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(Research Article)

Design and development of scavenging machine to control water pollution

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Abstract

Water is the most essential natural resource for human survival. Population explosion, industrialization, and technological advancement are responsible for generating solid, liquid, and gaseous waste that indiscriminately pollutes the environment. In particular, the solid waste when gets into water resource undergo decay which becomes a source of breeding of diseases causing mosquitoes that spread a number of diseases like malaria, dengue fever, chikungunya, brain fever, etc. The accumulated solids are blocking the flow of water as well as sewage. Nearly 40 million liters of wastewater are released into rivers and water bodies every day, but only a small fraction of it is properly treated. Water pollution causes diseases like Bronchitis, Tuberculosis, Asthma, Nausea, Typhoid, Diarrhea, etc., and it causes to kills more than 1.5 Indian children every year. To minimize and control water pollution, prevention of solid entering into the waterbody and the removal of the solid waste which is already present in the waterbody are important migrative actions. In the present investigation, an attempt is made to replace the manual scavenging of solid waste from waterbodies by the automated machine. The main advantage of the Automatic Scavenging Machine is to collects the trash from the water surface by conveyer, crushes it by shredder, and stores them in the trash storage tank for proper disposal. It stores large amounts of trash and cleans the solid waste within a few minutes. Hence the water becomes less contaminated and less harmful to humans and the environment.

Keywords: Scavenging machine; Water pollution control; Solid waste minimization; Shredder; Traction Control

1. Introduction

Every year, the world generated more than 2 billion tons of trash. That’s enough to fill over 8,00,000 Olympic-sized swimming pools. India is one of the top 10 polluted countries in the world. In India there are 351 polluted rivers are identified by “The Central Pollution Control Board” (CPCB) in 2018. Approximately 80% of India's rivers and lakes are severely polluted by raw sewage, silt, and garbage. Solid wastes are causative factors to create water borne diseases. These solid wastes are manually scavenged by workers.

Manual scavenging is the practice of manually cleaning and handling human waste, mainly in the context of developing countries with inadequate sanitation infrastructure. Manual scavenging involves working in hazardous environments, such as septic tanks and open drains, without proper safety equipment. Manual scavengers face numerous health risks, which can cause respiratory and skin diseases. This puts individuals at risk of asphyxiation, drowning, or exposure to toxic gases and chemicals, leading to fatal accidents and injuries. Efforts are being made globally to eradicate manual scavenging and provide affected individuals with alternative livelihoods, proper sanitation infrastructure, and social support. Mechanized and automated technologies, such as the scavenging machine, play a crucial role in addressing this issue by eliminating the need for manual scavenging and ensuring the dignity and well-being of individuals involved in waste management. Scavenging machine is designed to scavenge solid waste from the water surface and to control the water pollution.

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Anshul Mathur et.al [2021] designed a semi-automatic sewage cleaning machine used in manholes. The system includes a slurry pump and a DC motor connected to a battery. The process involves collecting sewage wastes using the slurry pump and throwing the waste back into the sludge tank. The sludge and water are separated using three filtration nets with decreasing sizes.

Mrs. Dinah Ann Varughese et.al [2018] designed an automatic drainage cleaning robot to control wastages in drainage pipes. The system involves regular filtration of wastage and treating substances separately. A robotic arm powered by a DC motor is used to remove sedimentation waste, and a sensor is used to identify sediment waste. A conveyor collects all the wait particles that float above water. The robot can move forward, backward, and in four directions.

S. Ramanathan et.al [2019] designed a semi-automated sewage cleaning machine. The machine uses a pneumatic piston connected to a wire rope, which is coupled with kinematic linkages to collect solid wastes from the sewage. The collected wastes are separated and stored in a chamber to decompose.

Raja Sudhan K.R et.al [2021] developed a semi-automated machine robot for sewage sludge removal. The robot inspects sewer lines for cracks, corrosion, obstacles, gas present, etc. The robot arm is settled through a few Axes, and a stepper motor is used to move the robot with different angles from left to right and then from top to bottom. The LCD module is used to view the sewage.

