DESIGN OF A WATER FILTRATION SYSTEM FOR PARTICULATE ADSORPTION, HEAVY METAL REMOVAL, AND WATER QUALITY ANALYSIS

ASHESI UNIVERSITY

CAPSTONE PROJECT

B.Sc. MECHANICAL ENGINEERING

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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.

LESLEY KWASI SEYRAM LARTEY

2021

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 another degree in this university or elsewhere.

Candidate’s Signature:

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Candidate’s Name:

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Date: ……………………………………………………………………………………………

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 College.

Supervisor’s Signature:

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Date: ……………………………………………………………………………………………

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ABSTRACT

Through activities such as illegal mining, improper waste disposal and improper farming practices, sediments, organic matter, and Heavy Metals (H.M.) eventually find their way into human food and water. With the aid of the SolidWorks Computer-Aided Design software (2020 package) and mechanical testing, a cost-effective water filtration system design was proposed, approved and built for particulate adsorption and heavy metal removal from contaminated water bodies. After studying the stress, fatigue and strain values from SolidWorks simulations, the filtration system was built and galamsey-contaminated water samples from River Pra in Ghana was passed through the filtration system to test its effectiveness. The filtration system proved to be very effective in the removal of zinc, cadmium, and copper as well as suspended particulates from contaminated water samples.

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Chapter One

1.0 Introduction

1.1 Background

Water is an essential resource needed for the smooth running of everyday human lives, from domestic to industrial use. The World Health Organization (WHO) defines potable water as water that is clean and transparent, odorless, with no objectionable taste, and free from any kind of microorganism or chemical substance in concentrations that can cause public health problem [1]. Despite the importance of water in our lives, it is quite saddening that 66% of the Ghanaian population currently lack access to clean and safe drinking water [2]. Unfortunately, most surface waters in Ghana have been polluted through illegal mining activities, farming activities that involve the use of chemical fertilizers or herbicides along riverbanks as well as inappropriate disposal of waste such as dumping of solid and liquid waste into our water bodies. Large sums of unprocessed waste from domestic and especially industrial systems end up as pollutants in our water bodies, these could be either groundwater or surface water [2].

These pollutants could be classified as *point source* pollutants such as illegal mines and wastewater treatment facilities or *non-point source* pollutants like runoff that includes sediments, fertilizer and even landfills that manage to seep waste into waterbodies. Constituents of these pollutants mainly include organic matter, microbial pathogens, and heavy metals such as arsenic, copper, and lead [3], all of which make the water unsafe to be consumed.

It is a known fact that large-scale mining and export of mineral gold have been an integral part of the Ghanaian economy [4]. However, this has not come without its problems. Aside from the licensed and authorized companies that deal in large scale mining, individuals or gangs have been mining on smaller scales in the last decade. It is important to note that these small-scale mines are mostly illegal and have come to be known as 'galamsey' (meaning gather and sell). Because the small-scale mines are unlicensed and unregulated, their activities are mainly targeted at making profits without regards for the environment or the destructions caused to surface water bodies they pollute by washing mineral ores and chemicals in them. This has led to the rendering of some water bodies such as River Ankobra, River Pra in the Western and Central Region of Ghana, respectively unsuitable for consumption and fishing [5]

Research has shown that when untreated mining wastes are directed into rivers, they become polluted with heavy metals, organic matter and soil sediments which has changed their appearances (color and taste) and negatively affected aquatic life as well as the lives of people who directly depend on these waterbodies for drinking and fishing [5]. In less than two years of illegal mining activities along River Ankobra in the Western Region of Ghana, Figure 1.1 depicts the consequence of Galamsey which has caused high levels of water pollution due to the selfish interests of a few individuals. Figure 1.2 also depicts the sad state f the River Pra. Unfortunately, the governments of Ghana in the past and present are doing little to curb the problem. The worst part of the story is that an expose documentary by the BBC through the Tiger eye team in Ghana [6] shows most top government officials to be part of the dealings and, therefore, any effort to use security agencies to fight this menace yields little positive outcomes.

Figure 1.1: The State of River Ankobra in Less than Two Years of Pollution Due to Galamsey Activities.

Figure 1.2: River Pra as of 20^{th} April 2021

1.2 Problem Definition

Through the unregulated disposal of mining and agricultural waste in Ghana, water bodies such as River Pra and River Ankobra have become polluted with soil sediments, nutrients, organic matter and heavy metals which makes them unsafe for human and animal consumption [6]. Heavy metals (HM) are any metallic chemical element that has relatively high density and are toxic or poisonous even at low concentrations. Some of these metals are Mercury (Hg), Cadmium (Cd), Arsenic (As) and, Lead (Pb) [5]. Mercury is highly used in the mining of gold at galamsey sites in Ghana due to its amalgamation properties. After use, large portions of Mercury end up as pollutants in our water bodies. HM are very dangerous to public health and unfortunately, the bioaccumulative nature of HM only means that the state of water pollution is only going to worsen unless action is taken.

The local communities have resorted to boiling the waters before drinking for fear of pathogens. However, this practice would rather lead to an increase in the concentration of HM in water which results in even far worse effects on the consumer [7]. There is the need to provide a cost-effective solution to ensure ultra-filtration and absorption of HM in wastewaters. This work seeks to address these challenges for improved outcomes.

1.3 Motivation and Justification

My motivation for this work has been to properly use green technology such as ceramic filtration for particulate removal, activated carbon for enhanced taste, odour removal, and particulate adsorption, as well as using orange peels for heavy metal adsorption. Some indigenous people resort to using filtration methods such as solar disinfection (ultraviolet-visible light), chlorination, boiling, cloth filtering and sieving [5]. Although some of these methods are somewhat viable, they cannot guarantee to be effective in absorbing or removing heavy metals in polluted water.

Some locals have also resorted to drilling wells and boreholes for water instead of relying on the polluted surface waters. Though these water sources may be relatively cleaner, it does not take away the possibility that other pollutants such as heavy metals leech through the soil and contaminate these dugout wells and, therefore, polluting them [8].

HM pose public health challenges and, therefore, warrant their removal using science and materials found within our environment to cut down cost. The result shall, therefore, be compared with the WHO guidelines for the pollution levels of waters.

1.4 The Goal and Specific Objectives

The main goal of this work is to design a water filtration system for particulate adsorption, heavy metal removal, and carry out water quality analysis. In order to accomplish the above-mentioned task, clear and specific objectives shall be aligned toward this goal. The specific objectives are:

- Perform field research on the effect of illegal mining activities on water pollution: by visiting and collecting water samples from various mining sites for analysis.
- Obtain conceptual designs using SolidWorks on possible filtration systems.
- Preparation and characterization of activated carbon from agricultural waste materials.
- Preparation of orange peels for the absorption of heavy metals in polluted waters.
- Molding ceramic filters with reinforced natural fibres to enhance porosity.

- Perform absorptivity test, turbidity tests, pH, and conductivity test on filtered waters.
- To carry out water quality analysis for before and after filtration.
- To carry out ompressive loading analysis on functioning and load-bearing parts.

Chapter Two

2.0 Literature Review

2.1 Heavy metals and their impact on human health.

Metals are natural substances with high electrical conductivity which voluntarily lose their electrons to form cations. Metals exist over the earth including the atmosphere, earth crust, water bodies, and can also accumulate in biological organisms including plants and animals [9]. The various metals that are currently known exist are grouped under their abilities to be essential, beneficial, and detrimental to human health.

Trace element recognized by the W.H.O to be essential for human health include Iron, Zinc, Copper, Chromium, Iodine, Cobalt, Molybdenum and Selenium but in small quantities for them not to be harmful when consumed [10]. Metals classified as beneficial to human health also include Silicon Manganese Nickel and Boron. These metals are essential to vegetative life forms but are not essential for human or animal life which explains why they are beneficial and not essential [10]. The category of metals known to be detrimental are those regarded to be purely toxic metals that do not provide any essential or beneficial health effects at any level of exposure. Most of the metals in this category are classified as heavy metals, some of which are antimony, arsenic, cerium, gallium, cadmium, chromium, cobalt, copper, iron, lead, mercury, manganese, and zinc. Some characteristics they have are their high specific density (above 5 g/cm$^{3)}$ with atomic weight greater than 40.04 and their ability to bioaccumulate in the human body, damage nucleic acids, cause mutation, mimic hormones which leads to the disrupting of the endocrine and reproductive system which can finally lead to cancer (Fig. 2.1) [9]. Table 2.1 presents the possible permissible HM in water.

One of the main avenues through which heavy metals encounter human food and water is through the by-processes of mining. In countries like Ghana where illegal small-scale mining is on the rise, water bodies such as river Pra and River Ankobra have seen elevated levels of heavy metals such as lead (Pb), mercury (Hg), cadmium (Cd), copper (Cu), zinc (Zn), cobalt (Co) arsenic (As) and nickel (Ni). These are the main heavy metals involved in the gold ore mining and refining process [11]. When consumed, these heavy metals have varying effects on human health, some of which shall be discussed in the forthcoming paragraphs.

2.1.1 Lead (Pb)

Lead is a bright silvery metal with a bluish hue when it is in a dry atmosphere. Humans mainly come into contact with these heavy metal through drinking polluted water, smoking cigarettes and coming into contact with house paint, gasoline and storage battery processing plants. Lead is toxic even at its lowest concentration and naturally non-degradable [11]. The lead in the atmosphere due to the exhaust gases of vehicles may get into the soil, flow into water bodies and be absorbed by plants. People who then drink from these polluted waters or eat these plants become exposed to the heavy metal. Consumption of this heavy metal can lead to loss of short-term memory or concentration, nausea, loss of coordination and neurological changes in the consumer. In high doses, it can be fatal [11].

2.1.2 Mercury

Mercury has a shiny silvery look and is liquid at room temperature. When it is heated, it becomes a colorless and odorless gas that is difficult to see with the naked eye. Due to its good thermal characteristics, it is used for making thermometers. Mercury can also be used in making car batteries and in metal processing industries [11]. One of the main sources of mercury pollution is through mining activities. In Ghana, mercury is an essential resource in recovering gold residue that cannot be easily removed from soil sediments. When mercury is added to a gold ore and soil mixture it forms an amalgam. It is now easy to obtain the gold by vaporizing the mercury away from the mixture. The now gaseous mercury can damage the digestive, nervous, and immune system when it is inhaled [12].

2.1.3 Manganese

Manganese is added to gasoline fuels as methylcyclopentadienyl manganese tricarbonyl (MMT) because of its abilities to increase fuel octane ratings. Due to this, exhaust fumes are very rich in manganese and this makes the heavy metal present in the air we breathe [9]. The inhalation of manganese results in permanent neurological manganism. This disorder causes symptoms such as tremors, difficulty walking, facial muscle spasms and hallucinations [13].

2.1.4 Copper

Copper is another heavy metal used in industries for making pipes, cables, and cookware [9]. One of the main reasons why it is used is due to its excellent thermal characteristics. It is a good conductor of heat (about 30 times better than stainless steel). It is also present in some birth control pills. Over the years, research [14] has concluded that some households that use copper pipes experience increased levels of copper poisoning which was linked to their drinking water.

