Design and Analysis of a Water Filtration System for the Removal of Heavy Metals Due to “Galamsey” Activities: Using Agricultural Waste Products

ASHESI UNIVERSITY

CAPSTONE PROJECT

B.Sc. Mechanical Engineering

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(85042020)

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CAPSTONE PROJECT

Capstone Project submitted to the Department of Engineering, Ashesi University in partial fulfilment of the requirements for the award of Bachelor of Science Degree in Mechanical Engineering.

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(85042020)

MAY 2020

DECLARATION

I hereby declare that this capstone is the result of my own original work and that no part of it has been presented for any other degree in this University or elsewhere.

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Candidate's Signature:

Date:

29/5/2020.…………………

I hereby declare that preparation and presentation of this capstone were supervised in accordance with the guidelines on supervision of capstone laid down by Ashesi University.

Supervisor's Name:

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Supervisor's Signature:

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Date:

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Abstract

Illegal mining is one of the major causes of water pollution in Ghana. Activities of illegal miners has led to the pollution of water bodies by Heavy Metals (H.M.) including other waste products, making it difficult for people, especially those in the rural areas to access clean waters for their various use. Computer Aided Design (CAD) software (SolidWorks 2018 package) was used to obtain conceptual designs for the water filtration system. A final proposed system was designed to fit the set requirements. The filtration system contains sub-systems, which contains agricultural waste products such as orange peels, for the heavy metals removal; carbon filters to remove impurities and improve the taste of the water. Ceramic filter was also proposed for the removal of the sediments from the wastewater. Furthermore, computer simulations were done on various part of the filtration system. Stress, strain, and deformation analysis were carried out on possible key parts and likely affected parts of the filtration system that may fail due to mechanical errors. The implication of the results was discussed the fabrication of the water filtration system.

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Chapter One

1.0 Introduction

1.1 Background

Water pollution is becoming a global concern [1]. Activities of productivity have turned to generate pollutants and unwanted by-products in water bodies. These pollutants may include microbial pathogens, nutrients, oxygen-consuming materials, heavy metals, and persistent organic matter, as well as suspended sediments, nutrients, pesticides, and oxygen-consuming substances [2]. Pollutants are the primary cause of water quality degradation in the world. More than 80 % of sewage in developed and developing countries discharged these untreated pollutants which leads to pollution of lakes, streams, rivers, and coastal areas around the world [3].

Ghana is recognized to be the second-largest producer of gold in Africa. In recent years, Ghana has been harassed with issues concerning illegal mining activities known as “Galamsey”. Galamsey is derived from the phrase “gather them and sell”. Galamsey is an illegal small-scale mining activity in Ghana. The unlawful small-scale mining activities, therefore, failed to conform to the environmental safety policies of Ghana [4]. Aside from the destruction of our virgin forests, farmlands (cocoa farms, palm plantation lands, etc.) and the vegetation, most of the water bodies are often polluted by the activities of the illegal miners in gold producing areas in Ghana. The unlicensed small-scale mining companies use rivers and other water bodies in their mining activities. The processing waste generated from their actions is then directed back to rivers and water bodies. In the East Akyem District of Ghana, rivers such as River Ayensu, River Birim, and River Densu have all been polluted by illegal mining activities. Mining activities have also polluted major rivers including River Ankobra in the Western Region of Ghana, River Pra in the Central Region, etc.

Meanwhile, most communities in Ghana depend mainly on these same water bodies for most domestic activities that includes as sources of water. Research has shown that processed waste from the illegal mining activities can sometimes contain heavy metals, bacteria, and other microorganisms, dirt and possibly change the colour and odour of the waters which pose danger to the lives of the people including aquatic lives.

(a) (b)

Figure 0.1: Dangers of Galamsey on the Environment: (a) Galamsey Activities on a Plantation and (b) Galamsey Activities on the Pollution on River Pra.

1.2 Problem Statement

Heavy metals (HM) are metallic elements with relatively high density compared to water. These metals are known to be very poisonous at low concentrations [5]. They can induce toxicity at low levels of exposures. Some of these metals include mercury (Hg), cadmium (Cd), arsenic (As), chromium (Cr), thallium (Tl), and lead (Pb). Accumulated HM in the body has severe long-term side effects such as reduce mental and central nervous function, dysfunction of liver, lungs, kidney, including other vital organs [5].

Most importantly, HM is known to be carcinogens that can cause cancer [5]. Although illegal mining activities have contaminated the rivers and water bodies, people still perform various operations with the water despite the risk of endangering themselves. To further highlight this problem, Ghana Water Company which oversees the distribution of safe drinking water to Ghanaians had to shut down a water treatment plant. This was due to high cost involved for the treatment of polluted water from sources of water polluted by illegal mining activities. Also, another water treatment plant at Kibi in the Eastern Region of Ghana was shut down because of the difficulty of treating these waters for the communities around.

1.3 Motivation and Justification

Attempts have been made by some affected communities, which result from using local treatment methods such as boiling and sieving. The method of sieving is only capable of separating coarse materials (dirt) from the water and nothing more. Boiling approach, on the other hand, may reduce microorganisms [6], however, it doesn't guarantee the removal of some bacteria [6] or HM. Boiling stands a higher chance of increasing the concentration of HM in water to double their initial values [6], hence results in high levels of sides effects. The fundamental skills and technological competence for treating polluted waters with HM are therefore beyond the knowledge levels of the affected communities. Moreover, it is also expensive to treat contaminated waters containing HM and hence, the local people cannot afford but resort to boiling and sieving.

A lot of projects have taken place to remove heavy metals from polluted waters. Banana and orange peels have been used as adsorbents for the removal of HM to make groundwater safe for drinking and other domestic use [7]. Large-scale municipal water treatment systems in the developing world typically employ conventional methods of water treatment such as mechanical separation, coagulation and flocculation, chemical purification, disinfection processes, biological processes, aeration, and membrane technologies. These technologies are often used in combination to increase the effectiveness of water treatment [8]. This gives rise to the cost of water filtration systems. Also, most research and developmental phases are still being considered around the world.

Research and developmental phase are still being considered around the world. This current project is focused on the development of a cheap and effective filtration system that could be implemented and used in affected communities in Ghana. The system would be user-friendly and environmentally friendly.

1.4 Goal and Specific Objectives

The primary purpose of this project is to design and analysis a water filtration system for the removal of heavy metals, dirt, and bacteria from “galamsey” polluted waters using an agricultural waste product such as orange peels in connecting filters. Moreover, the design would comprise of an activated carbon filtration unit from coconut shells to enhance the removal of dirt/particulates as well as odour.

In other to achieve the set goal, the following specific objectives would be considered during the execution of this project.

- Obtain an extensive review on illegal mining activities in Ghana and the possible sources of H.M. in surface water bodies.
- Obtain conceptual designs of a self-assembled water treatment system using SolidWorks.
- Visiting and collecting water samples from the mining site for analysis.
- Design circuit for electrical control of pumps and flow properties.
- Mechanical simulation and analysis of ceramic filtration system and geometry effects on mechanical durability.

- Mechanical simulation and analysis of the entire frame of the filtration system to optimize desired geometries and joining methods.
- Discuss the implications of the results for the potential design of a low-cost community-based water treatment system in Ghana.

1.5 Expected Outcome

This project seeks to provide a filtration system capable of removing heavy metals from polluted water by illegal mining activities. The filtration system will provide safe drinking water for communities affected by mining activities. This project will focus on design the requirements, material selection, simulation, and analysis of the mechanical and flow properties of the water treatment system. Recommendation would be presented for fully self-assembled filtration system that will incorporate the use of carbon filter and colloidal silver in the various filtration processes. Water quality levels test will be compared with the WHO limits to ascertain the efficiency of the current systems.

Chapter Two

2.0 Literature Review

2.1 Effects of Heavy Metals on Human Health

H.M. is naturally present in our environment which consists of the atmosphere, lithosphere, hydrosphere, and biosphere [9]. As such, humans easily get contact with H.M. through the consumption of foodstuff such as fish, inhaling of polluted air such as dust and fumes from cars, and drinking water [9]. Metals such as lead, cadmium and mercury are the main threats to human health as a result of their exposure. During mining activities such as "galamsey", some H.M. are released from ores and spread around the environment. Some are left in the soil as well as transported by air and water to other places [9]. This causes the environment to be polluted causing humans to be easily exposed to H.M. In industrial processes, most H.M. are used for various industrial purposes which in effect, some elements are released into the air as combustion or into water bodies or the soil as sewage discharge [9]. In addition to that, industrial products such as pesticides, cosmetics, paints, and herbicides serves as a source of H.M. which can be transported to different locations on water bodies or soils through erosion or acid rain. Pesticides and herbicides are increasingly been used in Ghana. Hence the need to treat surface water for possible H.M. removal before such waters could be consumed.

2.1.1 Lead

Lead is a bluish, bright silvery metal in a dry atmosphere [10]. Human easily gets exposed to lead through drinking water, cigarette, food, domestic sources, and industrial process. Some of the industrial sources include house paint, storage batteries, toys, and gasoline [10]. Once it is released into the environment and taken in by humans, it carried by the red blood cells to the liver and kidney, and redistributed to other parts of the body such as the teeth, hair and bones as phosphate salt. As a result of this, it can cause lead poisoning. Lead poisoning can cause headache, loss of appetite, abdominal pain, kidney damage, brain damage and many more.

2.1.2 Cadmium

This metal is mostly found in industries in the production of coatings, batteries, plastics, paints and many others. Cadmium is emitted to the atmosphere through cadmium smelters and industrial processes into air, sewage, groundwater, and the soil [11]. When it enters the earth, it is taken up by plants and by ingestion through contaminated foodstuffs, humans are easily exposed. Also, humans can easily be exposed to cadmium by inhalation from the air particles. Once cadmium particles get inside the body, it makes it difficult for the body to excrete, which causes the kidney to re-absorb back to the body thereby limiting its excretion. It causes severe damages to the lungs and respiratory irritation. It can also cause lung and bone damages in the body [12].

2.1.3 Mercury

Mercury is a shiny silver-white, odourless liquid metal which becomes colourless and odourless once heated. Mercury is used in producing thermometers, dental amalgams, and some batteries [13]. In Ghana, mercury is used in illegal mining to recover pieces of gold that is mixed in sediments and the soil. These settles and combines to form an amalgam. The gold is then extracted by vaporizing the mercury [14]. Once there is exposure of mercury to humans, it can easily damage the kidney and brain. The increased exposure can alter brain functions and lead to changes in hearing or vision, tremors, vomiting skin rashes, lung damage and, high blood pressure.

2.2 Conventional Methods for the Removal of Heavy Metal

Conventional methods are appropriate measures and techniques used to remove H.M. from water sources because of its harmful nature to humans. Some of the traditional methods used include reverse osmosis, ultra-filtration, chemical precipitation, and membrane filtration [15-19].

2.2.1 Reverse Osmosis

Reverse osmosis is a type of filtration that uses a semi-permeable thin membrane with pores small enough to pass wastewater for the removal of H.M. Some H.M. such as Zinc (Zn II), Cadmium and Copper, are usually removed from polluted water using reverse osmosis.

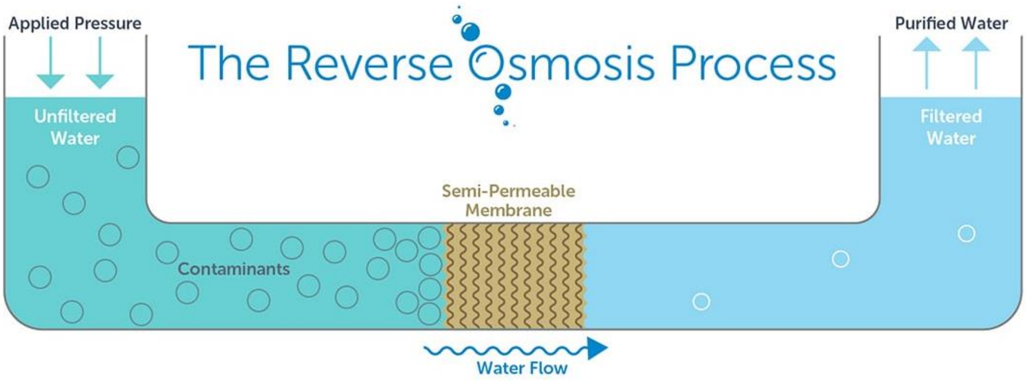


Figure 0.1: Reverse Osmosis Process [43].