Anagha Deogaonkar et.al [2019] developed a robot to unclog sewage channels. The robot removes dirt and facilitates the flow of water through the channels efficiently. The dirt is stored in the storage unit in the body, which is detachable and can be changed to facilitate continuous operation. Wall detection and water level monitoring sensors help the robot to avoid striking walls and monitor the level of water in the storage unit.

M. Mohamed Idris et.al [2017] designed and fabricated a semi-automated remote-controlled sewage cleaning machine. The machine is powered by two power window motors, which are controlled by a remote-control setup. An arm is used to lift and collect sewage, which is then thrown into a bin fixed in the machine at the bottom.

Tejinder Singh. P et.al [2019] developed a multipurpose modular robot that can be used for beach and sewage cleaning tasks. The robot is equipped with a claw to collect scattered garbage, and a sliding mechanism to remove garbage from sewages.

Baluprithviraj.K.N et.al [2021] designed and developed a sewage-cleaning mobile robot with an IR camera and sensor to remove blockages in sewages. The camera captures images inside the sewage that can be monitored using a PC, while the IR sensor detects the presence of blockages. The robot can remove the blockages using its arm.

P. Dhananchezhiyan et.al [2013] designed and developed a reconfigurable type autonomous sewage cleaning mobile manipulator to overcome the limitations of conventional sewage cleaning robots in cleaning variable diameter pipelines. The manipulator consists of various links and joints, which are driven by various motors.

G. Anil et.al [2022] conducted a short review on shredder machines and concluded that plastic shredders are commonly used for recycling electronic waste and organic waste. They also found that plastic waste can be converted into small pieces or granules by using a plastic shredding machine.

Sudhakar Reddy et.al have designed and fabricated the machine with belt drive which is a disadvantage of the slip of the belt in ever time and the torque is also low i.e., 7.4 Nm. There is a possibility of increasing the torque to crush the bottles at minimal time. They are used Mild steel as a frame that does not contribute anything to the crushing of the bottles. There is a possibility of alternative thinking of the frame. They are used Mild steel blades where life is minimal. There is a possibility of a better selection of the blade.

A.E. Oladejo et.al developed a Shredded Machine for processing of Agri-chemical. According to them, the shredding of twigs will provide an alternative for the use of Agri-chemicals. The machine consists of three-phase electric motor, bearings, structural frame, cutters, hopper, shredding unit, discharge chute, belt drive and shaft. The performance of the machine was evaluated and test results showed that there was a correlation between the weight of the shredded twigs and the shredding time and the weight of small bits of twigs collected increases with time.

2. Methodology

The proposed automatic scavenging machine is designed and fabricated to collect the floating solid waste from the surface of the water. The machine consists of a conveyor, a shredder machine, a storage tank, and a traction control system. The machine is designed to float on the surface of the water, and uses a conveyor to collect solid waste such as bottles, plastic cans, tins, and covers. The conveyor is driven by a geared motor, which rotates the belt and collects the waste. The waste is then put into a shredder machine, which is powered by a motor coupled with a gear box to provide more torque. The shredder machine is small in size and designed to crush the solid waste into a finite number of pieces, which are then stored in a storage tank. This technology has the potential to significantly reduce the amount of solid wastes particularly plastic waste in our oceans, rivers, ponds and waterways, and contribute to a cleaner and healthier environment. The proposed methodology of project work is shown in Figure.1.