Symptoms of copper poisoning include diarrhoea, headaches, and severe cases such as kidney failure.

2.1.5 Arsenic

Arsenic is the 20th most abundant element and its inorganic forms arsenate and arsenite are lethal to humans and other organisms. Humans get into contact with arsenic through drinking water contaminated with wood preservatives, herbicides, and pesticides. People in smelting industries are also at risk of arsenic poisoning [9]. Ingestion of arsenic in large amounts can lead to gastrointestinal symptoms such as severe vomiting, disturbances of the blood and circulation, damage to the nervous system, and eventually death.

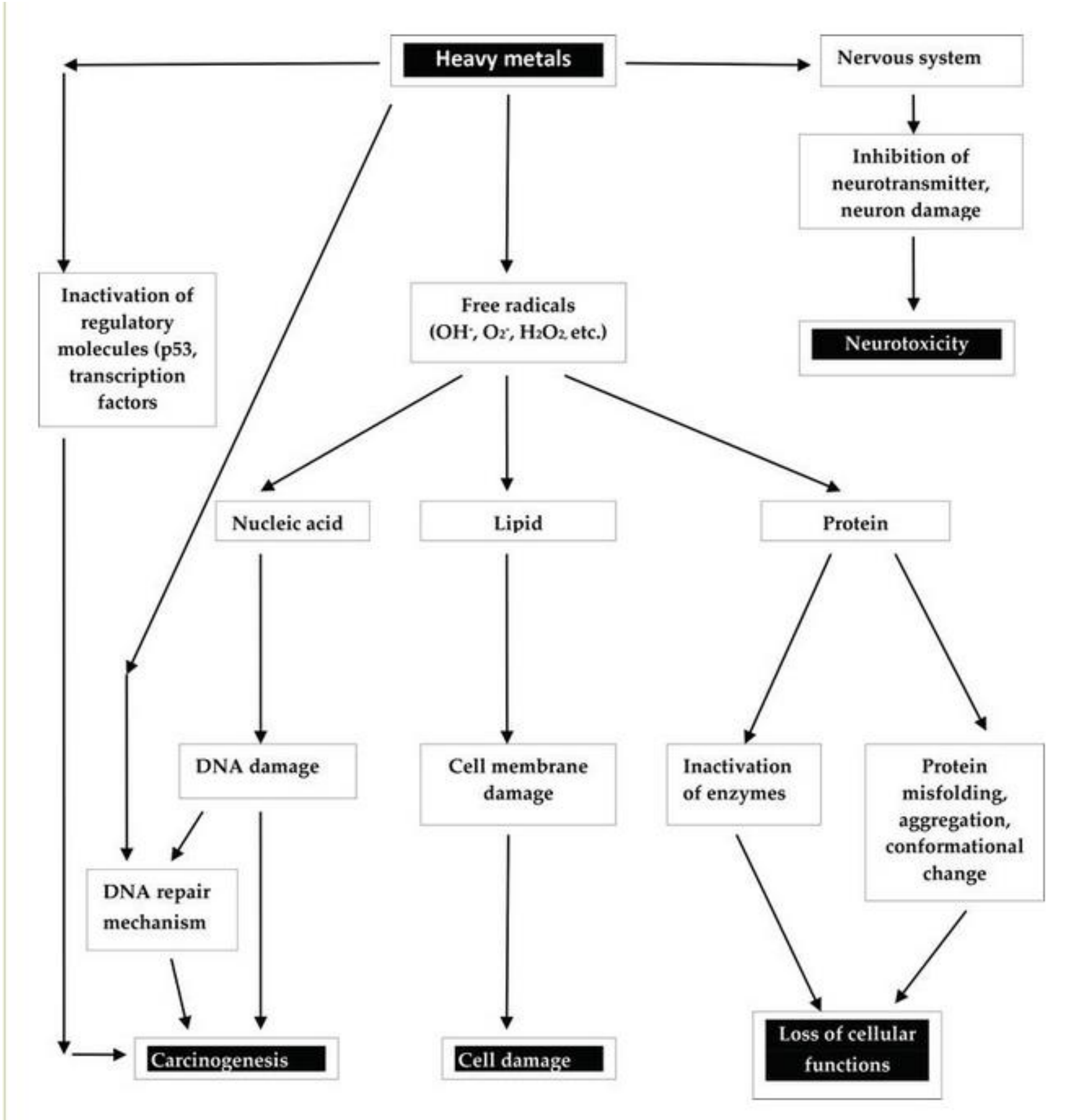

Figure 2.1: Pathway of heavy metals sources and exposure to humans [9].

Table 2. 1: Table of Maximum Permissible Heavy Metal Presence in water.

[9]

Heavy metals	EPA limits for drinking water (ppm)	OSHA limit in workplace air (mg)	FDA limit in bottled water/food(ppm)
Arsenic	0.01	10	-
Barium	2	0.5	-
Cadmium	0.005	5	0.005
Chromium	0.1	1	1
Lead	0.015	0.15	-
Mercury	0.002	0.1	1
Selenium	0.05	0.2	-
Silver	0.0001	0.01	-
Zinc	5	5	-

2.2 Conventional methods of water filtration

Water pollution caused by heavy metals from industrial and urban activities is a serious global issue due to its high toxicity, low biodegradability, and accumulation in the food chain [15]. Ever since the discovery of heavy metal pollution in water, there have been numerous experiments and tests done to remove or purify these waters for consumption. Some of the conventional methods applied are reverse osmosis, chemical precipitation, adsorption using activated carbon (highest efficiency>99%) and ultra-filtration [16].

2.2.1 Reverse osmosis

Reverse osmosis is a pressure-driven membrane technology that operates by rejecting dissolved salts, heavy metals, and particles from feed water bypassing the feed water through a semi-permeable membrane. The pressure gradient between the high-pressure feedwater and low pressure permeate acts as the driving force for the water across the membrane (Fig. 2.2). This occurs either through chemical potential difference or the concentration gradient of the water [17].

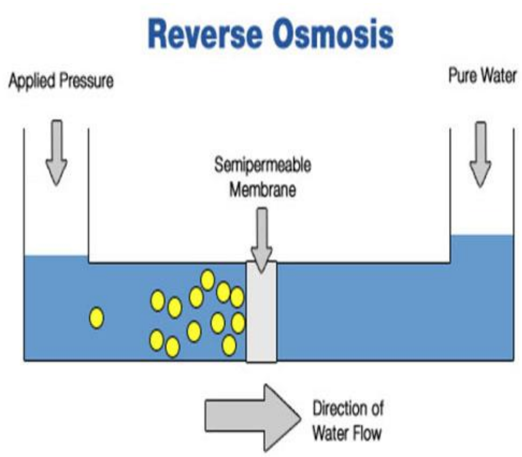

Figure 2.2: Reverse Osmosis illustration [18]

2.2.2 Chemical Precipitation

In treating HM polluted water by chemical precipitation, the ionic metals involved are converted into insoluble forms through a chemical reaction. The precipitating agent reacts with the ions and turns them into particles (Fig. 2.3) which can then be removed through settling or filtering [19].

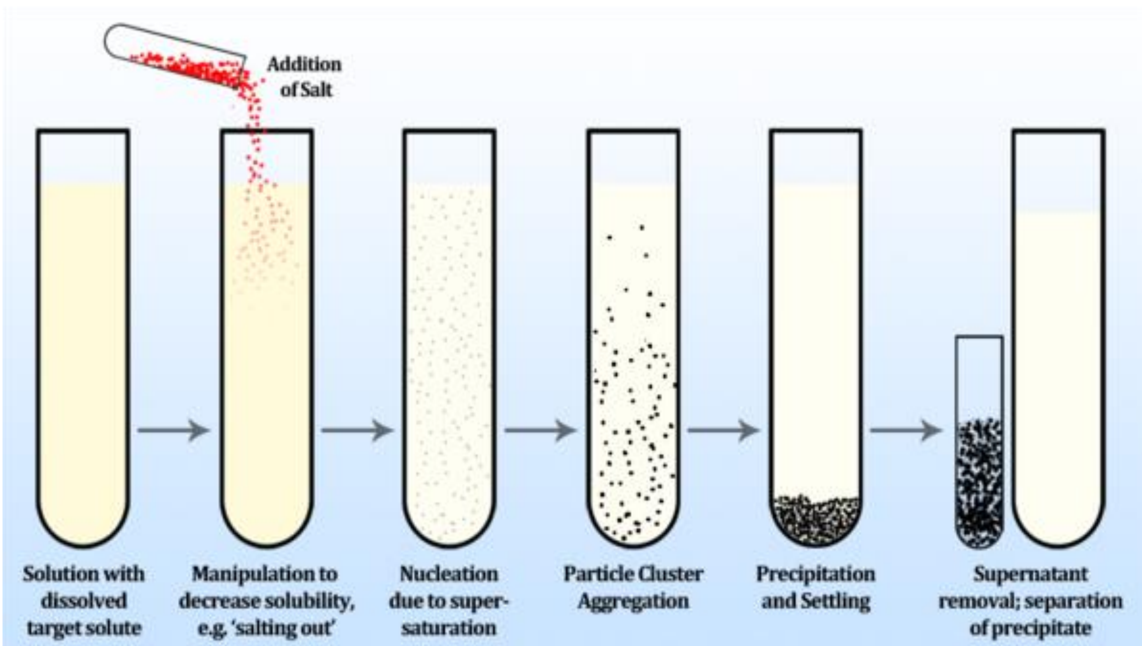

Figure 2.3: Chemical precipitation process, proceeding from an initial homogenous solution to the final separation of the target solute [20].

2.2.3 Ultrafiltration

Ultrafiltration is the process through which a series of barriers in the form of filters with gradually reducing micron size are used to filter polluted water and produce water with very high purity and low silt density (Fig. 2.4). With the assistance of a copolymer of malic acid and acrylic acid, it can remove H.M. from an aqueous solution. This filtration process is also capable of removing suspended solids, bacteria, and viruses.

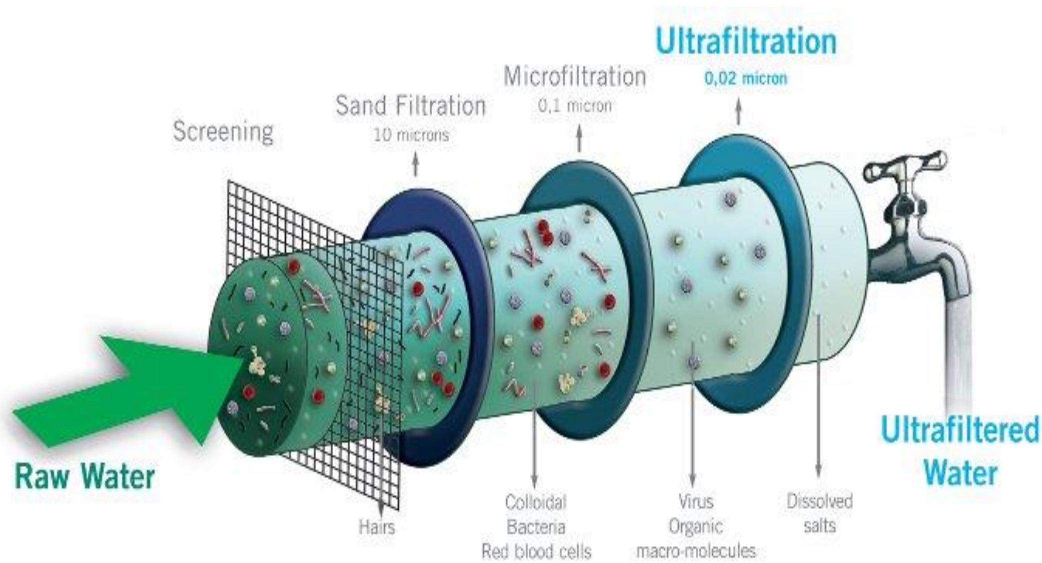

Figure 2.4: Illustration of ultrafiltered water [21].