2.2.2 Ultra-Filtration

This technique uses a permeable membrane separation process with small pore sizes in the ranges of 0.1-0.001 μ. When water passed through the membrane, it can retain the macromolecules, particles and colloids that are larger. With the assistance of a copolymer of malic acid and acrylic acid, it can remove H.M. from aqueous solution.

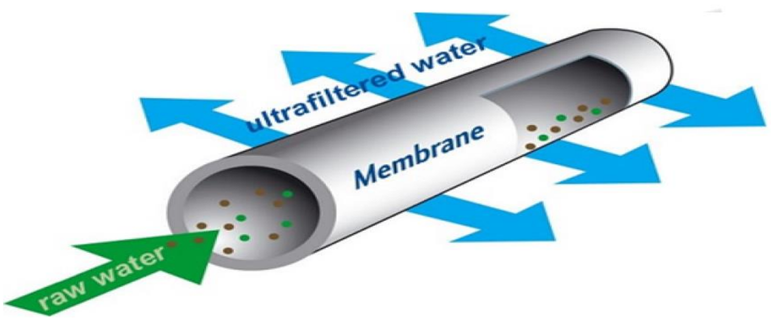


Figure 2.2: Ultrafiltration Process [44].

2.2.3 Chemical Precipitation

This method is the most widely used method for H.M. removal. H.M. are precipitated by precipitants which are chemical reagents and results to form metal hydroxides, carbonates and other insoluble solid particles that can easily be separated by sedimentation or filtration.

2.2.4 Membrane Filtration

This type of filtration technique is used for the removal of both H.M., solids and organic components as a result of its high separation efficiency.

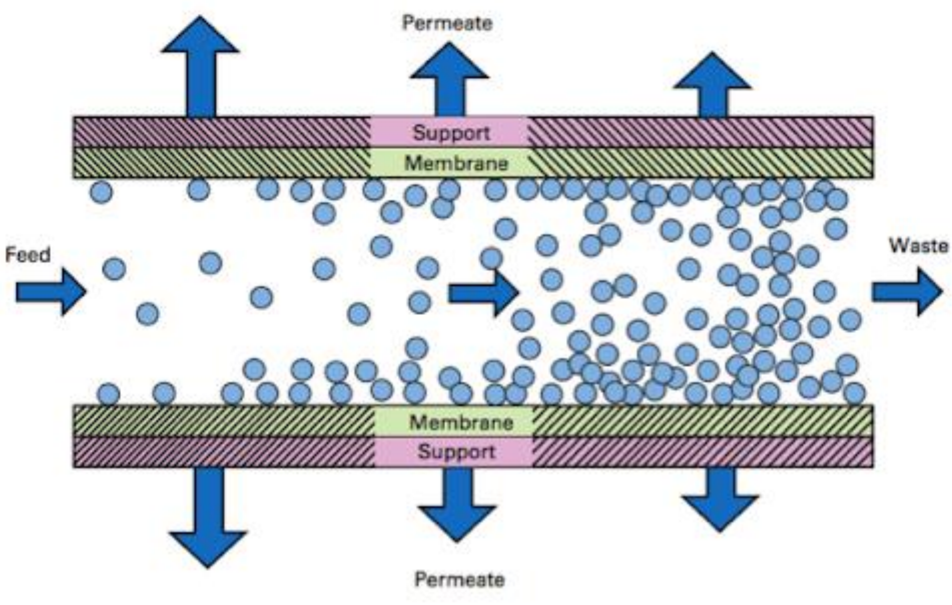


Figure 2.3: Membrane Filtration Process [45].

2.3 Low-Cost Removal of H.M.

Previous research in the last decades have provided vast information on eco-friendly and cheap methods of removing heavy metals from the environment. In 2016, Wael described how H.M. could be removed from drinking water using Activated Carbon (AC) obtained from Brown Algae [20]. The above studies also investigated the major parameter that affects biosorption. Some of the factors include temperature, solution pH, absorbent mass, contact time, and mixing speed.

H.M. pollution has been recognised as a significant environmental problem in surface and groundwater in so many countries around the world. Because of this, the US Environmental Protection Agency (USEPA), World Health Organization (WHO) and many government protection agencies have set the Maximum Permissible Limits (MCLs) for heavy metals in Industries.

Table 0.1: Table of Maximum Permissible Limits for Heavy Metals.

Metal	Primary Drinking Water Standard (MCL) mg/L	Secondary Drinking Water Standard mg/l	Hazardous Waste Screening Criteria (TCLP) mg/kg	TCLP Hazardous Waste Limit mg/kg	Common Range in Soils mg/kg	Livestock Water Quality mg/L	Surface Water Quality mg/l	Land Application of Sewage Sludge ppm
Aluminum (Al)		0.05 - 0.20			10,000 – 300,000	5.0		
Arsenic (As)	0.05		100	5.0	1-50; 1-40	0.5	0.04	75
Antimony (Sb)	0.006							
Barium (Ba)	2.0		2000	100.0	100-3,000		1.0	
Beryllium (Be)	0.004							
Cadmium (Cd)	0.005		20	1.0	0.01-0.7	0.5	0.02	85
Chromium (Cr)	0.1		100	5.0	1-1000; 5-3000	1.0	0.05	3000
Copper (CU)	1.3	1.0			2-100	0.5	1.0	4,300
Iron (Fe)		0.3			7,000-550,000			
Lead (Pb)	0.015		100	5.0	2-200	0.05	0.10	840

Manganese (Mn)		0.05			20-3,000			
Mercury (Hg)	0.002		4	0.2	0.01-0.3	0.01	0.002	57
Nickel (Ni)					5-500	1.0		420
Selenium (Se)	0.05		20	1.0	0.1-2.0	0.1	0.01	100
Silver (Ag)		0.1	100	5.0	0.01-5.0		0.05	
Thallium (Tl)	0.002							
Zinc (Zn)		5.0			10-300	25.0	5.0	

Compiled by: Brent L. Balentine 7/95 (Direction of Everett Wilson) (http://www.occeweb.com/og/metals-limits.pdf)

Previous researches have showed the possibility of H.M. removal using banana and orange peels. The study presented the eco-friendly approach (banana and orange peels) that could be used to remove HM from wastewater. Based on previous research, it was proven that banana and orange skins could be used as adsorbents to extract metals from wastewater [21]. This is because of large surface areas, high swelling capacities, excellent mechanical strengths, and are convenient to use and have great potential to adsorb harmful contaminants such as heavy metals [21]. Most industrial water treatment systems use Reverse Osmosis, Ultraviolet Purification, Filtration and Distillation, Electrochemical Reduction [21]. However, clear discussions on cost-effectiveness have not been highlighted in these approaches. The current project is, therefore, aimed to design a low-cost filtration system with self-assembly units to enhance user-friendliness. The stages of the filtration system would be well demonstrated to be accepted and implemented.

2.4 Biosorption

Biosorption is defined as the ability of biological materials to accumulate heavy metals from wastewater through metabolically mediated or physicochemical pathways of uptake [22]. Biosorption is a simple metabolically passive physicochemical process involved in the binding of metals ions (biosorbate) to the surface of the biosorbent which is of biological origin [22].

The use of microorganisms plan derived materials, biopolymers and agricultural waste can be used as biological removal. This reversible rapid process involves binding ions onto the functional groups which is present on the biosorbent surface by means oxidation. Some of the advantages are high efficiency, regeneration of biosorbent, no additional nutrients, low operational cost and many more. This can be used to remove contaminants from a diluted concentration [22].

2.5 Factors Affecting Biosorption

For biosorption, there are many complex processes that involves the binding of sorbate onto the biosorbent. The binding of metal ions can be physical (electrostatic interaction or Van der Waal forces or chemical (ion exchange) [23]. As a result of this, there are various factors that influence the biosorption process. This include biomass concentration, initial metal concentration and operational factors like pH, concentration of the initial metal ion, temperature, and concentration of the biosorbent.

2.5.1 Effect of pH

The presence of pH in wastewater can influence the metal chemical speciation solubility and the total charge of biosorbent [24]. When there is low pH in the wastewater, there exist a competition between the protons and metal ions for the binding sites causing the ions in it to be closely associate with the active ligands [25]. At higher pH, the H.M. in the wastewater might begin to precipitate and form hydroxides which hinders the biosorption process. This is because there exist lower number of H^+ ions and the number of active sites of the functional groups is free and exposed (negative charge) which will increase the bisorption by attracting positive charged metal ions [26].

2.5.2 Effect of Concentration of Initial Metal Ion

For initial concentration of metal ion, it can be overcome by mass transfer resistance between the liquid and solid phases [27]. The biosorption capacity of a biosorbent increases initially with an increase in metal ion concentration but the biosorption efficiency decreases when there is an increase in the metal ion concentration. Higher biosorption efficiency at low metal concentration is due to the complete interaction of ions with the available binding which sites results in higher rates of efficiency. At higher concentrations, the number of metal ions remaining unbound in the solution is high due to the saturation of available binding sites [28].

2.5.3 Effect of Temperature

Temperature deals with the thermodynamics of the process and kinetic energy of the metal ions [24]. With the temperature, there can be a positive or negative effect on biosorption at different intervals. When there is an increase or decrease in temperature, it causes a change in the biosorption capacity of the biosorbent. High temperature enhances the removal biosorbate, but the structural damage is also limited to the biosorbent [29]. Optimum temperature is needed for an efficient biosorption for maximum binding of the metal ions in the wastewater. In this context, a maximum biosorption of 86 % for cadmium ions was achieved at 40°C [30].

2.5.4 Effect of Concentration of the biosorbent dose

Stronger dosage affects the biosorption process since the biosorbent provide the binding sites for the metal [31]. When there is an increase of the biosorbent dose at a given initial metal concentration, it increases the biosorption of the metal ions due to its large surface area which also increase the number of available binding sites [31]. At lower concentrations of the biosorbent, the amount of metal biosorbed per unit weight of the biosorbent is high. Also, at high concentration of the biosorbent, the quantity of metal ion biosorbed per unit weight decreases. This is because of lower adsorbate to binding site ratio due to the insufficient amount of solute present for complete distribution onto the available binding sites and possible interaction between binding sites [32].

2.6 Adsorption Isotherms

Adsorption Isotherms deals with the equilibrium distribution of metal ions and how selective retention takes place when two or more biosorbent components and present. The nature of the interactions varies from system to system, so there are many adsorption isotherms models. [33]. The term "isotherm" can be defined as a curve explaining the retention of a substance on a solid at various concentrations [24]. With biosorption equilibrium isotherms, the biosorption capacities of different biosorbent for different pollutants can describe the process. Several isotherm models are available to describe the mechanism of the biosorption process and the equilibrium biosorption distribution. Some of the isotherms used in biosorption studies are Langmuir, Freundlich, and Temkin isotherms. However, the biosorption process may show better fit with a specific isotherm [34].

2.7 Scope of Work

The first chapter of the report presented the current issues surrounding illegal mining known as Galamsey. Effect of Galamsey activities that leads to pollution of water bodies have been highlighted. Literature review on methods of H.M. removal have been presented in the second chapter of this report. The third chapter summarizes the design and design requirements, materials selection and computational simulation of the water treatment system. Results and analysis are presented in the fourth chapter, while Conclusions and recommendations for a prototype of the water treatment system for H.M. removal are presented in the five chapter.

Chapter Three

3.0 Materials and Methods

3.1 Design Requirements

The following requirements were gathered based on the design choices:

- The materials use must ensure performance criterions are met. Example, mechanical durability of components and flow properties/parameters should be simulated to achieve desired outcomes.
- The filtration system should be a device that can function at the point of use and the cost of construction and maintenance should be cheap.
- The device should be able to remove H.M. from polluted water bodies by galamsey activities.
- The device should be able to remove bacteria with the use of a colloidal silver-impregnated ceramic filter. Also, any other impurities contained in the water should be removed as well.
- A storage tank must be available to store the clean, treated water for users to use without difficulty.
- The safety of the user should be ensured anytime by ensuring that water quality is maintained with routine testing/checking.

3.2 Materials Selection

Various materials were sourced for the fabrication of a filtration system. The clay was sourced from the Volta Region of Ghana. Sawdust materials were sourced from sawmills within Accra. Clay-sawdust composite was intended for the fabrication of ceramic-based filter for water filtration. Agricultural waste such as orange peels and banana peels were also sourced from fruit sellers at Kwabenya and its environment in Accra. Coconut husk/pods were obtained from coconut sellers to produce activated carbon. Steel pipes, galvanized steel square pipes, and aluminum metal sheet were also procured from metal shops at Kwabenya, Accra. Centrifugal water pump, Arduino Uno, and water flow sensor (Fig. 3.1) were supplied by Ashesi were supplied by Ashesi University, Department of Engineering.