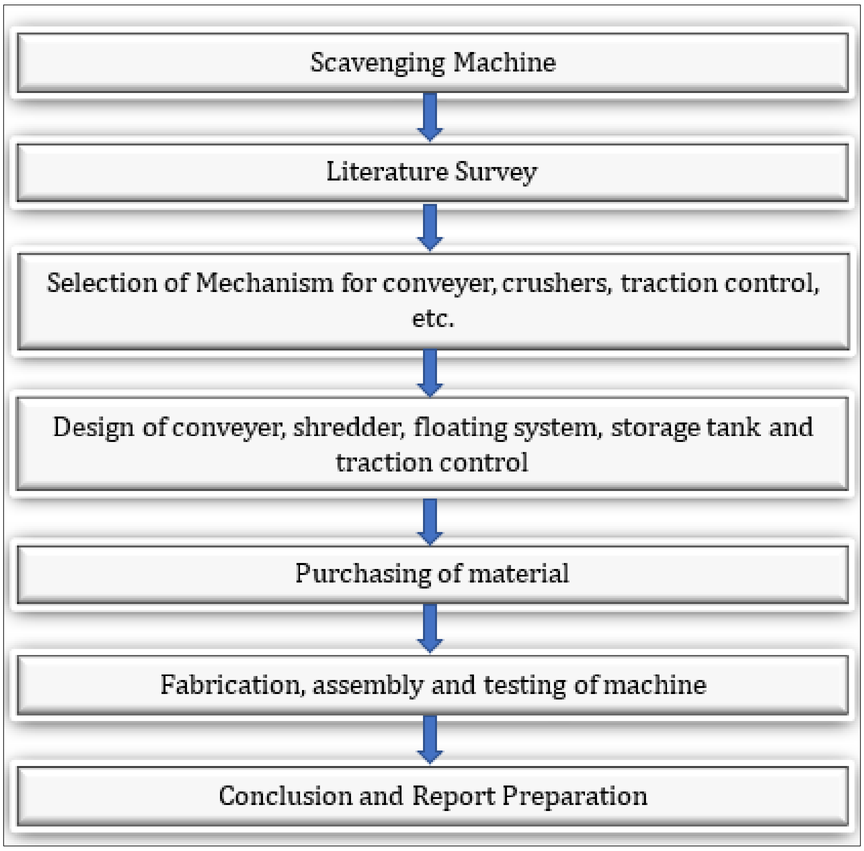

Figure 1 Project methodology

The Scavenging machine consists of four important sub-assembly. The design and analysis involve the design the shredder machine, conveyer system, floating system and traction control system and it is shown in figure 2.

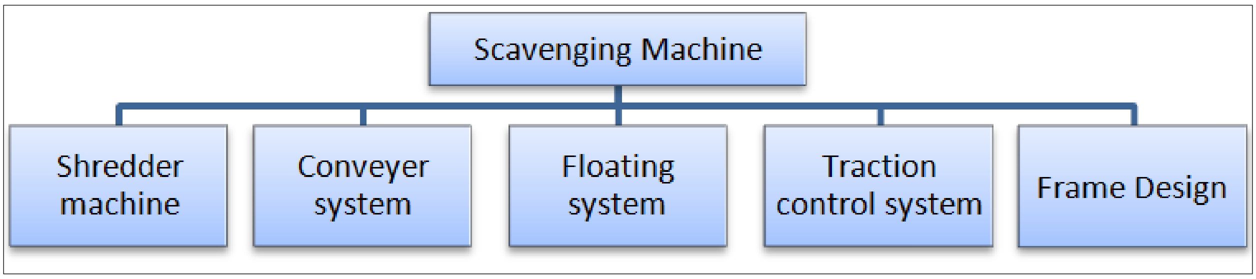

Figure 2 Assembly of scavenging machine

3. Design and development of Scavenging machine

3.1. Design and Calculation of Shredder Machine

A shredder machine is a mechanical device designed to crush and shred solid waste materials into smaller, manageable pieces for easy disposal or recycling.The shredder machine consists of a set of blades mounted on a rotating shaft that shreds the waste by applying cutting or shearing forces. As the solid waste is inserted into the shredder through a hopper that passes between the rotating blades on the two shafts, it undergoes a combination of crushing and shearing actions. The blades on each shaft work together to effectively break down the solid waste into smaller particles.

Due to the majority of plastic materials floating on the water's surface, the design and calculation of the shredder machine are based on the plastic of the Polyethylene Terephthalate (PET) type.