2.2.4 Adsorption using activated carbon

Activated carbon filtering works through adsorption, the process where pollutants in a fluid become trapped inside the pore structure of the activated carbon thereby purifying the fluid (Fig. 2.5). This process could be used for water purification, air filtering and industrial gas cleansing. The activated carbon could be in the form of a cloth or powdered granules. This form of filtration is also proven to remove odor and bad taste from the fluids it purifies. The activated carbon could be obtained from coconut shells, palm kernel shells or even watermelon husks [22]. Different sources of activated carbon provide different absorptivity results due to their varying carbon content and carbon sources. Apart from being a very effective method of adsorbing organic pollutants in fluids, activated carbon filters are cost-effective to make and their raw materials are abundant especially here in Ghana.

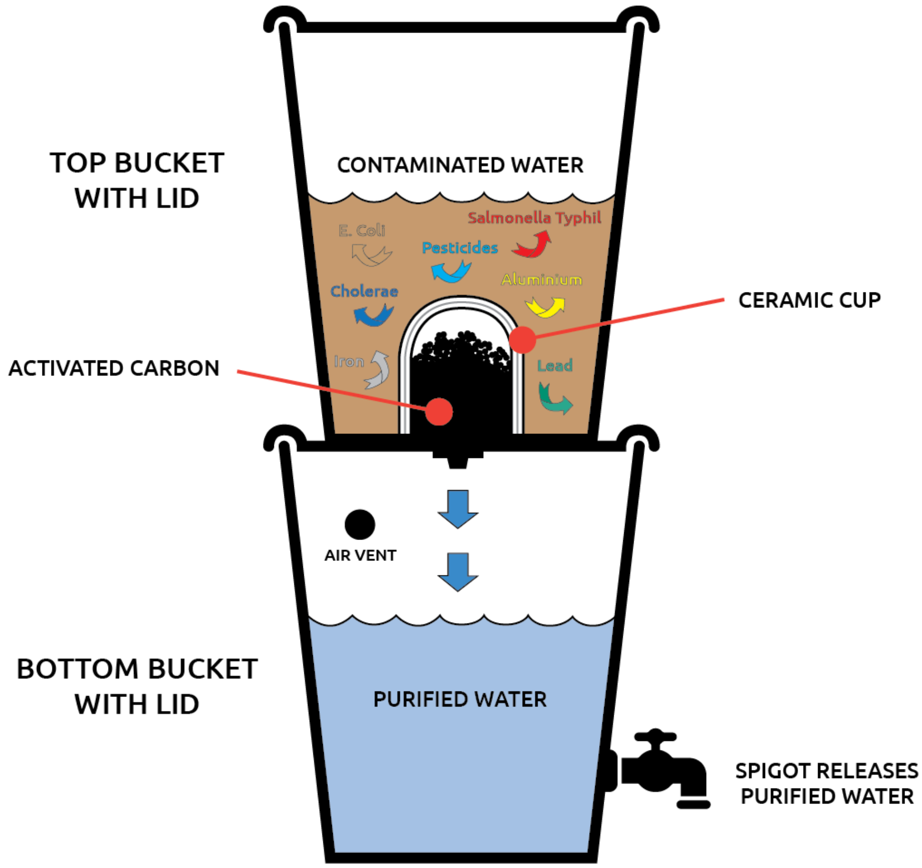

Figure 2.5: Illustration of Activated Carbon filtration [23]

2.3 Effective heavy metal removal from water

Even though to an extent activated carbon aids in the removal of heavy metals from contaminated water, Orange and banana peels have also been found to greatly aid in the removal of heavy metals in water through biosorption [24]. Biosorption is the ability of biological materials such as orange and banana peels to accumulate heavy metals from contaminated fluids. These materials can concentrate and bind heavy metals to their cellular structure, thereby purifying the water from heavy metals [25]. Other heavy metal removal processes include Ultraviolet Purification, Filtration and Distillation as well as Electrochemical Reduction but none of them proved to be as cost-effective and easily implementable as the use of orange skins and banana peels [24].

One of the core goals of this project is to build a very cost-effective purification system which is why I am more inclined to look deeper into the purification of water using activated carbon coupled with intense heavy metal adsorbers like banana peels and orange skins.

2.4 Scope of Work

Chapter one presented background information on water resources and pollution issues in Ghana. Motivation and proposed objectives for the project were also highlighted. The second chapter discussed the possible works done in water filtrations and some of their implications on water treatment. The third chapter presents the materials and methods section, especially on water filtration and water quality analysis with a homemade self-assembled system using local materials. Results and the implication of those results will be discussed in the fourth chapter of this capstone report. A summary of major results and recommendations for future works are presented in the fifth chapter.

CHAPTER THREE

Material and Methods

3.1 List of Materials

SolidWorks computed aided designing software was provided by the Ashesi University Engineering Department for three-dimensional modelling and simulation of all subsystems. The Logger Pro water quality analysis software, pH sensor, conductivity meter and turbidity sensor were also provided by the Ashesi University Engineering Department for the use of this project. Coconut activated carbon filters were supplied by Kofi Addae Boahen (Ashesi Alumni) who pioneered this study at Ashesi University in 2020. A 120-litre square polyvinyl chloride (PVC) trunk and a Veronica bucket were purchased from a provision shop in Ablekuma- Ghana to substitute for the storage tank and filtered water container, respectively. Two-inch diameter PVC pipes, flexible water hose, and rectangular steel frames were also procured from Chosen Son Ventures shop in Taifa for plumbing activities. A centrifugal water pump was also procured from the Ablekuma-Olebu Melcom store. Orange peels were locally obtained from fruit sellers in Ablekuma and processed into powder for HM absorption. Clay samples were supplied by a local clay vendor in Achimota for the fabrication of a ceramic filter.

Sawdust was sourced from wood production sawmills that dealt in Wawa wood processing to serve as a reinforced phase which when combusted, creates the necessary interconnected pores that enhance water filtration. An improvised homemade furnace was used to combust, and heat treat the clay. The polluted river water was collected from River Pra (6° 33' 59" N, 0°57’23” W) for filtration and analysis. Welding electrodes were also available to support the process of welding the steel frame.

(a) (b) (c) (d)


GAC
Filter shell
Activated carbon filter
catridge

(e) (f) (g)


Optima
PUMP OP-WP-90

(h) (i)

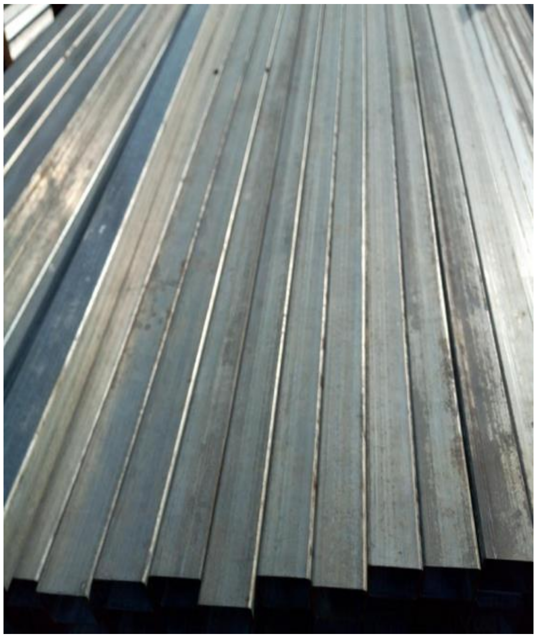

Figure 3.1: List of Materials Used in Building the Water Filtration and Absorption System: (a) P.V.C. trunk, (b) Veronica Bucket, (c) Activated Carbon Filter, (d) Clay sample, (e) Flexible Water Hose, (f) Centrifugal pump, (g) Dried orange peels, and (h) Square Steel Frames, (i) Crushed and sieved orange peels.

3.2 Design Requirements

- The entire system must be cost-effective in the sense that building and testing it should not exceed GHC 500.
- Appropriate material selection techniques must be implored to achieve the desire functionalities of components within the system.

- The device should be able to work continuously whilst requiring minimal maintenance.
- The ceramic filter should be capable of removing solid particles and macro pollutants in the water sample.
- The orange peel coupled with the activated carbon should ensure the removal of solid pollutants as well as heavy metals.
- The system must be easy to maintain, and it must filter at least 240 litres of clean water every 24 hours.
- The filtrate storage tank must be able to contain the purified water safely without getting it contaminated.
- The water pump selected should be able to pump the polluted water into the feedwater storage tank at a height of 2 meters.
- The scaffold for the filtration system made of steel should be able to provide and support the desire mechanical load.

3.3 Materials Selection and procedures

The system was divided into six subsystems (Fig. 3.2) depending on their functions. These subsystems are the

i. Storage container for polluted and filtered water.
ii. Organic matter, dirt and macro pollutant removal subsystem.
iii. Particulate adsorption subsystem.
iv. Heavy metal removal subsystems.
v. Plumbing subsystem.

vi. Structural and support subsystem. `

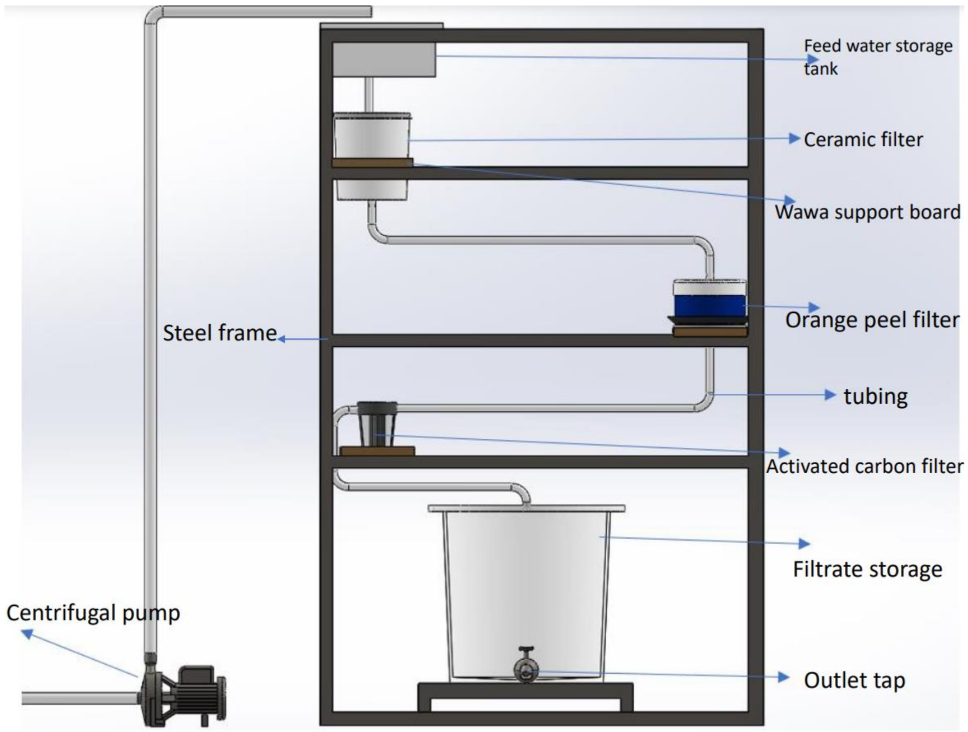

Figure 3.2: Fully Self-Assembled System for Water Filtration.

