - Average velocity of chain, $v = 1.355$ m/s
  - Velocity ratio, $i = 2$
  - Centre distance, $a = 508$ mm
  - Number of links in the chain, $L_n = 108$ links
  - Length of chain, $L = 1371$ mm
  - Power rating(kW) = 292.79 kW
  - Chain tension = 185185.18 N
  - Factor of safety, $f_s = 0.074$

- **Shaft:**
  - Torque transmitted by shaft, $M_t = 7087641.04$ Nmm
  - Diameter of shaft, $d = 56$ mm
  - Maximum shear stress, $\tau_{\text{max}} = 66.66$ N/mm²
  - Bending moment, $M_b = -5385164.8$ Nmm

- **Hopper:**
  - Volume of cuboid = $528 \times 10^4$ m³
  - Volume of prism = $264 \times 10^4$ m³
  - Total volume of a single hopper = $792 \times 10^4$ mm³
  - Inclination of hopper, $a = 15^\circ$
  - Mass of waste collected= $2.8$ kg

The figure 4 shows the dimensions of buggy. Figure 5 and 6 show the side view and the front view of the machine. Figure 7, 8, and 9 show the motions provided on the cleaning equipment. Chain system is used in this drain cleaner machine, where the sprockets are connected to each other, same as in bicycle. There are hoppers attached to the chain that rotates and it moves vertically downwards. Gears are used for rotating movement of chain where shafts are connected. When the motor runs the shaft connected to the gear rotates and simultaneously the gear rotates thus driving the chain. The horizontal movement of hopper is used to collect the wastes on the sides of the drain. This movement is achieved by using a shaft built with grooves.
Figure 4 Dimensions of Buggy

Figure 5 Actual Model (Front view)  

Figure 6 Actual Model (Side View)
This horizontal motion can be achieved by the rotation of hand wheel. As the hand wheel is rotated, the shaft having grooves attached to the chain, rotates and the waste can be collected with help of hopper moving left and right. The shaft with grooves is mainly selected as it has a locking system. The vertical movement is not similar to horizontal movement. Here, a rack and pinion arrangement is used to move the chain and sprocket arrangement upwards and downwards. It then collects wastes and are dumped into the waste compartment. The waste contains both solids and liquids. The waste compartment is designed in such a way that there are pores at the bottom of the compartment to remove the liquids.

**Sprocket**
- Pitch angle, $\alpha = 18.947^\circ$
- Pitch circle diameter of sprocket, $D = 79.3\text{mm}$

**Chain**
- Average velocity of chain, $v = 1.355\text{m/s}$
- Velocity ratio, $i = 2$
- Centre distance, $a = 508\text{mm}$
- Number of links in a chain, $L_n = 108$ links
- Length of chain, $L = 1371\text{mm}$
- Power rating(kW) = 292.79
- Chain tension = 185185.18N
- Factor of safety, $f_s = 0.074$

**Shaft**
- Torque transmitted by shaft, $T = 7087641.04\text{Nmm}$
Moment, \( M = 6981403.87 \text{ Nmm} \)
Equivalent twisting moment, \( T_{\text{equivalent}} = 1222515.825 \text{ Nmm} \)
Diameter of shaft, \( d = 47 \text{ mm} \)

**Bucket**
- Volume of cuboid = \( 528 \times 10^4 \text{ mm}^3 \)
- Volume of prism = \( 264 \times 10^4 \text{ mm}^3 \)
- Total volume of bucket = \( 792 \times 10^4 \text{ mm}^3 \)
- Inclination of bucket, \( \alpha = 15^\circ \)
- Mass carried by each bucket, \( m = 2.77 \text{ kg} \)

8. Conclusion & Scope of the work

The drain cleaner can also be used in domestic and industry areas in every country. A model design was created for the manufacturing of manual drainage cleaner. The part of the machine, for the drain buggy was carried out as per the data obtained from using the suitable equations. This can be useful during the monsoon because during this season our drains are usually overflowing and blocked by solid waste. The following values were obtained from the respective equations for the respective designs, as follows:
- A sprocket of diameter 79.3 mm was obtained as a suitable value for the design.
- A chain of 1371 mm length having 108 links was obtained as a suitable value for the design.
- A shaft of 56 mm diameter was obtained as a suitable value for the design.

Sanitation is one of the very basic amenities required for a living being. Providing such a technology can change the pathetic sewage conditions faced by the people in towns and cities. The machine proposed is manually operated. More twist and turns can be created in this area in a fabulous way. The manually operated machine proposed has many areas that can be made into automatic in the near future and can be controlled by keypads and joysticks. This whole machine runs on battery power. In the near future this can be replaced using solar panels, so that it becomes more reliable and less maintained machine. The machine proposed has been fixed to certain measurements such as, drain length and width. Here, there is a wide range of scope where the machine can pick up any drains of any size and shape so as to clean. Sensor can be placed in the waste compartment so as to give a stress signal when the compartment becomes full.

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