3.1.1. Shredding force on blades

The blades are used to shred the solid waste material into pieces.PET plastic material properties,

$\sigma_t = 80$ MPa
$\mu = 0.3$ to 0.4
Hardness = 94 to 101
Poisson's Ratio = 0.37 to 0.44
E = 2 to 4 GPa
FOS = 1.5

Breaking Strength of PET plastic material,

$$\text{Breaking strength} = \text{FOS x Allowable stress}$$
$$= 1.5 \text{ x } 80$$
$$= 120 \text{ MPa}$$

The Cross-sectional area of the material to be cut,

$$\text{Area} = \text{Width of the cutting blade x Thickness of plastic material}$$
$$= 2 \text{ x } 0.5$$
$$= 1 \text{ mm}^2$$

The shredding force required to cutting the plastic bottles,

$$F_s = \text{Area x Breaking Strength}$$
$$= 1 \text{ x } 120$$
$$F_s = 120 \text{ N or } 12.23 \text{ kg}$$

Therefore, the shredding force required to cut the plastic bottles is minimum 120 N or 12.23 kg**.**

3.1.2. Torque required to crush the PET plastic

Cutting Blade Specification,

Physical Properties,

Ultimate Tensile Strength = 400 MPa

Yield strength = 320 MPa

Young's Modulus = 200 GPa

Density = 7750 kg/m^3

Poisson's Ratio = 0.31

Dimensions,

Outer diameter of blade (OD) = 5 cm

(R = 2.5 cm or 0025 m)

Thickness = 2 mm or 0.002 m

Torque required crushing the PET plastics,

$\text{Torque}_{\text{Blade}}$= Shredding Force x Distance

= 120 x 0.025

= 3 Nm or 30 kg cm

Therefore, the minimum torque required to crush the PET plastic is 3 Nm or 30 kg cm.

3.1.3. Torque required on shredder shaft to crush the PET plastics

The shredder machine consists of two shafts. One shaft has 23 blades that give a torsion of shaft, and there's 12 blades cut at same time based on configuration.

$$\text{Torque}_{\text{Shaft}} = \text{Torque}_{\text{Blade}} \text{x} \text{Total}_{\text{Blade Cut}}$$

$= 3 \text{ x } 12$

$= 36 \text{ Nm}$

Total torque on shaft $= 36 \text{ x } 2$
$= 72 \text{ Nm}$

Therefore, the minimum torque on shaft required to crush the PET plastic is 72 Nm or 720 kg cm.

3.1.4. Calculation of total cutting force (Shredding force)

Calculate the total cutting force on all the blades at one time. Since there are 12 blades cutting at the same time, the total cutting force is,

Total cutting force = Cutting force x Number of blades

= 120 N x 12

= 1,440 N

Therefore, the shredding force is 1440N.

3.1.5. Selection of Bearing

Readily available bearings were used since they have standard and cannot be constructed in the workshop. They were selected based on the required inner and outer diameter.

Diameter of shaft = 10 mm

Deep groove ball bearing is selected.

- **Step 1 -** Specification of selected Bearing,

d = 10 mm

D = 35 mm

W = 11 mm

- **Step 2 -** Estimate the radial force acting on each shaft (F_r),

The radial force is equal to the total cutting force divided by the number of shafts. Since there are two shafts, the radial force on each shaft is:

Radial force (F_r) = Total cutting force / No of shafts

= 1,440 N / 2

= 720 N

- **Step 3 -** Estimate the axial force acting on each shaft (F_a),

The axial force is equal to the torque on the shaft divided by the effective radius of the shredding blades. The effective radius is 25mm, the axial force on each shaft is:

Axial force (F_a) = Torque / Effective radius

= 72 Nm / 0.025 m

= 2,880 N

- **Step 4 -** Calculate the equivalent load (P),

$P = (XF_r + YF_a)\ S$ (Ref. by PSG Design data book: 4.2)

Where P – equivalent load, X – radial factor, Y – thrust factor, and S – service factor

$F_a/C_0 = 2800/3600 = 0.77$

$F_a/F_r = 2800/720 = 3.89 > e$

From PSG design data book, pg.no: 4.4,

X = 1; Y = 0

From PSG design data book, pg.no: 4.2,

S = 1.5 for rotary

∴ P = ((1 x 720) + (0 x 2800)) x 1.5

= 721.5 N

The equivalent load acting on bearing is 721.5 N

- **Step 5 -** Checking of bearing capacity,

Speed of shredder = 3 rpm,

Approximate Life = 10000 hrs.