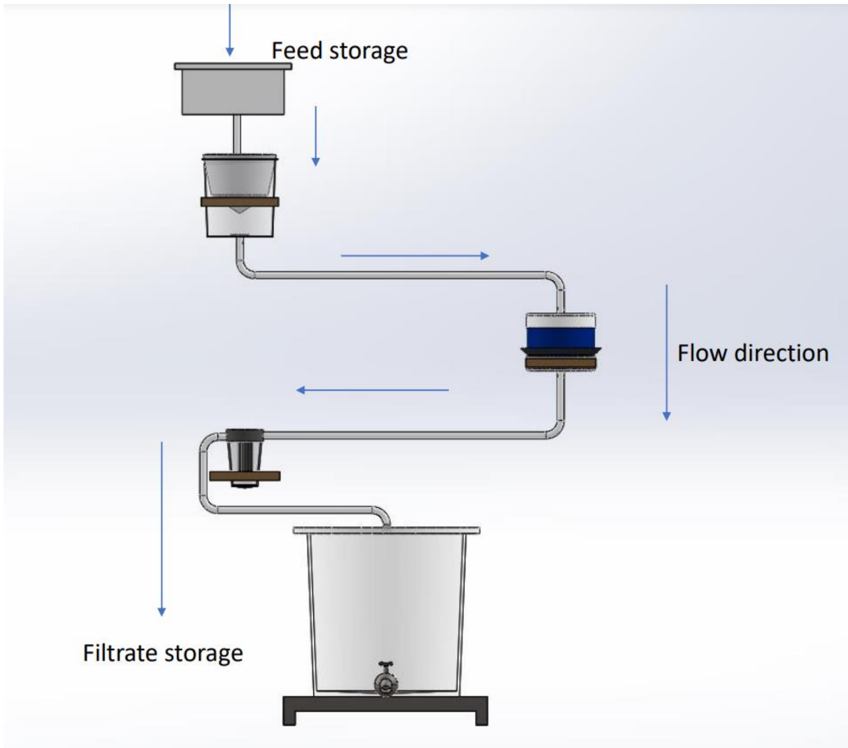

Figure 3.3: Flow chart of the Water Treatment System.

3.2.1 Storage subsystem

A 120-litre, square trunk (figure 3.1(a)) was converted into a storage tank for the fed water. An outlet was made, and a 2-inch water hose was used to connect the feed water tank to the first stage of filtration which is the ceramic filter. The hardened P.V.C used means that the trunk is both strong and durable because it would not biodegrade in a short period. After all, the duration for biodegradation for P.V.C plastic is not less than 20 years [26].

A 128-litre Veronica bucket (Figure 3.1(b)) was used as the container for storing the filtrate. It already comes with a tap and a lid which makes it perfect for dispensing clean water.

3.2.2 Organic matter, dirt and macro pollutant removal subsystem

When the feedwater is obtained from the water bodies, it contains some dissolved salts, soil sediment and organic matter which are not good for human consumption. The first stage of purifying the water is to be able to remove the macro pollutants and gradually reduce the micron size of filtration until the water is purified. From research, [27] a ceramic filter (Figure 3.5) would be the best cost-effective device that has pores about half a micron in size can be used to trap impurities as the water passes through them. The inner parts of the filter have sharp angles that further prevent any impurities from getting through them. Because of the tiny size of these pores, the water that is filtered comes out very fine and clean.

This is however not enough to remove heavy metals from the water. To increase the porosity of the ceramic filter as well as increase its flexural strength, combustible organic materials such as sawdust are added to the clay to form a composite. This composite is then used to form the ceramic filters. For the implementation of the ceramic filters to be effective, the organic (sawdust) content of the composite must be burnt away at high temperatures. The holes left behind in the ceramic filter by the sawdust burning will then increase the porosity of the filter and allow more water to be filtered per unit time [28]. A seventy-thirty clay to sawdust ratio was used in the forming of the ceramic filter. After mixing the clay, sawdust the mixture was wetted with water, rolled and cold-worked until an even texture was obtained. The composite was then moulded around a large conical funnel (figure 3.4) to give it a well-tapered edge. The moulded matrix was left to dry at an average temperature of 25°C for 10 days. The ceramic filter was then baked at 700°C for 3 hours to achieve the final filter in a homemade furnace (Figure 3.7). 11cm x 4cm x 2cm brick samples (Figure 3.6) were made and baked using the same clay-sawdust mixture to be used for impact testing. The enhanced porous ceramic structure was used for first stage filtration to prevent impurities from getting through them. Water turbidity was characterized at this stage and results were compared with unfiltered water (which served as a control).


Figure 3.4: Conical funnel for moulding **Figure 3.5**: Molded ceramic filter


Figure 3.6: Brick samples to be used for drop tests. **Figure 3.7**: Homemade furnace in operation

3.2.3 Particulate adsorption subsystem

Activated carbon has been proven to be very effective in particulate adsorption due to its high carbon content and ability to attract and capture organic pollutants from fluids. The source of the carbon was decided to be coconut shells mainly through the results from the Pugh chart in table 0.2.

Table 3. 1: Particulate organic matter removal/adsorption using activated carbon from palm kernel, coconut shells and watermelon husks using a sand filter as the standard.

	Sand filter	Palm kernel	Coconut shells	Watermelon husk
PRICE	S	-	+	-
ABSORBENT CAPACITY	S	-	+	+
STRENGTH OF ADSORPTION	S	-	+	_
ODOR REMOVAL	S	+	+	+
TASTE IMPROVEMENT	S	+	+	+
SCORE	4	4	10	6

Coconut shells proved to be the best option for the project, so a coconut shell activated carbon filter with a pore size of $5\mu m$ was obtained in (figure 3.1(c)).

3.2.4 Heavy metal removal subsystems.

As stated earlier the best cost-effective options for making a filter that can effectively remove heavy metals from polluted water is to use orange peels and banana peels [24]. These two options were then compared using a Pugh chart (Table 3.2) to decide on the best option.

Table 3. 2: Heavy metal removal using orange peels, brown algae and banana peels using the Big Blue K.D.F. filter as the standard.

	Big Blue KDF filter	Orange peels	Brown algae	Banana peel
PRICE	S	+	-	+
EFFECTIVENESS OF REMOVING MERCURY, LEAD COPPER ARSENIC(>50%)	S	+	+	+
STORAGE LIFE	S	+	+	-

TASTE IMPROVEMENT	S	+	-	+
SCORE	4	8	4	6

Through the Pugh chart, it was decided that orange peels would be the chosen material for the heavy metal removal process.

Orange peels were then obtained, washed twice with filtered water and dried for 5 days to ensure all the moisture content had escaped. These orange peels must be properly treated to help increase the adsorption capacity [29]. The orange peels were dried in the preheated furnace which was at 75°C for 5 hours [30]. After being dried the orange peels were manually crushed (Figure 3.8) and sieved with a 2mm sieve (Figure 3.9) to obtain a fine orange peel powder. This is going to be the section for heavy metal removal in the system.

Figure 3.8: Orange peels being crushed. **Figure 3.9**: Orange peels being sieved.

3.2.5 Plumbing Subsystem

Standing at a height of 2 meters, the storage tank for the feed water can either be filled via a centrifugal pump (figure 3.10) or manually by climbing a ladder to pour the polluted water into the tank. When a centrifugal pump is being used, it should be able to pump water to the required height with ease. A pump with a maximum operating height of 60 meters was obtained and used as it was the smallest available pump on the market. Two-inch diameter P.V.C pipes were used for the main plumbing works. One pipe connects the pump to the source of polluted water (from the river or stored in a barrel) and another 2.1-meter tall pipe connects the pump to the feed water tank (figure 3.11).

Due to the winding nature of the filtration setup, I found it easier to use a 1.5-inch flexible water hose (figure 3.1(e)) for the plumbing network from the feed water tank, through the ceramic filter, through the orange peel and activated carbon filter and finally into the filtrate storage tank.

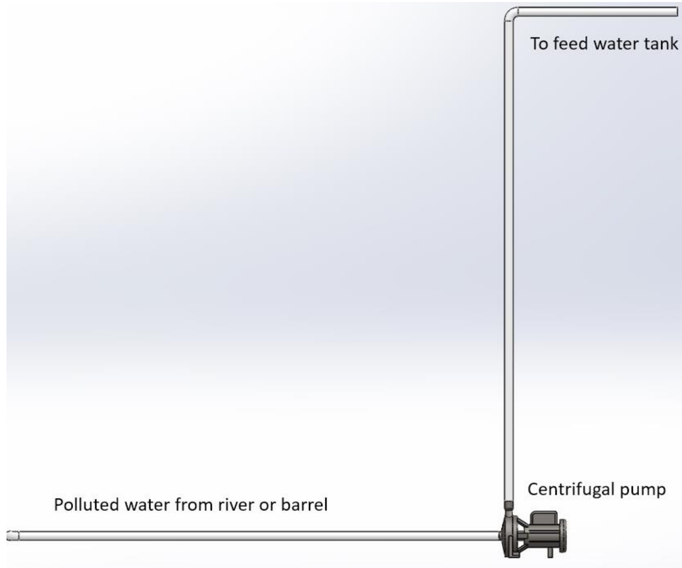

Figure 3.10: Centrifugal pump **Figure 3.11**: Centrifugal pump C.A.D. setup

3.2.6 Structural and support subsystem

2.5 X 5 X 0.2 cm galvanized rectangular steel pipes were selected for the fabrication of the frame of the filtration system. This specific steel pipe was selected because according to the simulations I ran, using its smaller counterpart the 2.4 X 4X 0.2 cm square tube would have failed under the load it is meant to carry. Picking a size higher than it, (the 6 X 3X 0.3cm) would comfortably carry the load but would have been overdesigned and cost more. Another reason for selecting galvanized steel square tubes was that the zinc coating they have to prevent the steel from rusting, these pipes are relatively affordable and can withstand high mechanical stress. I already had a steel welding machine and electrodes so it influenced my decision on which material to use for the frame as I would not have had to outsource a welding machine or electrodes thereby reducing cost.