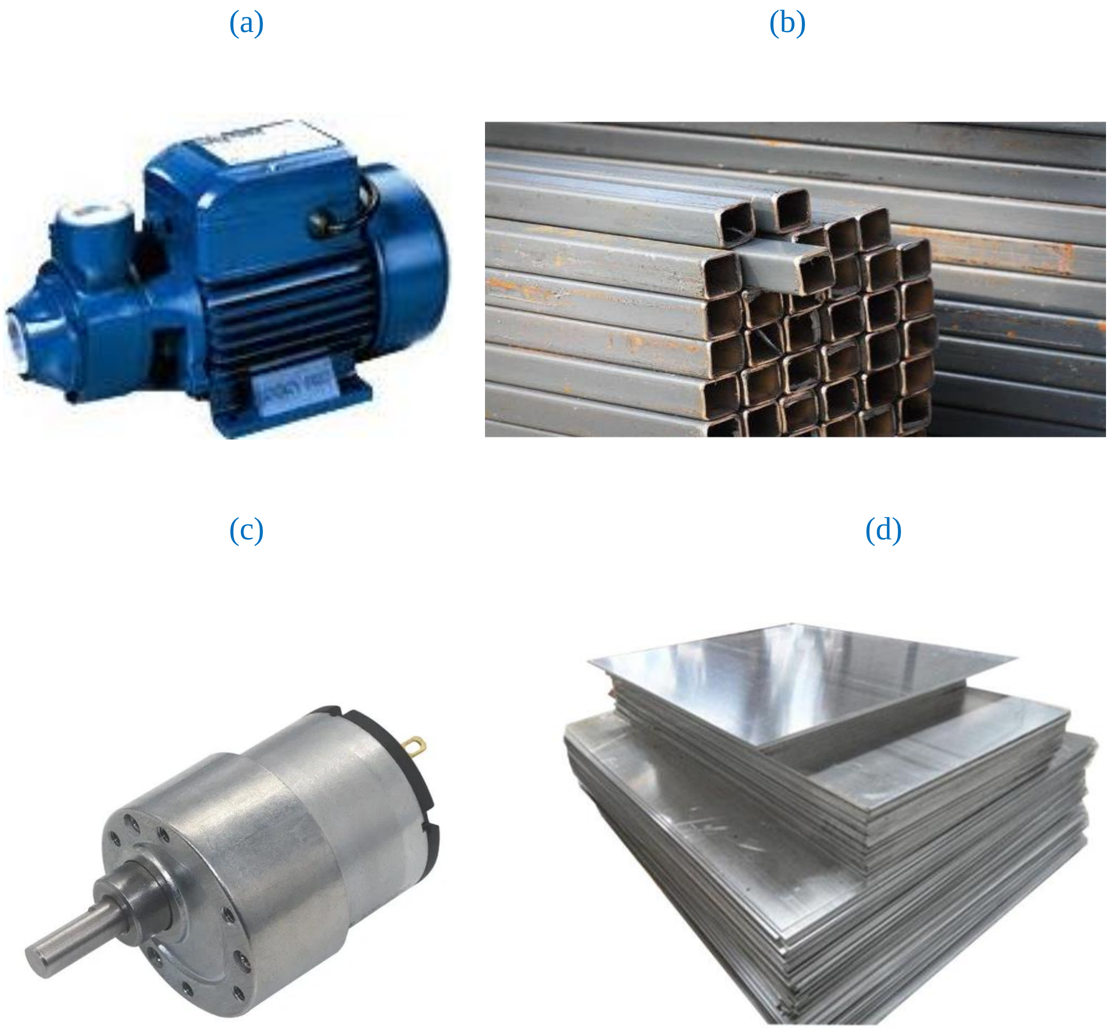


Figure 0.1: Materials List and Components Use: (a) centrifugal water pump, (b) galvanized steel square pipes, (c) brushless DC stepper motor, and (d) aluminum metal sheet.

(e) **(f)**

(g)

Figure 0.2: Materials List and Components Use: (e) Arduino Uno and, (f) water flow sensor and (g) activated carbon filter.

3.3 Justification for Materials and Components

Clay is an important material that could be formed as ceramic composite with reinforced sawdust. Firing the ceramic composites at higher temperature decomposes the organic matter (the sawdust) to produce a porous medium for water filtration. Porosity is how permeable a material becomes to allow fluid flows through it under the effect of a pressure gradient [35].

For the pores to influence the filtration of the wastewater, the pores created must be isolated and interconnected [35]. The ceramic matrix needs to be fired between the range of temperature 900-1000°C to achieve good sintering and flexural strength [35].

Orange peel is one of the most efficient adsorption technologies which can be used as an alternative to remove H.M. from wastewater [36]. Orange peels are low cost adsorbents which contain xanthates which is most prominent because they are highly insoluble, easy to prepare with relatively inexpensive reagents and have high stability constant values of the metal complexes formed [36]. These orange peels must go through proper modification which will help increase the adsorption capacity [36].

Coconut husk/pods can be acquired from the shell of the coconut. It is used in the production of activated carbon. The function of the activated carbon is to remove harmful impurities from the wastewater. Activated carbon is highly porous and has a very large surface area such that it makes it an effective adsorbent. The large surface area relative to the size of the actual carbon particle makes it easier for the removal of the impurities.

The centrifugal water pump uses energy to transfer water from one point to the other. By doing this, it increases the pressure in intake lines using pipes. The working principle of the water pump mainly depends on the positive displacement principle as well as kinetic energy to push the water. The pump uses an alternative current (AC) to power the motor of the pump which rotates the impeller of the pump to supply water within the filtration system.

Galvanized steel square pipes were considered for building the frame of the filtration system. They have protective zinc coated to the steel to prevent it from rusting. Also, this is easy to weld components together. These pipes are cheaper and have long life expectancy and can withstand mechanical damage.

Aluminum sheets (1mm thick) were considered for building the body of the filtration system due to its corrosion resistant and lightweight material.

Arduino is an open-source microcontroller board which is equipped with sets of digital and analog input and outputs. The microcontroller is used to program, to control and sense objects used in the automation of essential parts of the systems. For this purpose, the Arduino uno will be used to measure the flow rate at each point of the system.

The water flow sensor is used to measure the flow of liquid through the pipes of the system. This will allow the study of discharge and flow patterns in the pipe.

3.4 Experimental Procedures

3.4.1 Preparation of Orange Peel Powder

Once the orange peels are acquired, the peels are washed with distilled water to remove the dirt and dried in a convection oven for 24 h between 70°C to 80°C [36,37]. Once this done, it was finally crushed and sieve to acquire the powdered orange peels.

3.4.2 Preparation of Activated Carbon

The preparation of activated carbon begins with the coconut husk converting to pure form through heating. Carbonization was done using the box-type resistance furnace at a temperature of 400°C for 1 hr. The charcoal product was quenched using H_3PO_4 and $ZnCl_2$ as activating agents [38,39].

3.4.3 Fabrication of Clay Ceramic Filter

The clay and sawdust were crushed in a wooden mortar and pestle and sieved. The mixture was 25% sawdust and 75% clay. The clay and sawdust were mixed-and then wetted by adding water. The sample was rolled and cold worked to attain a homogenous mixture and a strong.

The clay was moulded into the flowerpot shape (**Figure *0.3***) allowed to dry at an average temperature of 25°C for about 15 days. After which the filter was then placed in furnace to be and fired between the temperature of 900°C to 1100°C.

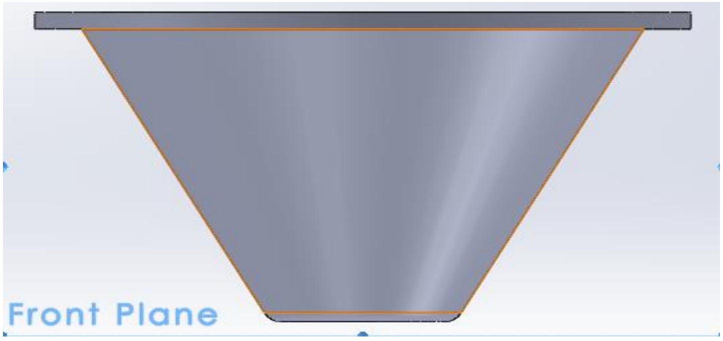


Figure 0.3: SolidWork Illustration of the Ceramic Filter.

3.5.0 Design and Simulation

3.5.1 Conceptual Design 1

The first conceptual design was proposal to filter wastewater to be safe for the user. It consists of the ceramic filter placed in a cylindrical shape container. The advantage of this design was that it could remove sediments from the wastewater. A disadvantage of this design was the fact that, the removal of impurities may not adequately be removed. Moreover, product from the water was not safe enough for the user in terms of heavy metal remove.

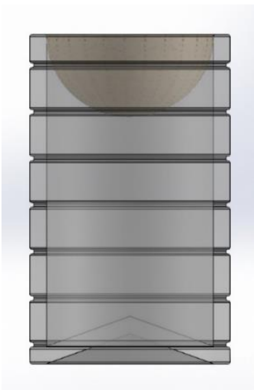


Figure 0.4: Conceptual Design 1.

3.5.2 Conceptual Design 2

For the design in *Figure 0.5*a below, it consists of the ceramic filters placed at the joint which connects the two barrels. *Figure 0.5*b consists of a ceramic filter containing powdered orange peels in the top barrel to remove target H.M. The filtered water is collected at the bottom tank. In this design, it was difficult to place the carbon filter which will remove the odour and impurities from the water. This was a disadvantage from the design.

(a) (b)

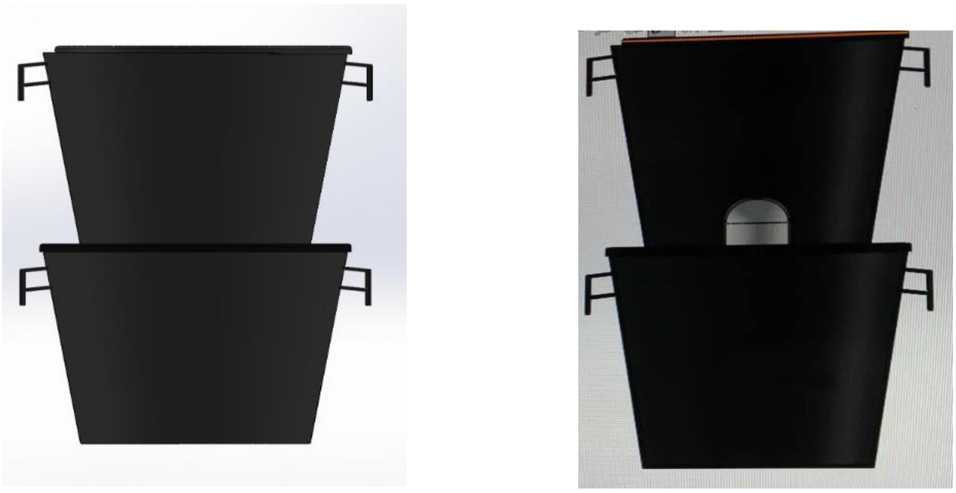
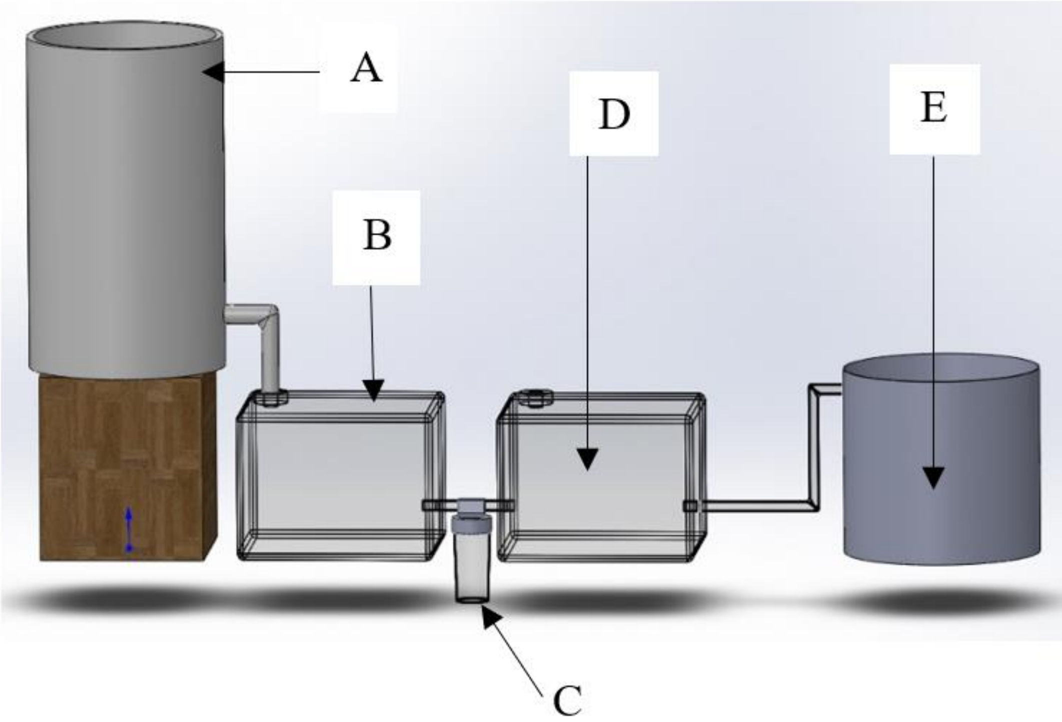


Figure 0.5: Conceptual design 2 with a ceramic filter: (a) no orange peels, and (b) contained orange peels.