C/P = 8.43 (Ref by PSG data book pg.no: 4.6)

C = 8.43 x P

= 8.43 x 721.5

C = 6082.245 N < Dynamic capacity, 6300

So, The Design is safe. Deep groove ball bearing, 6300 is selected.

3.1.6. Selection of Motor, Gearbox and Battery

Based on above shredder specification, the specification of the motor, gearbox and battery descriptions are given below

Motor Specification:

Name= Mercedes Benz 407 DC Wiper Motor

Speed = 55 RPM

Power = 17 W = 17/746 = 0.0228 Hp

Torque = 45 kg.cm

Gearbox Specification:

Name = Casting Worm Gearbox

Gear Raito= 20:1

Torque = 135 Nm

Battery:

Name = JC Lead acid battery (researchable battery)

Volt = 12 V

Amps = 7.2 Ah

3.1.7. Calculation of Shredder Speed (Gearbox output speed Calculation)

The Shredder machine shaft is connected by output shaft of gearbox which is run by wiper motor.

Output speed = Input speed by motor / Gearbox Ratio

= 55 / 20

= 2.75 ≈ 3 rev/min

The shredder speed is 3 rev/min.

3.1.8. Shredder machine loading capacity

Shredder capacity = (60 x Power input x Shredder speed x Shredder torque) /

(2π x Gearbox ratio x Material density)

= (60 x 0.0228 x 3 x 183.1) / (2π x 20 x 1.38)

= 4.65 kg/hr ≈ 5 kg/hr

Therefore, the Shredder load capacity is 5 kg/hr and the designed shredder machine is shown in figure.3.

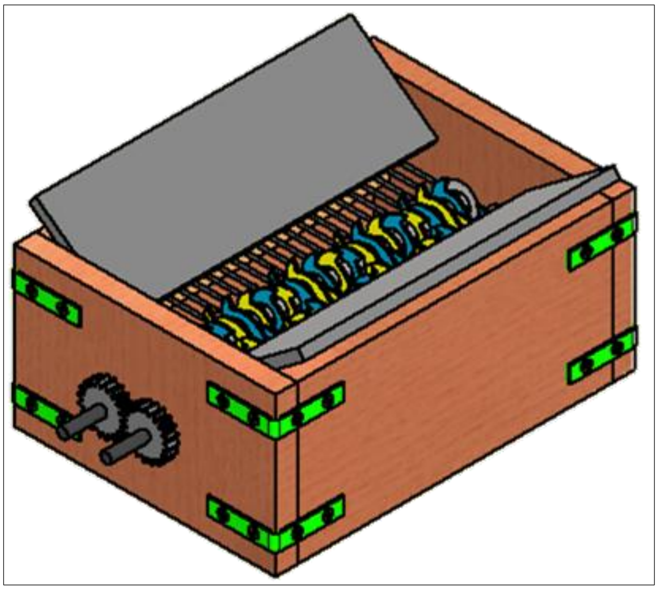

Figure 3 Assembly of scavenging machine

4. Conveyer system

The conveyor system is a crucial component of the proposed scavenging machine. It is responsible for collecting floating solid waste from the water surface and transferring it to the shredder machine for further processing.

4.1.1. Design and Calculation of Conveyer

Speed required for conveyer system is approximately 10 -15 rev/min. Auto vehicle DC gear motor is selected which has the speed of 65 rev/min.

To attain the required speed ratio, spur is used.