Figure 3.12: Steel frame

3.3 Design and simulation

All subsystems were designed using the SolidWorks 3d designing software and assembled before physical building takes place. The computer-aided designs of all the subsystems are as follows.

3.3.0 Feed water storage tank

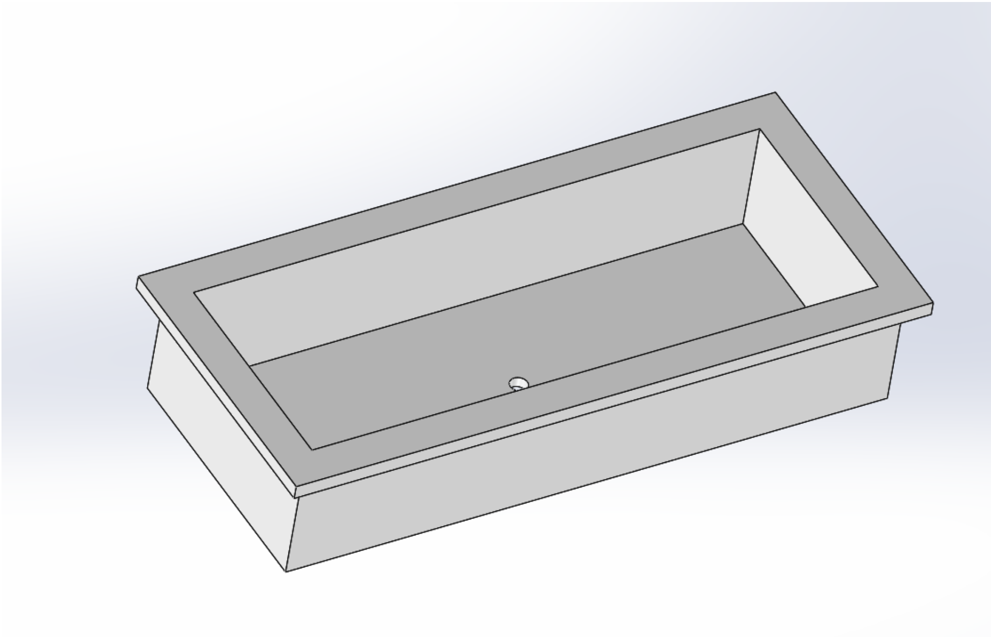

Figure 3.13: Feed water tank

3.3.1 Ceramic filter

The entire ceramic filter setup consists of the ceramic filter itself, and the ceramic filter container.

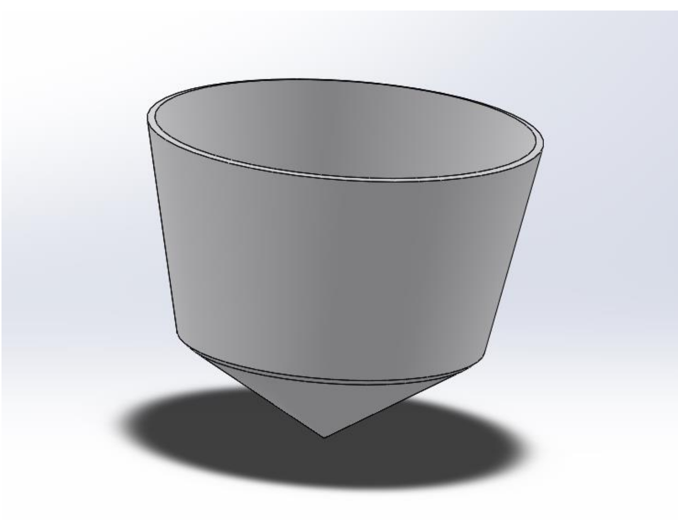

Figure 3.14: Ceramic filter

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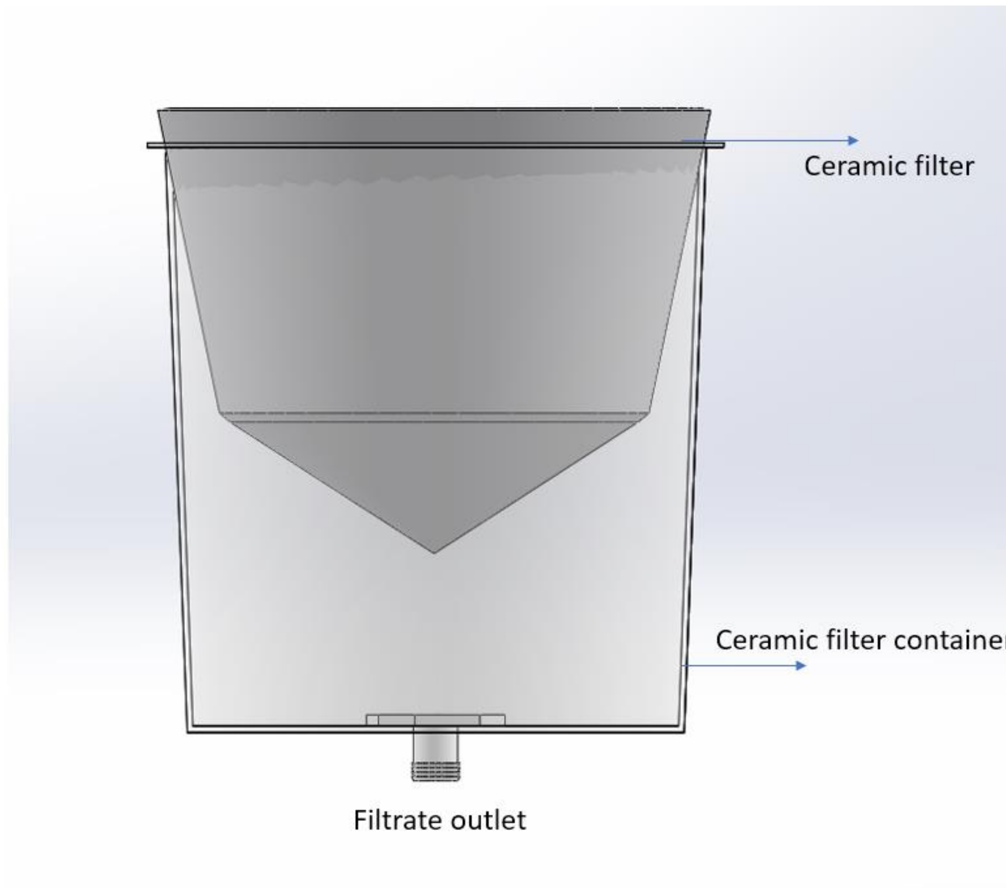

Figure 3.15: Ceramic filter assembly

3.3.2 Activated carbon filter

The activated carbon filter consists of the powdered activated carbon, the 0.1-micron filter paper the carbon rests on and the P.V.C pipe tubing that forms the body of the filter.

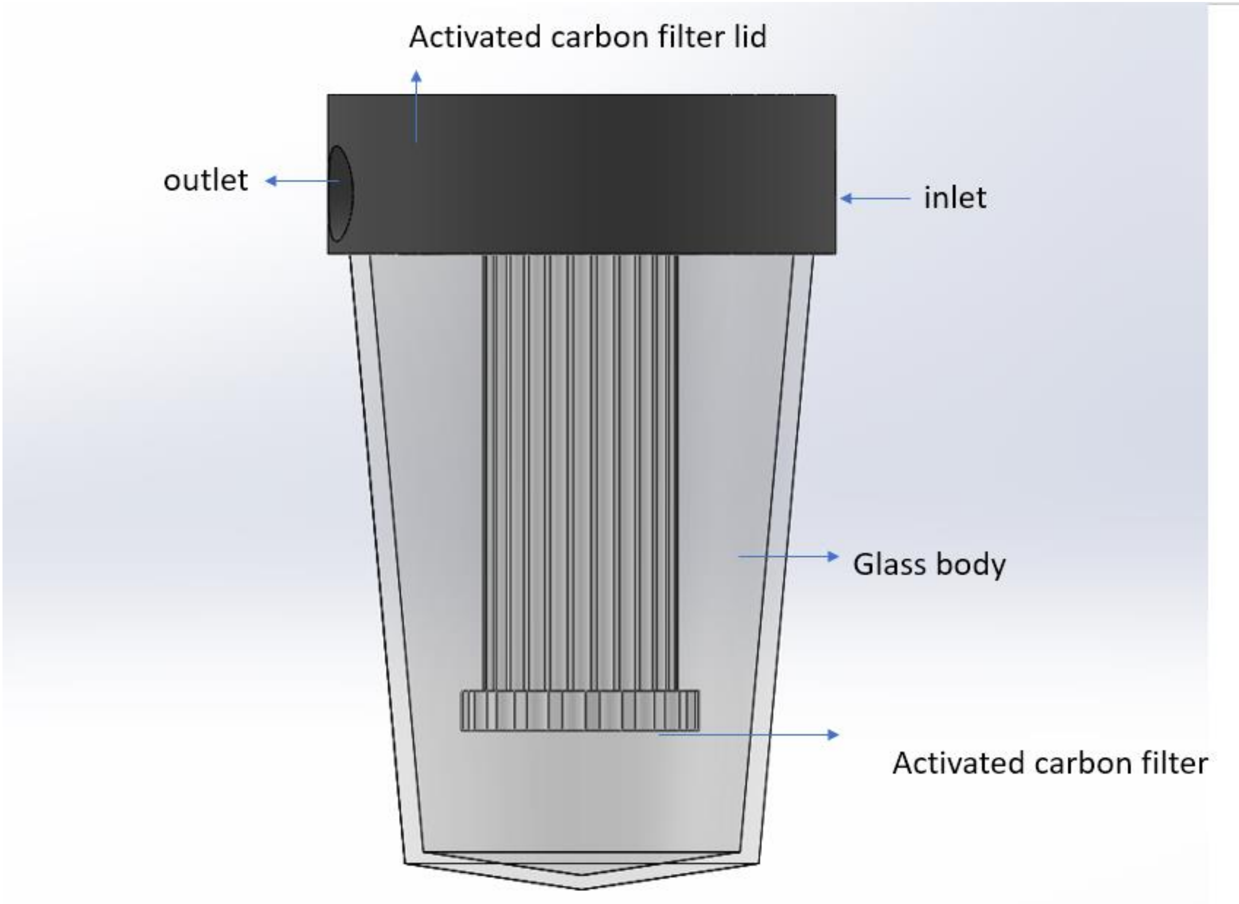

Figure 3.16: Activated carbon filter

3.3.3 Orange peel filter

The orange peel filter consists of the powdered orange peels, the 0.1-micron filter paper the orange peel powder rests on and the P.V.C pipe tubing that forms the body of the filter.