3.5.3 Conceptual Design 3

For this design, it consists of 5 substations for the filtration as shown in *Figure 0.6*. This involves the ceramic filter, orange peel filter, carbon filter and the storage tank for the filtered water. The ceramic filter labeled A will remove sediments from the wastewater at the beginning stage. From there, filtered water flows to the orange peel units labeled B and D where orange peels are mixed with the water and continuously stirred with an incorporated propeller to remove H.M. The next treatment unit is a carbon filter labeled C to remove odour and impurities from the wastewater. Once this process is done, the water is stored in a storage tank labeled E for end use. However, this system was not portable for the user.

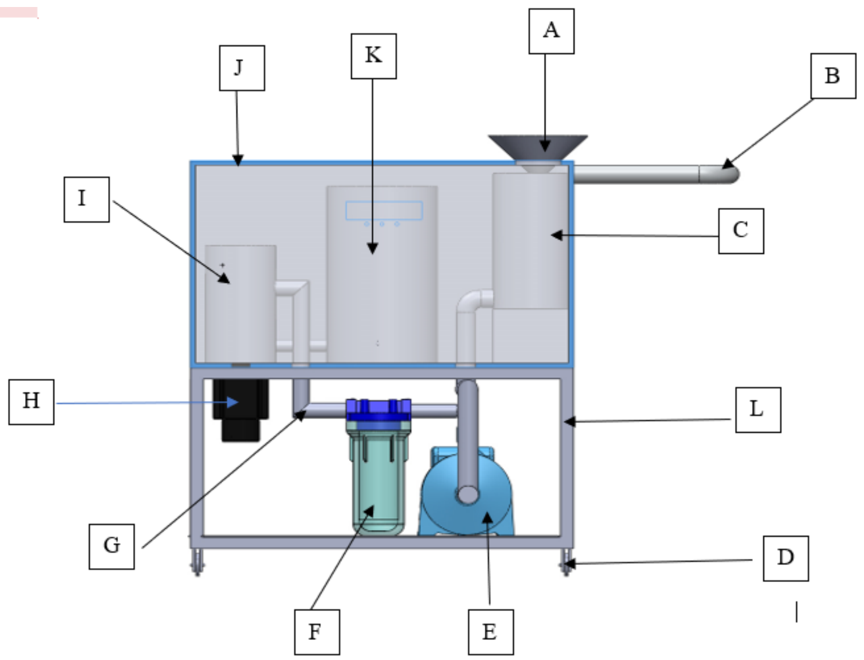


[A] Ceramic filter, [B and D] Orange peel units, [C] Activated carbon unit, [E] is a storage tank.

Figure 0.6: Conceptual Design 3 with labelled substations.

3.5.4 Proposed Final Design

After various iterations of the different conceptual designs, *Figure 0.7* shows the final proposed design for the filtration system. This consist of a portable system for user which ensured mobility. It also consists of a pump (E) which will help increase the flow of the water in the pipes. The funnel (B) at the top will also be used to direct the wastewater to the ceramic filter. The ceramic filter (C) is to ensure that sediments are removed from the wastewater. This system also consists of electrical components; AC water pump, Arduino Uno, water flow sensor in the filtration system, and a propeller with a miniature motor to ensure continuous mixture.



A Funnel, B Handle, C Ceramic filter, D Tyre, E Water pump, F Carbon filter, G inline pipe, H Stepper motor, I Orange peels filter unit, J Metal Sheet Covering, K Water storage unit, L System structure.

Figure 0.7: Proposed Final Unit.

1.6 Mechanical Computational Simulations and Analysis

3.6.1 Mechanical Optimization of Ceramic Filter

The optimization of the ceramic filter deals with the change of dimensions, the apparent porosity, absorption, the compressive strength, and the bending strength

The diameter of the ceramic filter would be measured before and after firing to measure the percentage change in the dimensions of the filter.

$$P_d = \left| \frac{d_a - d_b}{d_b} \right| \times 100 \quad (3.1)$$

where P_d is the percentage change in diameter of ceramic filter disc (in mm), d_b is the diameter of the ceramic filter before firing (in mm), d_a is the diameter of the ceramic filter after firing (in mm).

The apparent porosity and absorption were determined, respectively according to ASTM-C 373-88 standards, 2006 [40].

$$\eta = \frac{\text{Msa}-\text{Md}}{\text{Msa}-\text{Ms}} \times 100 \tag{3.2}$$

$$Wa = \frac{\text{Msa}-\text{Md}}{\text{Md}} \times 100 \tag{3.3}$$

where Md is the dry mass (g), Msa is the saturated mass (g), Ms is the suspended mass in water (g), Wa is the water absorption (%), and η is the apparent porosity (%).

The compression test will be performed according to ASTM-C773-88 standards, 2016 [41]. The bending strength with the equation below:

$$\sigma_c = \frac{F_c}{A_b} \tag{3.4}$$

where σc is the compressive strength of the ceramic filter (MPa), Fc is the total load of the ceramic filter at failure (N), Ab is the Area of the bearing surface of the ceramic filter (mm)

The bending test is performed using ASTM-C674-88 standards, 2006 [42]. The equation below is used.

$$M = \frac{3L\text{Fb}}{2bd^2} \tag{3.5}$$

where M is the Bending strength (MPa), L is the distance between the supports, F_b is the Load applied (N), b is the width of the ceramic filter, d is the thickness of the ceramic filter.

3.6.2 Optimizing the Shaft diameter

The shaft is connected to propeller to stir in the orange peel unit. The stepper motor used to turn the shaft produces an angular velocity of 10 -15 rpm. The turning effect as the shaft rotates is known as Torque. Knowing the torque produce from the 12 V, 15 rpm brushless motor which is 1.4709975 Nm with diameter 37 mm, the maximum shearing stress was numerically determined.

$$\tau = \frac{Tc}{J} \tag{3.6}$$

where τ is the shearing stress (Pa), T is the torque produced from the stepper motor (1.471), c is the radius of the shaft, J is the polar moment of inertia, and is given by:

$$J = \frac{\pi C^4}{2} \tag{3.7}$$

$$\therefore \ \tau = \frac{2T}{\pi c^3} \tag{3.8}$$

3.6.3 Mechanical Optimization of the Frame

The study of the framework deals with how the structure could handle the weight of the filtration units and other components such as the motor in addition to external forces such as gravitational force when acted on it. Analysis were made to the yield strength using stress and strain analysis to determine if the structure would deform plastically/fails. The total force acting on the structure was found using the numerical formula:

$$F = ma \tag{3.9}$$

where m is the mass of the filtration system and a is the acceleration due to gravity.

1.6.4 Optimizing the handle diameter

The handle **Figure *0.8*** can be distorted if it is designed with inappropriate diameter or subjected to load exceeding its peak load. The applied force, F by an average person of mass 70kg. Assuming an acceleration due to gravity, g of 9.8 m/s^2, the force of 686 N acting on the handle to lift the filtration system was determined from:

$$F = mg \tag{3.10}$$

where m is the average mass of a person. The cross-sectional area of the rod was calculated as $0.0925\ m^2$ from:

$$A = 2\pi rh + 2\pi r^2 \tag{3.11}$$

where r is the radius of the rod, and h is the height of the rod.

Knowing the yield strength of the selected material (1060 Alloy steel with a yield strength of 2.757×10^7 N/m^2), the calculated cross-sectional radius was determined from:

$$\sigma_y = \frac{F}{A} = \frac{F}{2\pi rh + 2\pi r^2} \tag{2.12a}$$

The designed radius of the rod was then determined from equation 2.12b with a force of 2F using a scale factor of 3.

$$\sigma_y = \frac{3F}{A} = \frac{3F}{2\pi rh + 2\pi r^2} \tag{2.12b}$$

where all the constants have their usual meaning.

The handle was simulated using Solidworks 2018 to analyze the static deformation when a force of 686N was applied to the handle. The material used was 1060 Alloy steel with a yield strength of 2.757×10^7N/m^2.

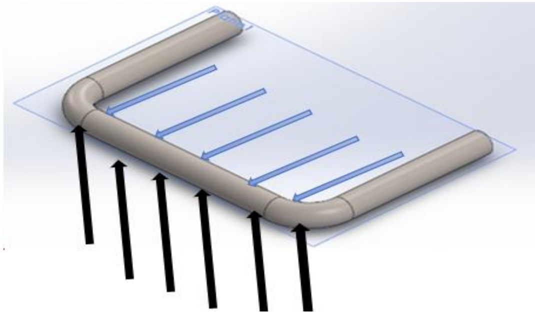


Figure 0.8: The handle of the filtration system.

1.6.5 Optimizing the Tyre

The rod of the shaft should be capable of supporting the weight of the framework structure and the various sub-unit of systems. Alloy steel with a yield strength of $6.204 \times 10^8 N/m^2$ was selected for the shaft rod. A single shaft would experience a force applied to it in four-point bending mode (Fig. 3.8a). The total weight of the filtration is distributed among the four mobile tyres which support the system via shaft (Fig. 3.8b). It comprised of diameter of 3.6cm and a material of alloy steel was chosen. The total weight of the system was 120 kg given a total load of about 1.176 kN on the shaft. This force is distributed on tyres of the system comprising of 294N on each tyre. Mechanical simulation with SolidWorks (2018 version) were performed to obtain the stress, strain, and deformation of the shaft at control mesh size.

(a) (b)

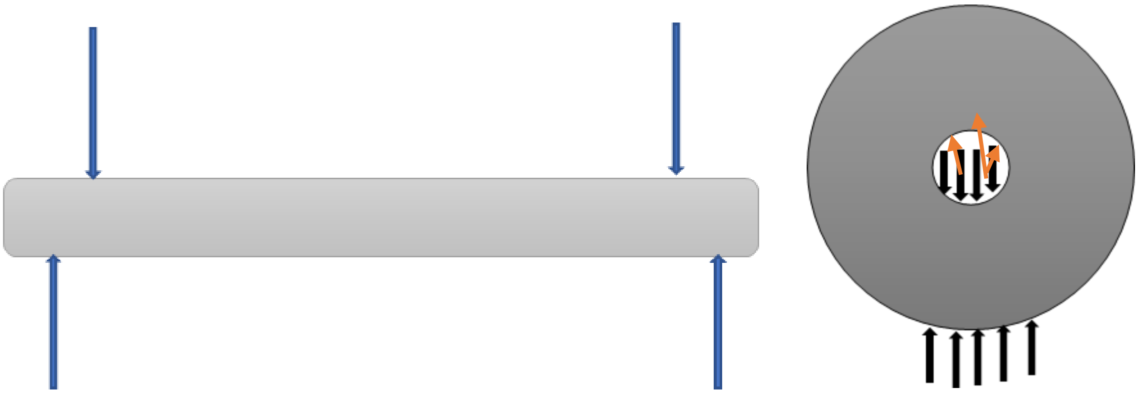


Figure 0.9: Load applied on the rod of the shaft tyre rod: (a) Four point-bending test and (b) Compressive force acting on the tyres.

With the yield strength of the alloyed steel, a scale factor of two was used to determine the radius of the rod for the shaft. The designed radius of the rod was then determined from equation 2.13 with a force of 3F (using a scale factor of 3).

$$\sigma_y = \frac{3F}{A} = \frac{3F}{2\pi rh + 2\pi r^2} \qquad (2.13b)$$

where all the constants have their usual meaning. The height of the shaft was estimated as 3.0 cm.