Number of teeth on driving gear= 8

Number of teeth on driven gear = 49

Speed of driving gear = 65 rev/min

To calculate the speed of driven gear,

Gear Ratio = No. of teeth on the driven gear / No of teeth on the driving gear

= 49 / 8

= 6.125

Speed of driven gear = Speed of driving gear / Gear Ratio

= 65 rpm / 6.125

$\simeq$ 10.61 rpm

Therefore, the speed of the driven gear is approximately 10.61 rpm.

4.1.2. Motor and its Battery

Motor Specification,

Name = Auto Wiper Motor

Speed = 65 rev/min

Voltage= 12 V

Torque = 35 kg.cm

Battery,

Name = Gold Inventor, Researchable battery

Volt = 12 V

Amps = 8 Ah

4.1.3. Modeling of Conveyer System

The conveyer is designed based on the design calculation and scavenging machine specifications. The perspective view and exploded view of conveyer 3D model as shown in figure.4, which helps to understand the manufacture to assemble the parts easily. The conveyer consists of the following parts such as Frame, Roller, Motor and spur gear, Holder, Bearing and Belt.

Figure 4 Conveyer System

4.2. Floating system

The floating system is an important component of the scavenging machine. The whole weight of the machine was acted on a floater which uses Archimedes' principle to lift on the water surface.

4.2.1. Principle of Floating System

Archimedes' principle is a fundamental law of physics that explains why objects float or sink in fluids.According to Archimedes' principle, an object immersed in a fluid experience an upward buoyant force that is equal to the weight of the fluid displaced by the object. In other words, if an object weighs less than the amount of fluid it displaces, it will float; if it weighs more, it will sink.

This principle is based on the fact that fluids, such as water or air, exert pressure in all directions. When an object is submerged in a fluid, the pressure on the bottom of the object is greater than the pressure on the top. This creates an upward force on the object, known as the buoyant force.

$$F_{buoyant} = \rho V g$$

where $F_{buoyant}$ is the buoyant force, ρ is the density of the fluid, V is the volume of the fluid displaced by the object, and g is the acceleration due to gravity.

4.2.2. Design and Calculation of Floating System

The weight of the scavenging machine (object),

W = 48 kg ≈ 50 kg

The PVC pipe is used for floating system. This pipe has connected in rectangular shape using L-bow. Dimension of the given pipe has given below,

Diameter of the Pipe = 6 inch = 0.1524 m

Total length of the pipe = 10 ft = 3.048 m

Total Volume of pipe (V), $V = \pi r^2 h$

$= \pi \times 〖0.0762〗^2 \times 3.048$

$= 0.0555\ m^3$

Water Density (ρ) = 1000 kg/m^3

To calculate the weight of the fluid displayed on water,

Buoyant Force, $F_b = \rho \times V$

$= 1000 \times 0.0555$

$= 55.59 = 60\ kg > W$

The Buoyant force 60 kg is greater than the object weight 50kg. Therefore, the Scavenging machine (object) will be float on water. So, the design is safe.

4.2.3. Modelling of Floating System

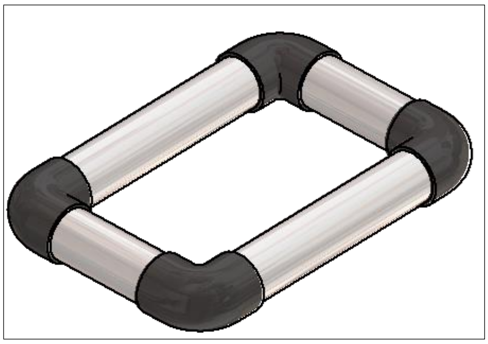

Figure 5 Floating System

The PVC pipes used in the construction are chosen for their buoyancy and ability to support the weight of the system and collected waste. By selecting pipes with a larger diameter and wall thickness, the overall buoyancy of the system is increased, allowing it to float on the water's surface. The floating system is shown in figure 5.