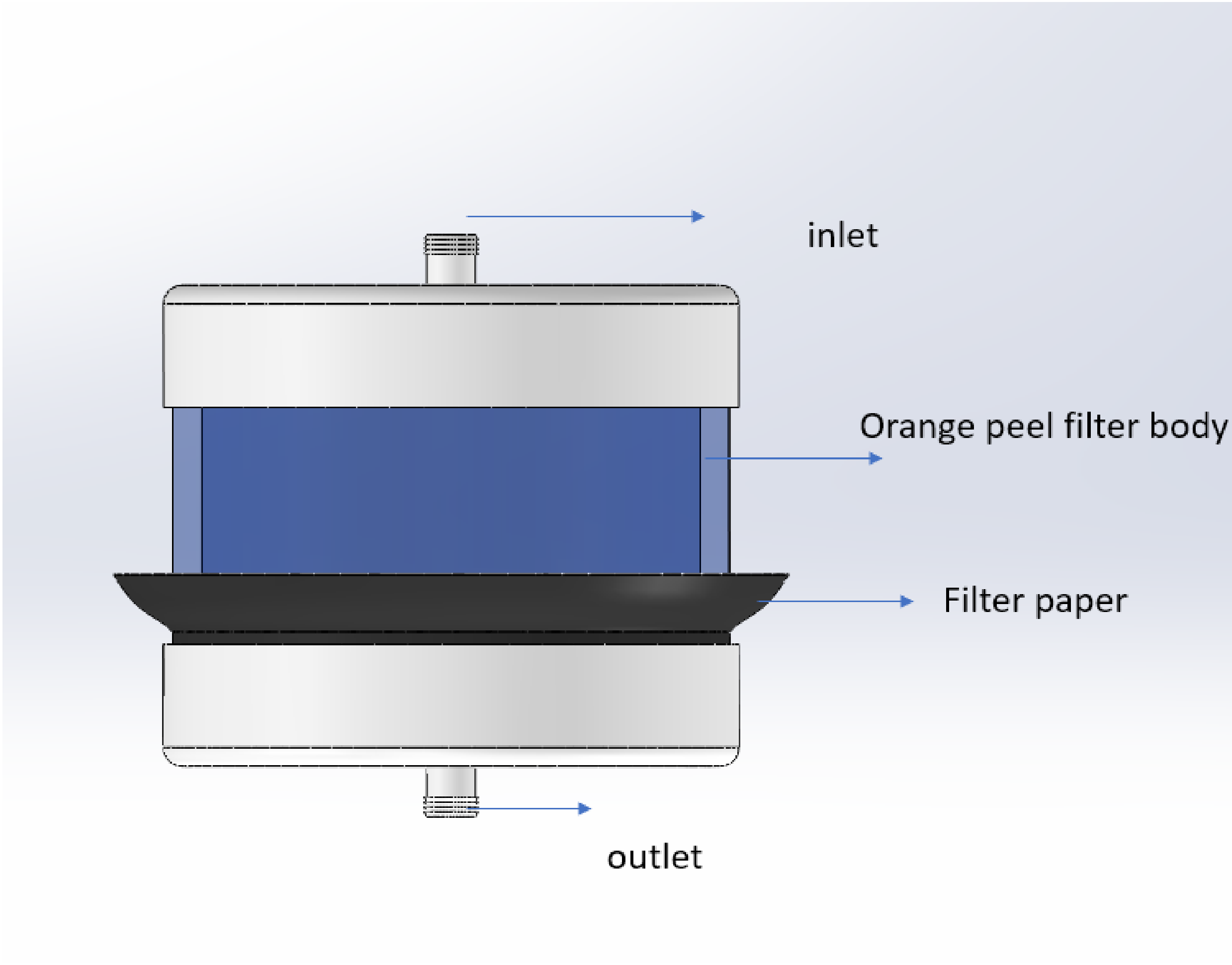

Figure 3.17: Orange peel filter

3.3.4 Filtrate storage tank

This contains the veronica bucket and the tap for the water outlet.

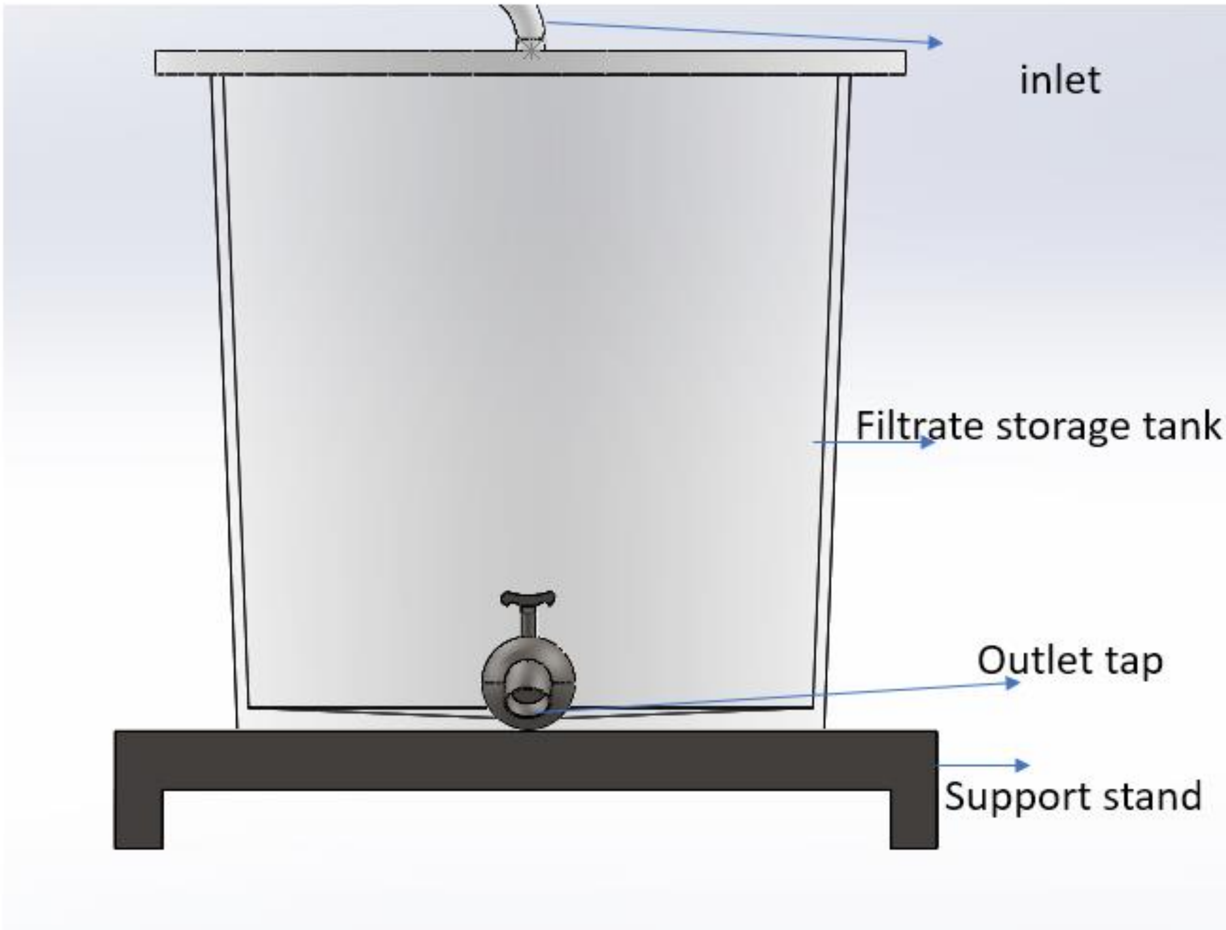

Figure 3.18: Filtrate storage tank

3.3.5 Steel frame

This contains the steels frame welded together through 2.5 X 5 cm square steel tubes.

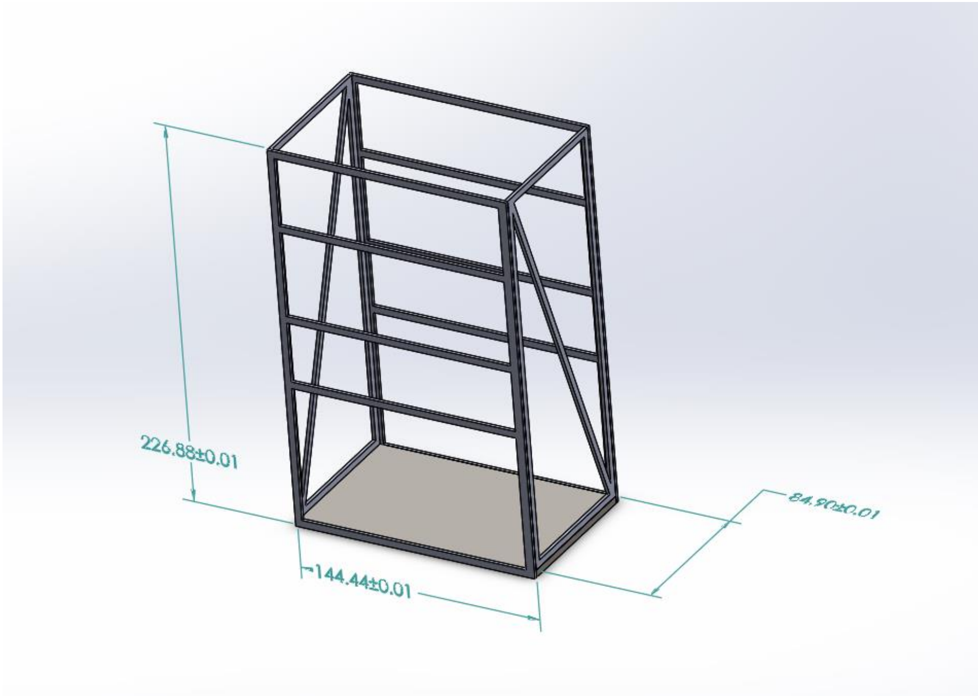

Figure 3.19: Steel frame

All measurements are in centimetres.

3.3.6 Wooden Wawa boards that attach all filtration units to the steel frame

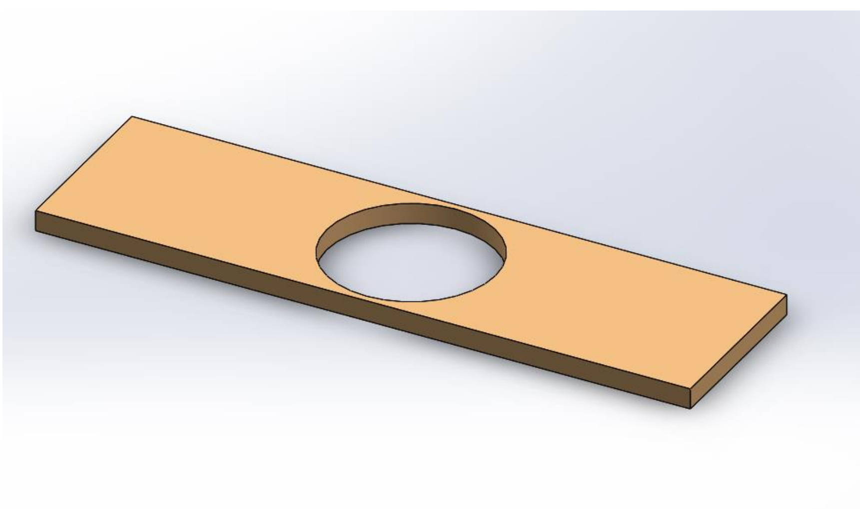

Figure 3.20: Wawa support board

3.3.7 Final assembly

Final assembly explained;

The centrifugal pump pulls polluted water from the river or a storage barrel and pumps it against gravity into the feed storage tank. Once in the storage tank, the water falls by gravity through the water hose plumbing into the ceramic filter where macro pollutants are removed. By gravity, this filtrate (filtrate1) moves into the activated carbon filter subsystem and adsorption occurs, thereby purifying the water from organic matter particulates. It then becomes filtrate 2. Filtrate 2 then falls into the orange peel filter and heavy metals are removed. This now becomes filtrate 3. Filtrate three then enters the filtrate storage tank and is ready for testing. Water samples were collected after each filtration stage for testing. The water samples were taken to the Ghana water Research institute located at 2nd Csir Cl, Accra Ghana for water quality analysis and trace metal testing.