1.6.6 Simulation of the Stirrer Shaft

From the numerical analysis, the torque produced from the brushless stepper motor was used was 1.471 N.m. Mechanical computational simulations of the stirrer shaft were then conducted. The part attached to the motor was made static. The torque was applied to the free length of the shaft where the twisting force takes the place. Twisting stress distribution, strain and deformation were simulated. Probing was done along the shaft and the quantitative data is also reported.

(a) (b) (c)

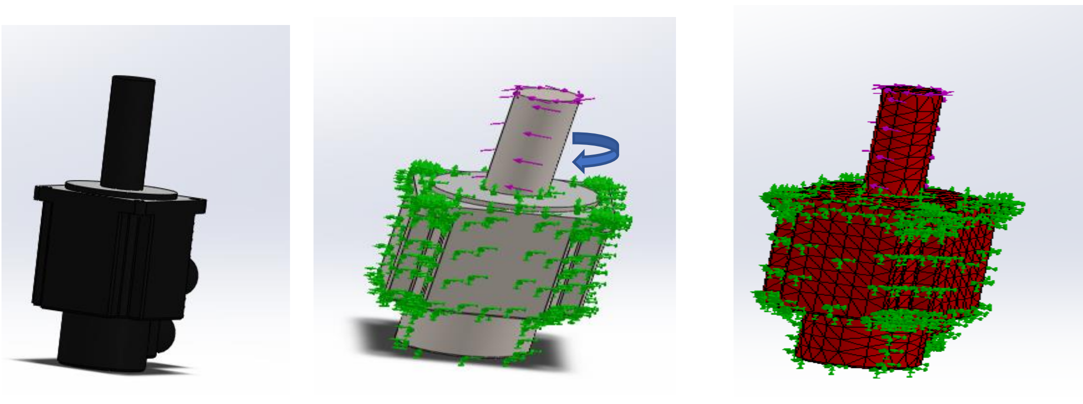


Figure 0.10: Stirrer shaft under torsional force: (a) Original diagram, (b) Stirrer shaft under torsional force, and (c) Meshed image of stirrer shaft.

1.6.7 Electrical Circuit

In Figure 0.11, it shows the flow sensor and LCD display circuit which is used to measure the flow of the wastewater in the inline pipes and displayed on the LCD. The image shows the initial implantation on breadboard to demonstrate how it will look. Final implementation will be put in a circuit box which will help protect the circuit from external damages.

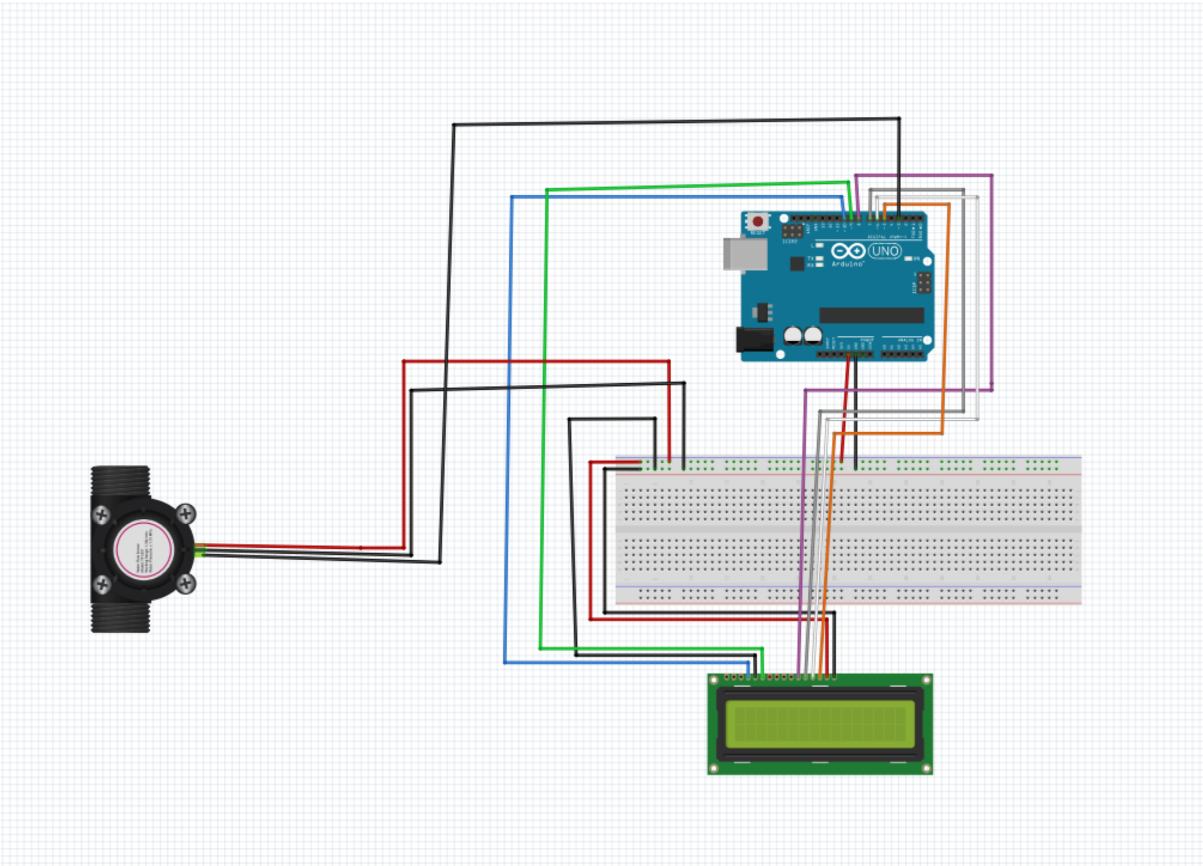


Figure 0.11: Water Flow Sensor and LCD display Circuit.

Chapter Four

4.0 Results and Analysis

This chapter discusses the results obtained from simulations that were perform on various part of the filtration system. This was to ensure that once the various parts were put together, the system will be able to perform its required function.

4.1 Numerical Results

From the numerical method, the shear stress of the stirrer was determined to be 50.62 Pa. This was within minimal forces required by the motor to achieve adequate mixing. The overall load acting on the filtration system was numerically determined to be $1176\ N$. The designed diameter of the shaft and hand were determined with a safety factor of 3 were 32mm and 635.5 mm, respectively.

4.2 Handle Analysis

For the handle, the force applied to it was 637 N. From **Figure *0.1***a, the minimum shearing stress of the shaft was 6.054×10^{2} N/m^{2} and the maximum shearing stress was 1.868×10^{5} N/m^{2} with a yield strength of 2.206×10^{8} N/m^{2} using a material of plain carbon steel. The calculated stress of the handle was $7417.139\ N$. From **Figure *0.1***b, displacement was high at the point where the user will hold to move the filtration system. The observed peak shear strength, 1.868×10^{5} Pa was less than the yield shear strength of $2.206\text{x}10^{8}$ N/$m^{2}$of the handle. This implies that the handle would not experience any plastic deformation when loaded under static loading. Hence, it is safe to be use for the intended application under static loading.

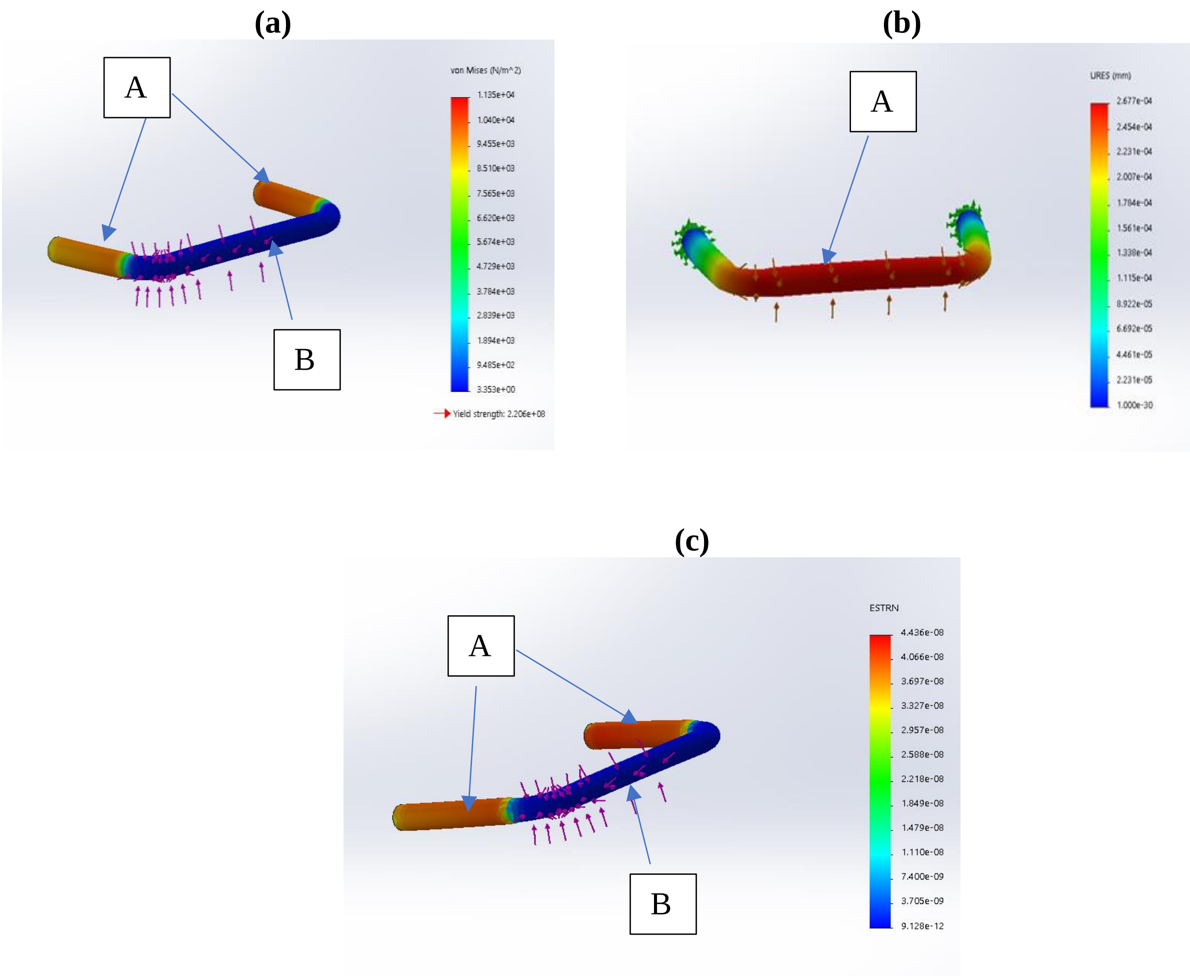
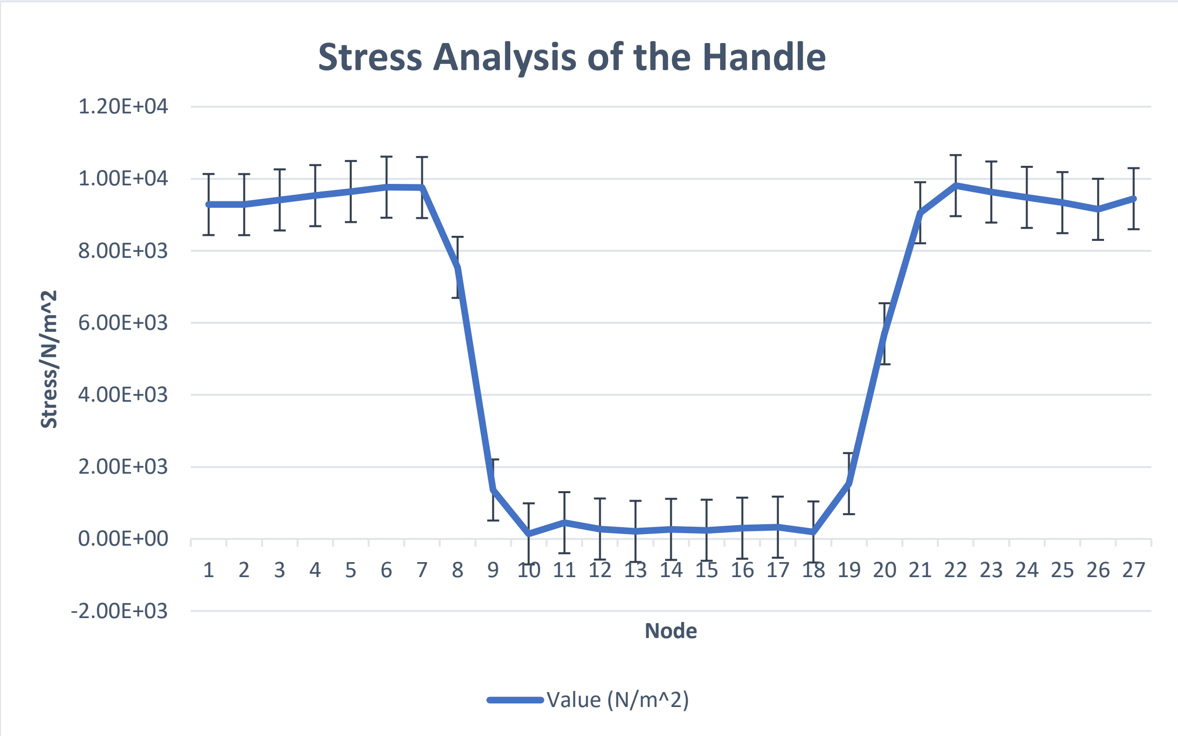