4.3. Traction Control System

The traction control for a floating system is the mechanisms or techniques used to facilitate movement and control the direction of the scavenging machine while collecting waste in water. It helps ensure that the system can navigate through the water efficiently and effectively gather floating debris. The system equipped with a propulsion mechanism to generate movement. The propellers create a propulsive force to propel the system forward. The propulsion method can be powered by electric motors and the propeller is shown in figure 6. .

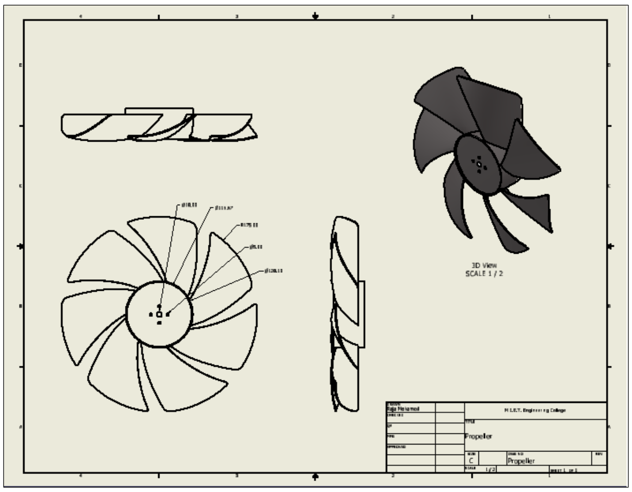

Figure 6 Propeller for Traction Control

4.4. Frame Design

The frame subassembly is essential to support and accommodate the various components of the scavenging machine. Made of mild steel (MS) for strength and durability, the frame features1.25-inch square sections. Arc welding is used to connect these components, providing a strong, stable structure that can withstand the stresses of use. Serving as the structural foundation of the machine, the frame provides the necessary support and integration points for other major components, including the gearbox, engine, conveyor, battery and traction system and it is shown in figure 7..

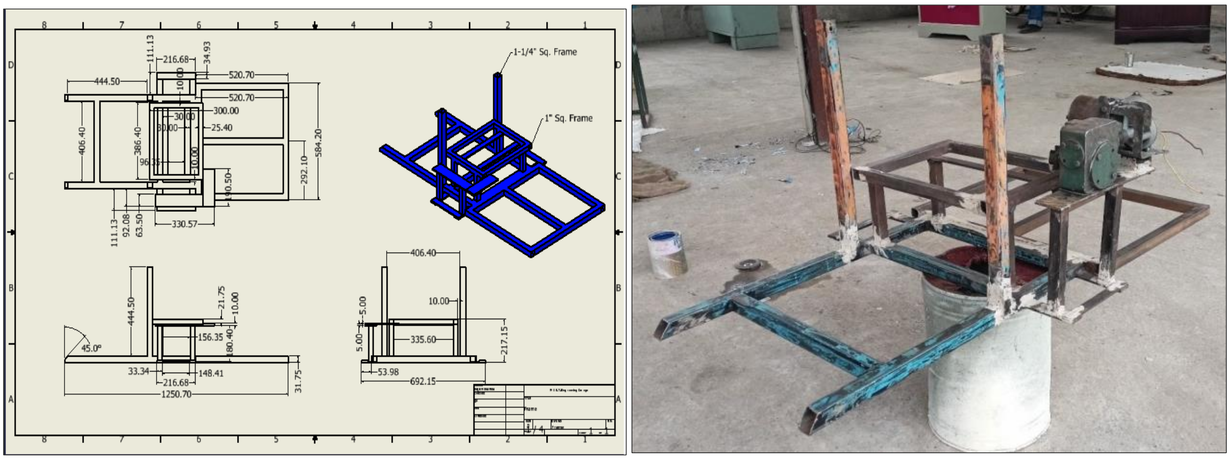

Figure 7 Floating System

4.5. Integration of sub-assembly into main assembly

The main assembly of the scavenging machine consists of all the sub-assemblies that work together harmoniously and effectively collect solid waste from the water surface. The frame acts as a foundation, providing stability and support, and the PVC pipe float is firmly fixed to keep the machine afloat on the water. The shredder mounted on the16cm high frame effectively shreds large waste, and provided with a storage box at the bottom to store the shredded plastic wastes. A conveyor system is welded to the front of the frame collects solid waste from the water surface and transfers it to the storage box. At the rear, a traction control with an electric propeller ensures a controlled ride. Additionally, the battery and 5 kg steel cube are placed at the rear edge of the frame to centralize the machine's gravity, providing stability and balance. The completed scavenging machine is shown in figure 8.