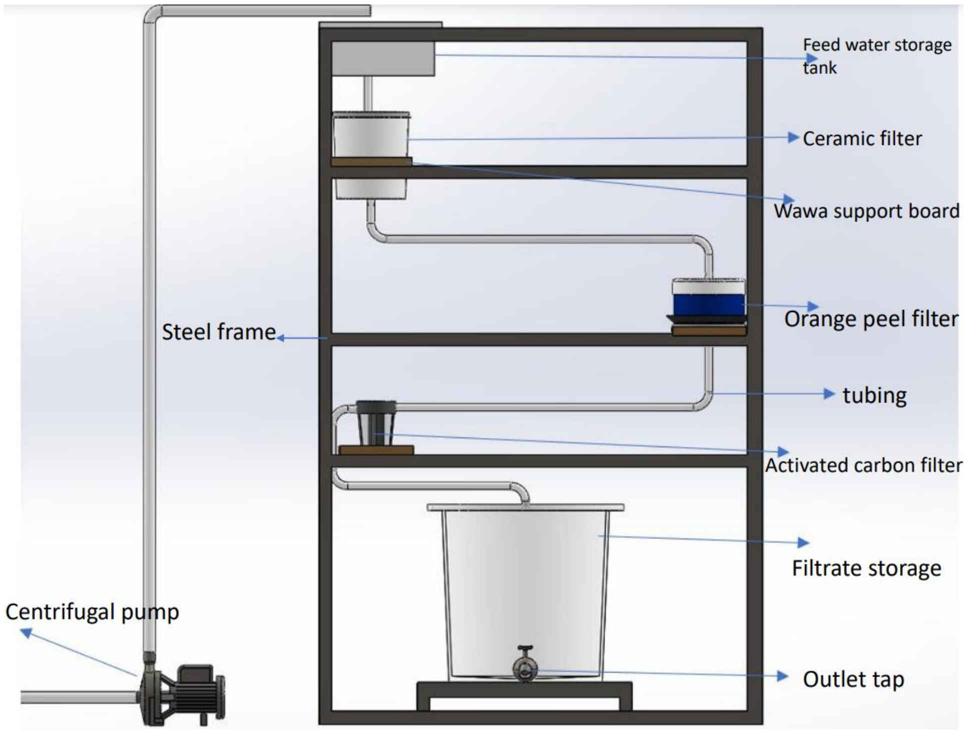

Figure 3.21: Final C.A.D. assembly

Figure 3.22: Final built assembly

3.4 Simulations and optimization of subsystems

After calculating the entire volume of the feedwater storage tank is 120 litres. Now we know that 1 litre of water weighs approximately 1kg. That would mean that there is 120 kg of water in the feedwater storage tank, including the weight of the tank, I arrived at 125 kg for the entire feed water storage system. The same thought process and calculations were used for all subsystems and arrived at a compressive total load of 1488.0614 Newtons. This force was then distributed across the steel frame at all the points where the subsystems would be placed and a static load analysis was performed on Solidworks to test the yield stress of the frame in order to obtain a reasonably safe factor of safety.

In figure 3.41 we have the load analysis result showing that we achieved a yield strength of 2.920e +08 Newtons per meter squared. When you observe the frame we can see that there is no point on the frame that experiences stresses close to our yield strength value. This concludes that the design is safe to use.

3.4.1 Finding the maximum loading on the steel frame.

Weight of feedwater storage tank

Volume= 120 liters.

Mass of water when full=120kg.

Mass of trunk= 5kg.

Total mass = 125kg

Weight of entire feed water storage tank = **1225N.**

Total weight of Ceramic filter assembly

Mass of ceramic filter-3kg

Mass of ceramic filter container-1.5kg

Mass of wooden Wawa support board -1.5kg

Mass of water that can fill the ceramic filter -3kg

Total mass of ceramic filter setup = 9kg x9.8ms^2 **= 88.2N**

Total weight of orange peel filter assembly

Height-18cm.

Radius-12cm.

Volume= 3.142x12^2x 18

=8.143liters

Using the assumption that one litre of water equals 1 kg,

The mass of water that fills the filter is 8.143kg.

The filter paper has negligible mass.

Orange powder =0.5kg.

Mass of the plastic filter container = 0.5kg.

Mass of wooden Wawa support board = 2kg.

The total mass of orange peel filter setup =12.143 kg

Using g as 9.8ms^2, the total force the orange peel filter exerts on the steel frame is **119.0014N**

Total weight of activated carbon filter assembly

Mass of dry activated carbon filter -2kg

Mass of water that fills the filter- 1.5kg

Mass of wooden Wawa support board = 2.2 kg.

The total mass of the activated carbon filter is 5.7kg

Using g as 9.8ms^2, the total force the activated carbon filter exerts on the steel frame is **55.86 N**.

The total compressive force the steel frame is subjected to by all the subsystems except the filtrate storage tank is

=Total weight of feed water storage tank+ Total weight of Ceramic filter assmebly+

Total weight of orange peel filter assembly + Total weight of activated carbon filter assembly

=1225N+88.2N+119.0014N+55.86 N.

=**1488.0614N**

N.B., it is important to know that the filtrate storage tank does not rest on the steel frame, it rests on a wooden stool that rests on the ground. Therefore. the filtrate storage tank does not exert any force on the steel frame but just on the wooden support stool.

<u>Total weight of filtrate storage tank</u>

The volume of water it can contain = 128 litres.

128 liters of water = 128kg.

Mass of empty storage tank = 5 kg.

Total mass of filtrate storage sub system = 128+5 =132kg

Total force it exerts is,

Force = mass x acceleration due to gravity

132 x 9.8 =**1293.6N**

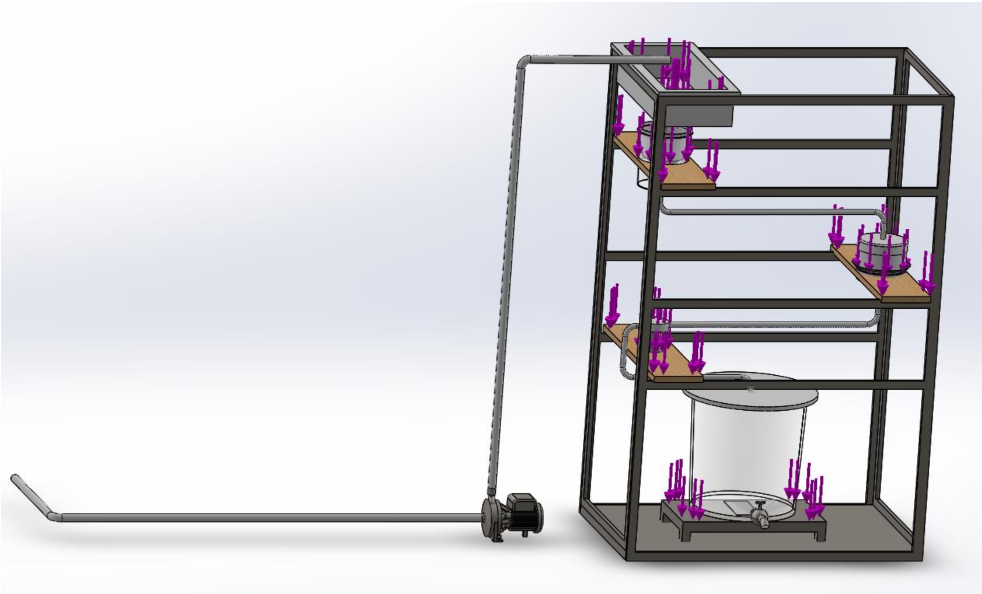

Figure 3.23: Load analysis of steel frame

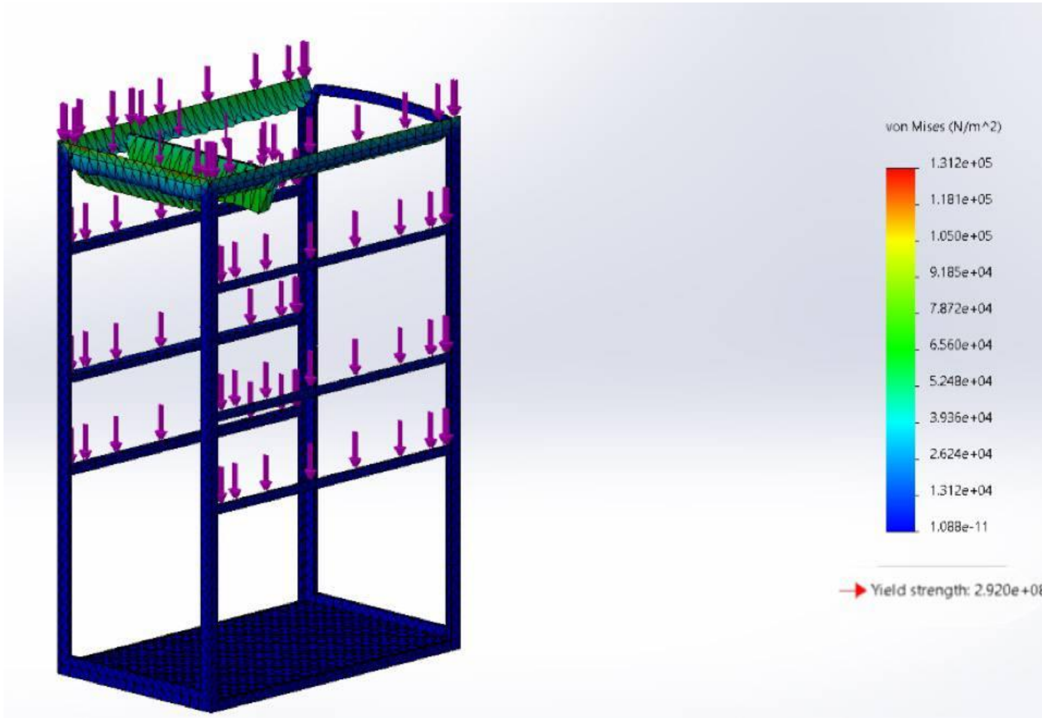

Figure 3.24: Load analysis of steel frame

3.5 Mechanical and computational analysis

3.5.1 Optimization of the ceramic filter

Knowing the volume of water that the ceramic filter can contain (3 litres) this was converted into a downward acting force on the ceramic filter (29.4Newtons) and a SolidWorks static simulation was run to see how it would behave under loading conditions.