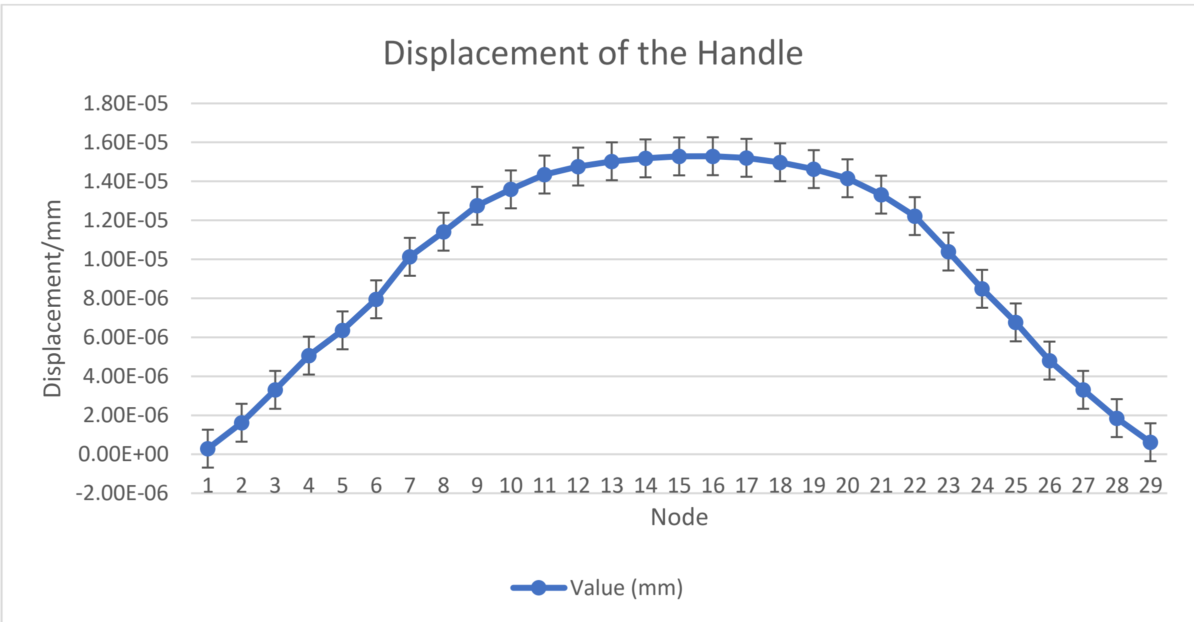
Figure 0.1*:* Simulated results on the handle: (a) stress distribution on the handle, (b) displacement of the handle, and (c) strain distribution on the handle.

The quantitative data was also drawn from the stress, displacement, and strain of the handle. From **Figure 0.2**a, the stress was higher at areas where the handle was fixed, at Point A to the filtration system with a stress value of 9.76x10^3 N/m^2 and lower at the Point B (3x10^2 N/m^2) where the user will hold the handle as shown in **Figure *0.1***a. Also from **Figure 0.2**b, displacement was higher at the middle section of the handle as pointed in Point A with a deformation of 1.53x10^{-5} mm as shown in **Figure *0.1***b. From **Figure 0.2**c, there was much higher strain at the part of the handle which was fixed to the filtration system at Point A with a strain concentration of $9.96x10^4$ N/m^2 and was lower at the point where the user holds the handle at Point B as shown in **Figure *0.1*c**.

(a)



(b)



(c)

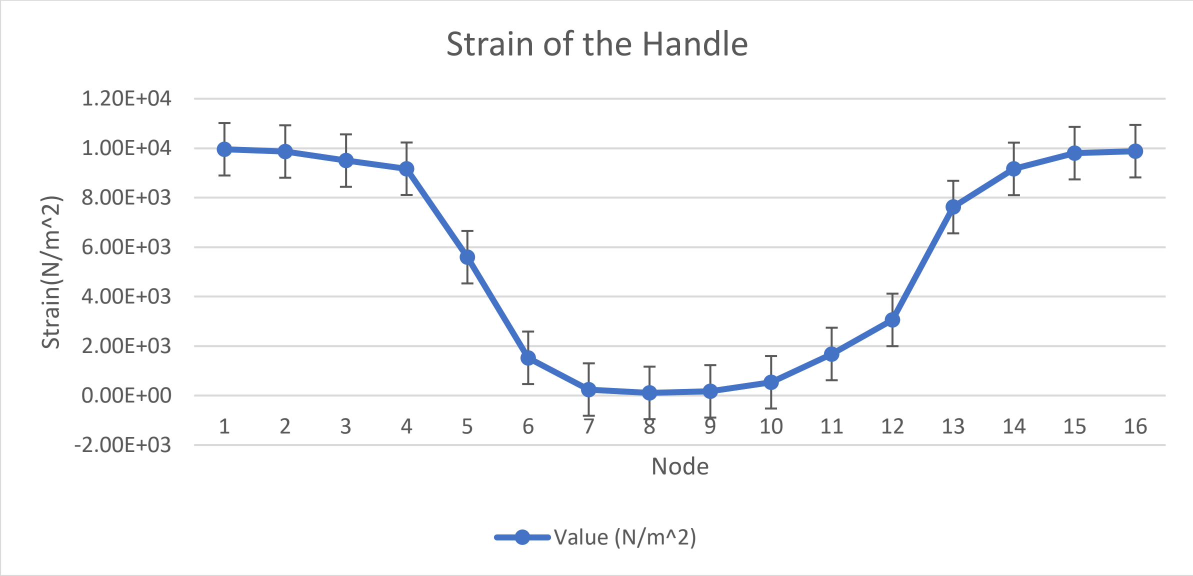


Figure 0.2: Quantitative data probed from the handle: (a) stress distribution on the handle (b) displacement of the handle, and (c) strain distribution on the handle.

4.3 Tyre and Tyre Rod Analysis

Analysis on the tyre and tyre rod were simulated based on the maximum weight that was applied to it. Since the weight of the system was estimated as 120 kg, the maximum applied force was calculated to be 3528 N using a scale factor of 3. Since the force applied is distributed among the four tyres. The force on each tyre and tyre rod was 882 N. From **Figure *0.3***a, simulations were performed on the tyre rod. The minimum stress of the tyre rod was 1.190×10^{6} N/m^2, whiles the maximum stress was 1.156×10^{7} N/m^2. The yield strength of the tyre rod was 2.482×10^{8} N/$m^2$for a carbon steel. The maximum strength of the tyre rod was less than the yield strength indicating no plastic deformation. Hence, the material will not yield and therefore, it can withstand the static loading during service at room temperature.

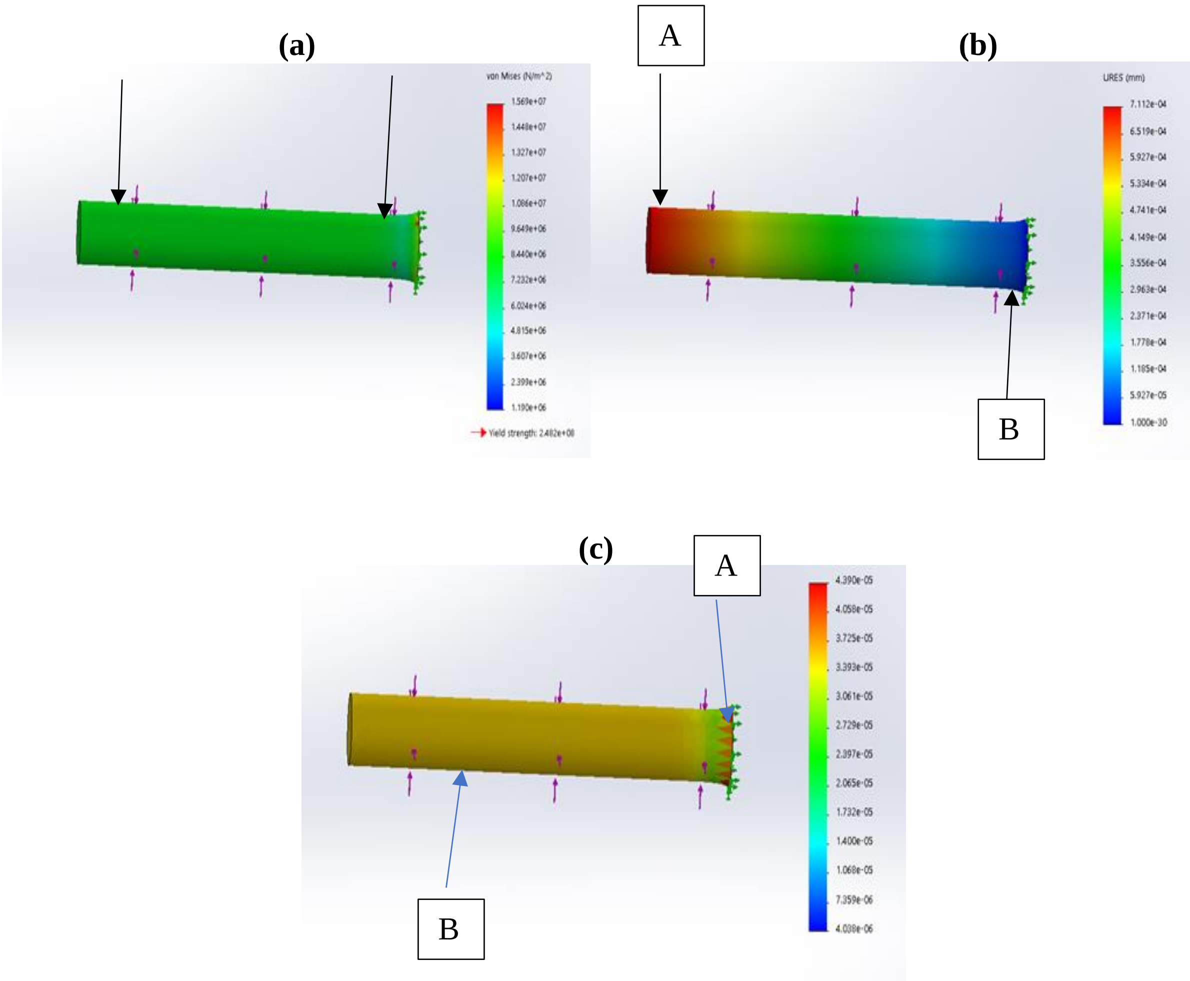
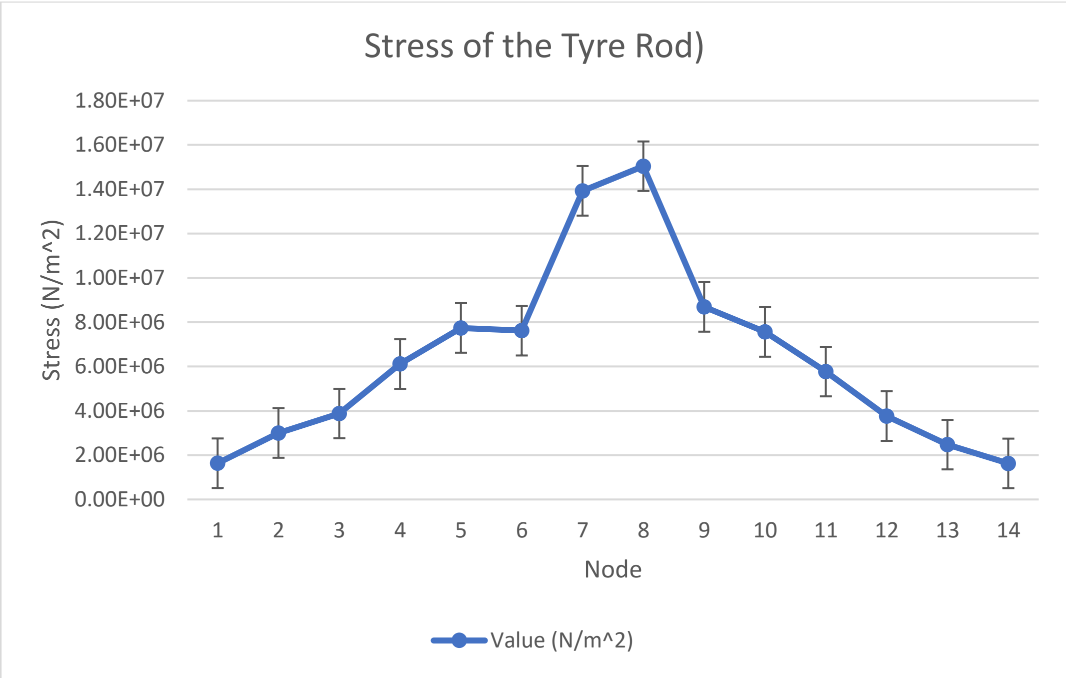


Figure 0.3: Simulated results on the tyre rod: (a) stress distribution on the tyre rod (b) displacement of the tyre rod, and (c) strain distribution on the tyre rod.