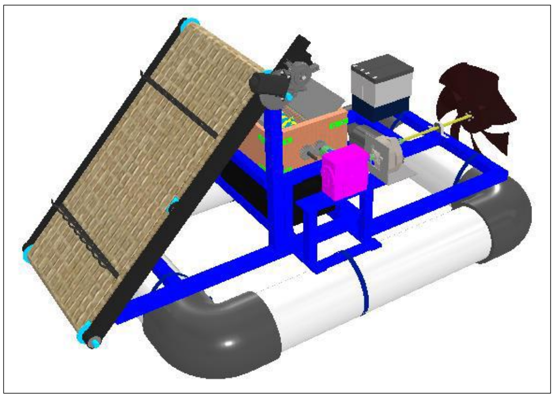

Figure 8 Scavenging Machine

5. Field test of system

The built scavenging machine prototype shown in figure 9 is underwent extensive testing to evaluate its solid waste collection and processing performance and efficiency. The prototype was tested in a stream of water, simulating real-world conditions under which the machine would be used to collect waste. The vehicle successfully floated on the water, demonstrating the effectiveness of the flotation system assembly. This allowed the vehicle to remain afloat throughout the testing process. The sweeper demonstrated the functionality of the conveyor and shredder assembly by effectively collecting solid waste from the water surface. The collected waste is effectively shredded and stored in storage containers, indicating that the overall system is operating successfully. The testing phase confirmed the feasibility and functionality of the machine, demonstrating its potential to effectively solve water pollution problems.

Figure 9 Scavenging Machine

5.1. Testing result

The automatic waste scavenging machine developed under this project is a highly efficient and effective means for solid waste disposal and water pollution control. Automatic harvesting machines are built and tested and its result are given below

- **Assemblies, components and total weight:** The total weight of the machine including all components is 60 kg.
- **System Capacity (Shredding Capacity):** The machine has a capacity of 5 kg per hour and can collect up to 5 kg of solid waste per hour.
- **Shredding speed and torque:** The shredder is driven by a motor with gearbox that delivers a crushing speed of 3 rpm and a torque of 135 Nm.
- **Speed of the system in water:** The machine is designed to move at a speed of 5 km/h and can cover a large area in a short period of time.

- **Conveyor speed with load pulling function:** The conveyor is driven by a 12V DC gear motor at 10RPM and can lift up to 3kg.
- **Storage Capacity:** The storage tank capacity of the machine is 5kg. This means it can store up to 5kg of solid waste at a time.

The results show that using this machine can significantly reduce the amount of solid waste, especially plastic waste, in waterways and contribute to a cleaner, healthier environment.

6. Conclusion

Water pollution is a significant problem worldwide and automatic waste scavenging machine is an innovative solution to prevent solid waste pollution of water bodies. These machines operate safely and reliably, significantly reducing the amount of plastic waste in oceans, rivers, ponds and waterways. It provides a sustainable alternative to manual waste collection by eliminating direct contact with workers and increasing efficiency. The ability to operate continuously and the potential future integration of artificial intelligence highlight its promise for protecting the environment and improving public health. The design of the machine allows it to handle large quantities of waste, reducing the burden on the recycling process. It can also operate in a variety of water conditions, making it versatile and adaptable. The introduction of these technologies represents an important step towards sustainable waste management. By adopting these machines, communities can actively promote clean waterways and healthy ecosystems. Automated waste disposal represents progress in solving one of the most pressing environmental problems of our time.

Compliance with ethical standards

Acknowledgments

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Disclosure of conflict of interest

No conflict of interest to be disclosed.

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