From **Figure *0.5***a, the tyre rod stress was higher at the point where the force was being applied as shown in ***Figure 0.3***a. Also from **Figure *0.5***b, the displacement for tyre rod was high at Point A (7.09 $\times 10^{-4}$ mm) of the tyre rod and low at Point B (6.63 $\times 10^{-5}$ mm)of the tyre rod as shown in ***Figure 0.3***b. The strain was higher at Point A (4.32 $\times 10^{-5}$ N/m^2) of the tyre rod and mid-range at the surface where the force was applied at point B (3.98×10^{-6} N/m^2) in ***Figure 0.3***c.

(a)



(b)

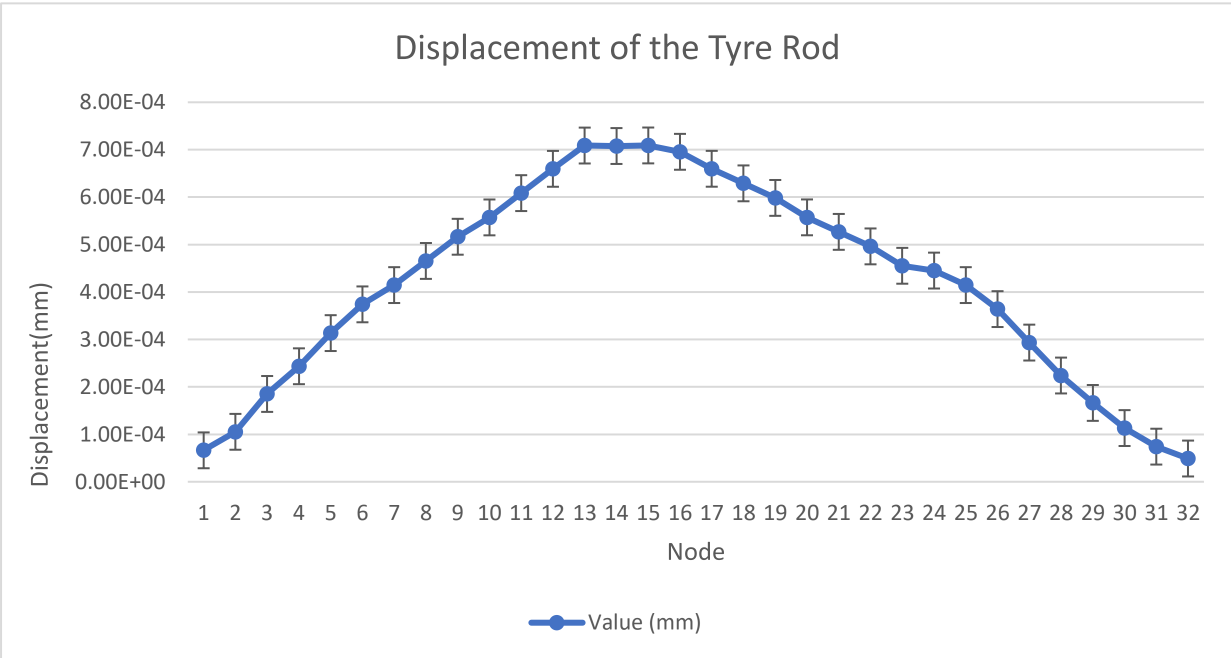


Figure 0.4: Quantitative data probed from the tyre rod: (a) stress distribution on the tyre rod, and (b) displacement of the rod.

(c)

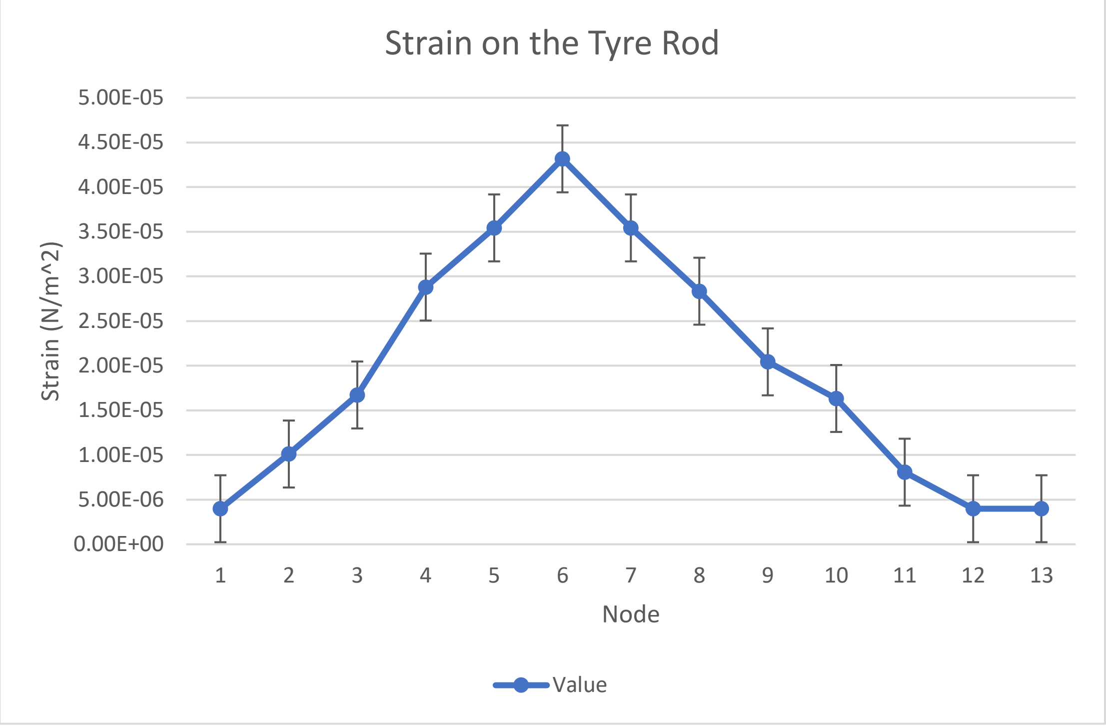


Figure 0.5: Quantitative data probed from the tyre rod: (c) strain distribution of the tyre rod.

For the tyre, the minimum stress of the tyre was 4.568 $\times 10^4$ N/m^2, whiles the maximum stress was 1.5$\times 10^7$ N/m^2. Material used was epoxy resin with yield strength 1.08$\times 10^8$ N/m^2. The maximum strength of the tyre was less than the yield strength indicating no plastic deformation. Hence, the material will not yield and therefore, it can withstand the load during service at room temperature.

(a) (b) (c)

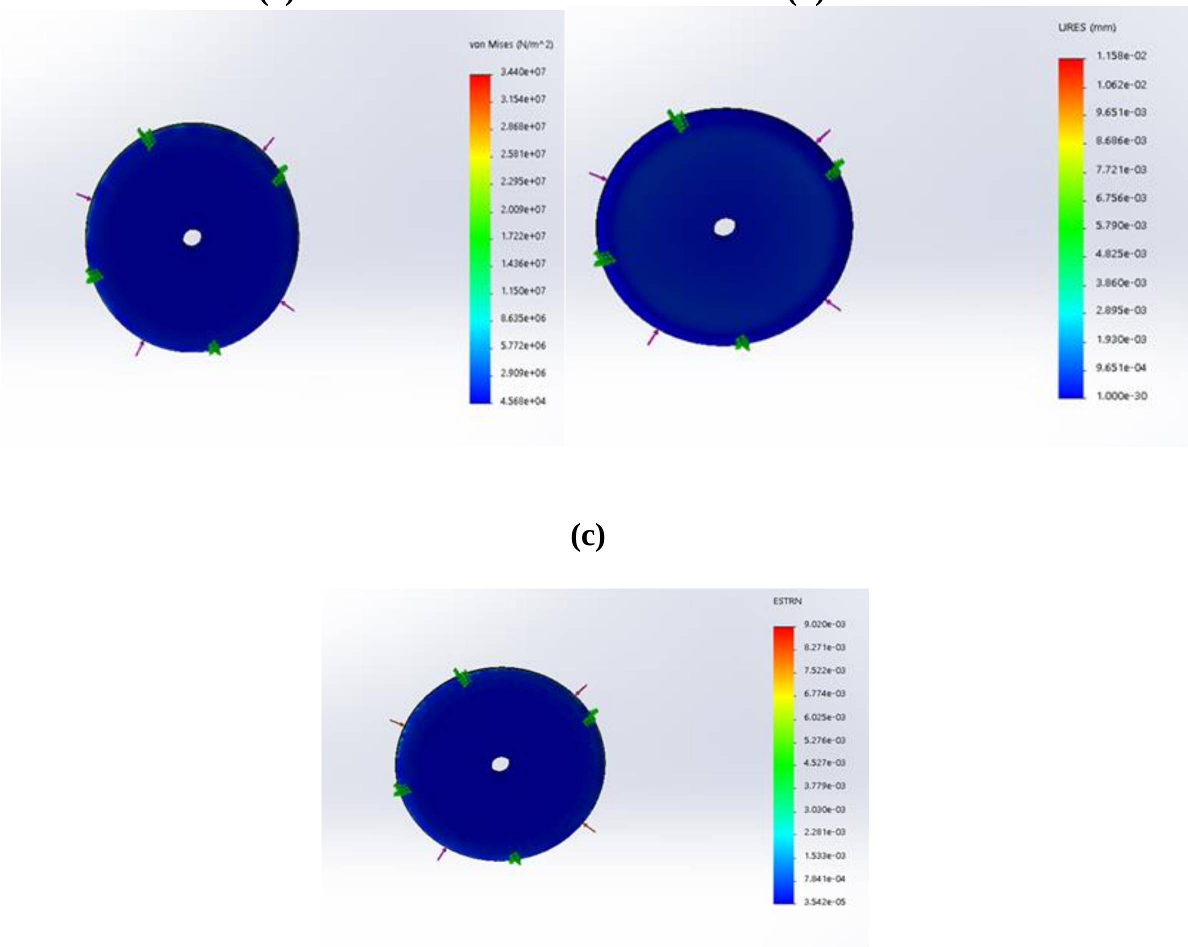
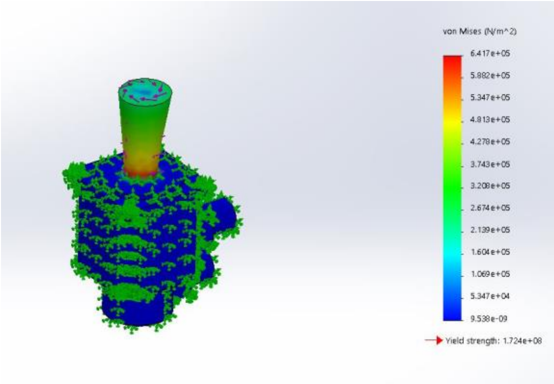
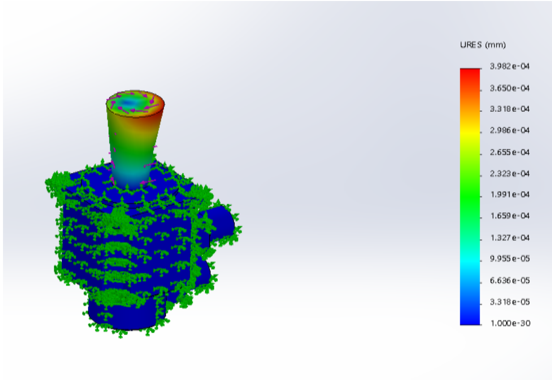


Figure 0.6: Simulated results on the tyre: (a) stress distribution on the tyre, (b) displacement of the tyre, and (c) strain distribution on the tyre.

4.4 Shaft Diameter Analysis

For-the stirrer in the orange peels filter, the torque produced from the brushless stepper motor was used to calculate the shear stress for the shaft connected to the stirrer. The torque applied to the shaft was 1.471 N. From **Figure *0.7*7**a, the minimum shearing stress of the shaft was $1.218\times10^{-2}\mathrm{N}/m^2$ and the maximum shearing stress was $2.297\times10^{5}\mathrm{N}/m^2$. The calculated shearing stress which was $50.62\ \mathrm{N}/m^2$ was between this range. The observed peak shear strength, $2.297\text{x}10^5$ Pa was less than the yield shear strength of $1.724\text{x}10^8$ $\mathrm{N}/m^2$of the shaft. This implies that the shaft would not experience any plastic deformation. Hence, it is safe to be use for the intended application that would ensure long fatigue life of the part.





(c)

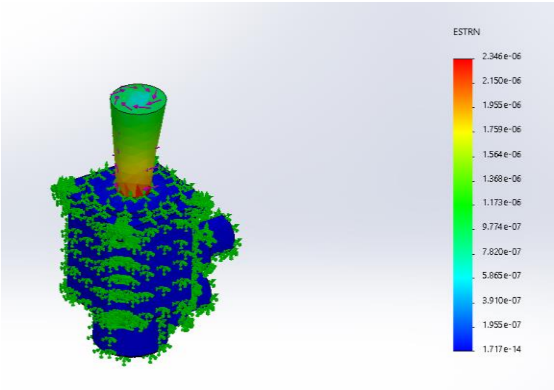


Figure 0.7: Torsion simulation of the shaft of the motor: (a) Stress distribution, (b) displacement, and (c) strain.

4.5 Framework Results and Analysis

The framework structure was simulated based on the maximum weight that was applied to it. Since the weight of the system was estimated as 120 kg, the maximum applied force was calculated to be 3528 N. The minimum stress (**Error! Reference source not found.**) of the framework was 7.987×10^3 N/m^2, whiles the maximum stress was 6.361×10^7 N/m^2. The factor of safety of the structure was 2. The yield strength of the framework structure (galvanized steel) was 2.039×10^8 N/m^2. The maximum strength of the frame was less than the yield strength indicating no plastic deformation. Hence, the material will not yield and therefore, it can withstand the load during service at room temperature

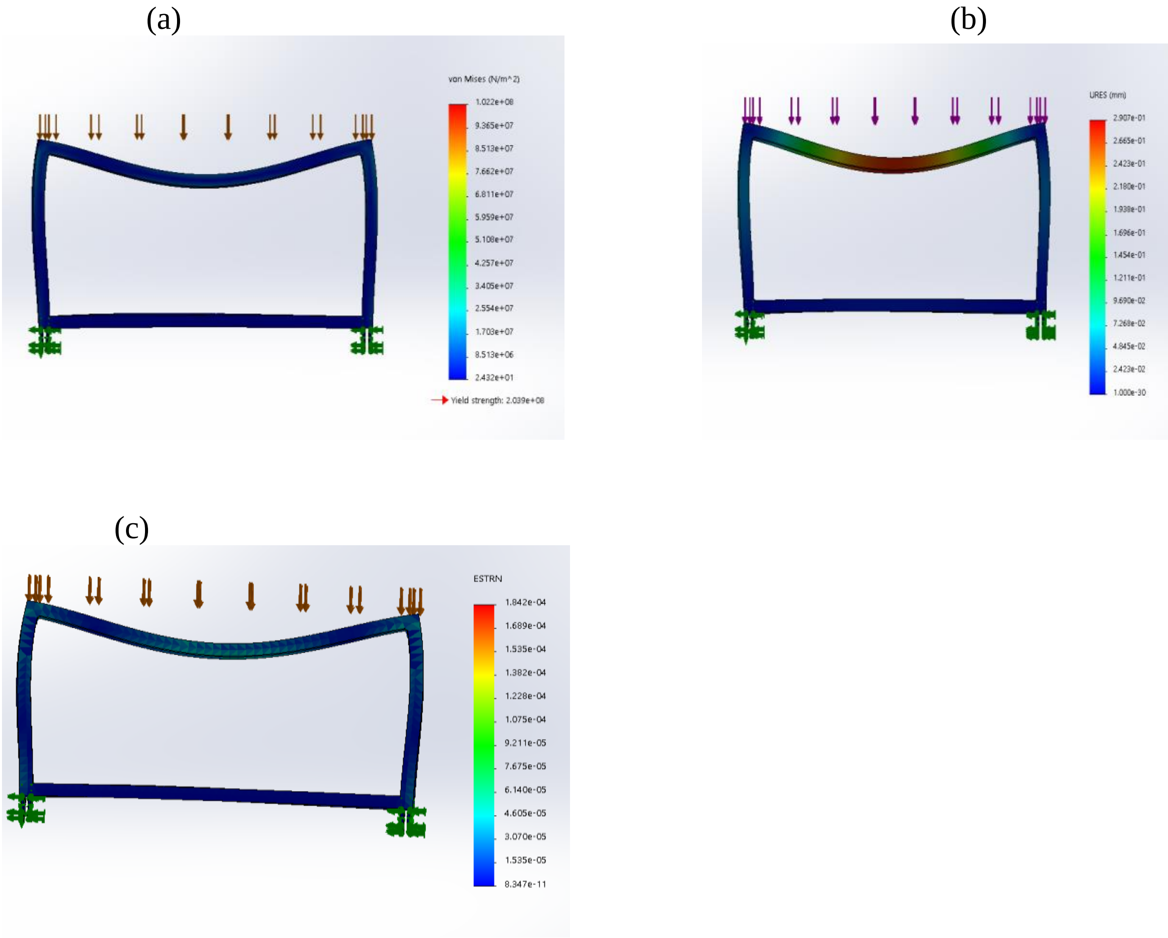


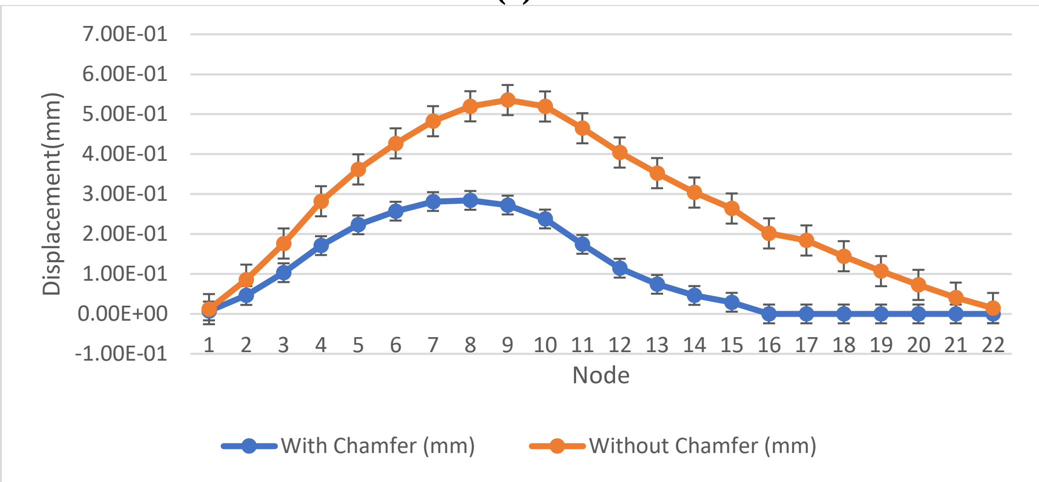
Figure 0.8: Mechanical simulation of the shaft of the motor: (a) Stress distribution, (b) displacement, and (c) strain.

The quantitative was compared using a framework with a chamfer and one without a chamfer. The maximum stress for the framework with chamfer was low as compared to the one without a chamfer as shown in

Figure 0.9a. From

Figure 0.9a.i., the maximum stress for the framework with chamfer was 2.10×10^7 N/m^2 and the maximum stress for the framework without the chamfer was 4.00×10^7 N/m^2. The percentage decrease of the maximum stress when the chamfer was added to the joints was 47.5%. This shows that the stress reduced as chamfers were put at the joints of the framework. Also, same was for the displacement of the framework. With the chamfer, the displacement was 0.284 mm and .545 mm without the displacement. The percentage decrease for displacement when the chamfer was added was 47.88%, This shows the displacement was significantly reduces as the chamfer was introduce to the joints of the framework.

(a)



(b)

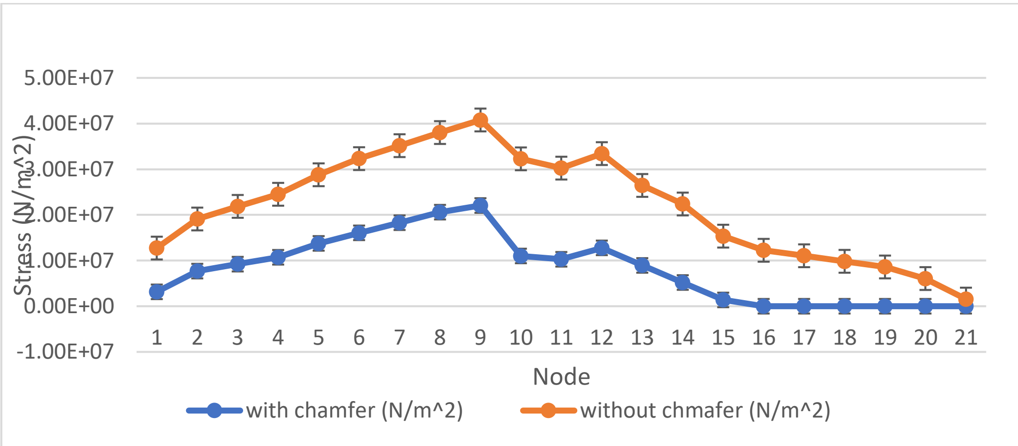


Figure 0.9:Quantitative data probed from the framework: (a) stress distribution on the framework with chamfer and without chamfer and, displacement of the framework with chamfer and without chamfer.

Chapter Five

5.0 Conclusions and Recommendation for Future Work

5.1 Conclusions

This work presents the design, analysis, and simulations of structural requirements for a water filtration system for the removal of heavy metals from 'Galamsey' polluted waters. Based on the analysis performed on the various parts of the filtration, the diameter of the tyre rod should be increased at a value greater than the estimate done to avoid failure due to fatigue. This will ensure that the product is used for an extended time before the rod deforms permanently. Also, the framework structure of the filtration system would be capable of supporting the whole system if the right materials and design consideration are met. It is therefore, recommended that the frame should be built within good tolerance or with increase thickness. Based on the quantitative data from

Figure 0.9, adding chamfer at the joints, especially during welding would reduce stress concentration at sharp edges and corners that would reduce deformation.

The torsion produced from the shaft for the stirrer was credibly good. This show that the designed diameter with a safety factor of 3 was appropriate. The shear stress produced due to the torque from the brushless dc motor will ensure the shaft last longer. Also, the handle of the system designed with stress below the yield strength. This will ensure the handle supports static loads. This also means that the selected geometry and materials selected were with the right fit.

5.2 Limitations

A lot of challenges hindered the accomplishment of the goals that were set to make this process a success:

1. Due to the ongoing pandemic (COVID-19), it was difficult to meet the initial goal of the project which was to design a fully functional water filtration system for the removal of heavy metals from polluted water. Although fabrication begun, work could not be completed and hence, goal could not be achieved.

5.3 Future Works

Illegal mining activities have endangered our water bodies for a long time. It will, therefore, take a very long time to acquire the polluted water bodies back to their natural state. Once this project is built on a larger scale, the filtration system can reduce the side effects of heavy metal consumption by citizens who drinks from the polluted water bodies.

Unlike the modern technologies currently in use which are associated with expensive processes to filter water, the current system hopes to use agricultural waste products such as orange peels or banana peels to reduce the cost of filtering polluted water in Ghana.

Due to the recent, epidemics happening across the world, a sensor can also be used to discharge water from the filter through a tap to help prevent the spread of viruses. Based on the designs, simulations and analysis, this work can be implemented in the future to help filter polluted water.

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