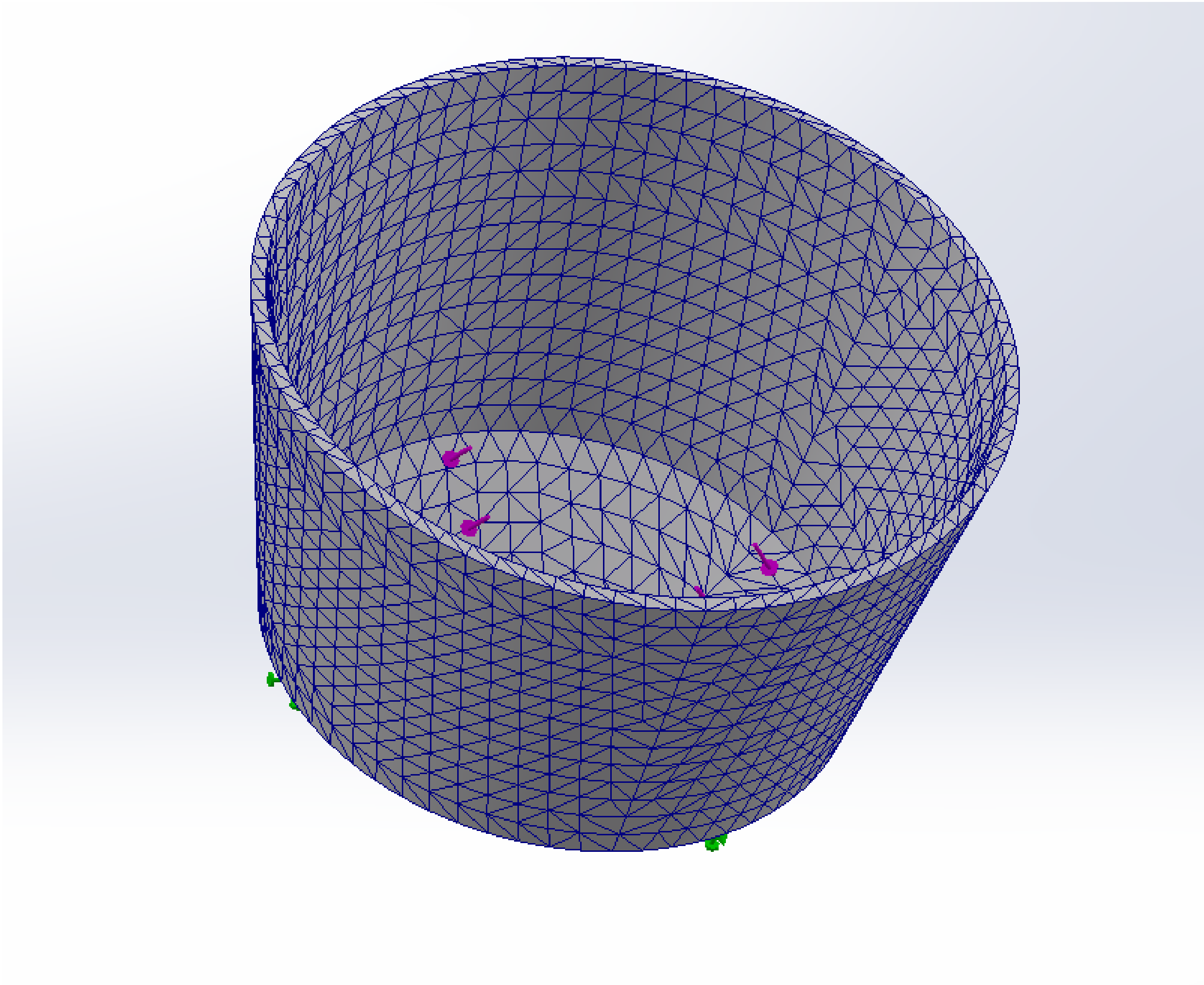

Figure3.25: Ceramic filter mesh study

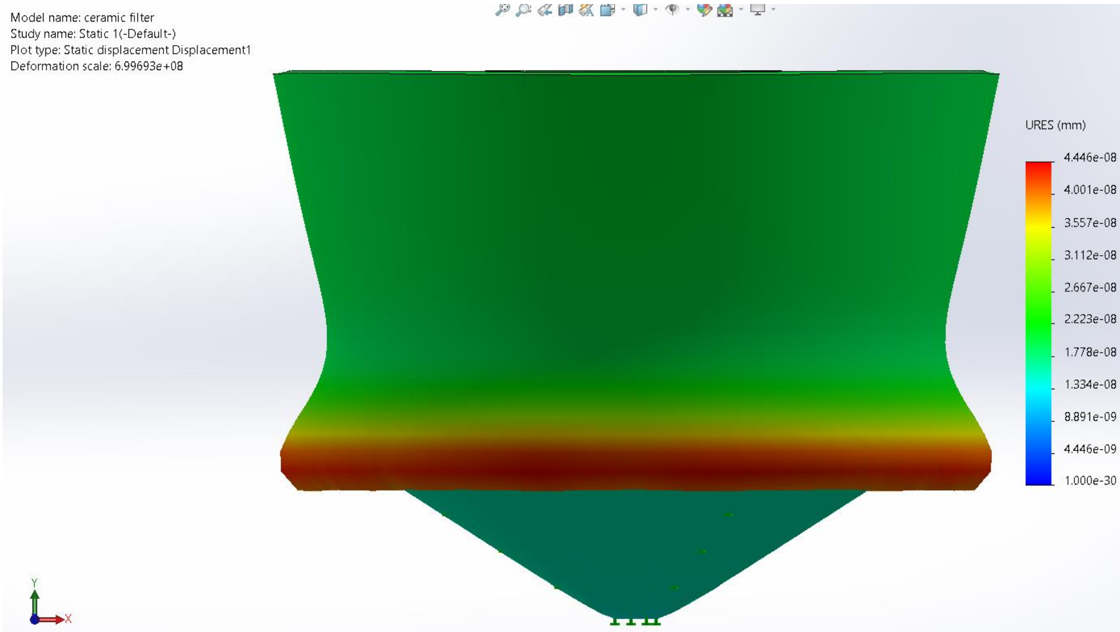

Figure 3.26: Ceramic filter displacement study

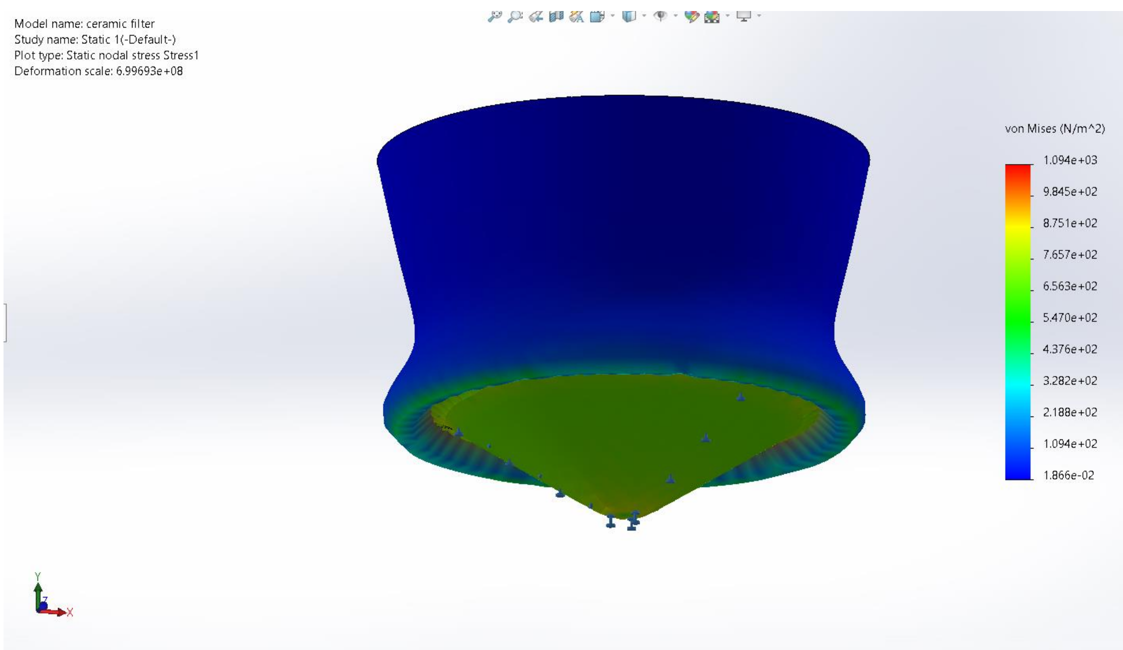

Figure 3.27: Ceramic filter Von Mises stress simulation study. With a yield strength of 2.236e+04N/m^2, the ceramic filter is not going to fail under normal loading conditions.

3.52 Apparent porosity, absorption and Impact test.

3.52 (a) Apparent porosity and absorption tests

After being baked, the ceramic filter and ceramic bricks were subjected to apparent porosity, absorption, and Impact test to find out their mechanical characteristics.

The first test done was to find the apparent porosity and absorption of the ceramic filter according to ASTM-C 373-88 standards, 2006 [31]. The ceramic filter was weighed with a weighing scale when it was dry, suspended in water and after it was left in the water to be saturated. The following calculation was then made.

Md= 3000g

Ms=2000g

Msa=3500g

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

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

Where Md is the dry mass (in grams), Ms is the suspended mass in water (in grams), Msa represents the saturated mass (in grams), Wa stands for the water absorption (%), and η is the apparent porosity (%) of the ceramic filter.

$$\eta = \frac{3500-3000}{3500-2000} \times 100 \quad = \mathbf{33.33\%}$$

$$Wa = \frac{3500-3000}{3000} \times 100 \quad = \mathbf{16.67\%}$$

3.52 (b) Impact test.

The 11cm x 4cm x 2cm baked brick samples in figure 3.7 were used to conduct impact tests.

The bricks were dropped from varying heights until a fracture was observed in the sample. All brick samples experienced their cracks at an average dropping height of 100 cm from the ground. This heigh of 100cm, as well as the weighed mass of the brick at 0.5kg, were used to calculate the average instantaneous force needed to fracture the sample.

The brick's final velocity is first determined with the formula below.

V= √2gh

Where V is the final velocity upon impact, g is the acceleration due to gravity at 9.8ms^2 and h is the100cm dropping height.

V= √2 x 9.8 x0.1

V=1.4ms-1

We then find the Network done by the brick using.

W net=0.5 x m x V^2

Here, W net is the net work done by the brick, m is the mass of the brick and V is the final velocity.

W net=0.5 x 0.5 x 1.4^2

W net= 0.49 J

The average impact force can then be found using,

F= W net/height

Where F is the average force

F= 0.49/0.1

F= 4.9 Newtons.

The average force needed to fracture the brick is **4.9 Newtons**

3.5.3 Mechanical optimization of the Wawa support boards

Knowing the total downward force exerted on the Wawa board by the ceramic filter assembly, a static Solidworks compression loading simulation was run and the results are explained below. With a yield strength of 2e+07N/m^2, the board is not going to fail under normal loading conditions. This is because, as seen on the simulation results (Figure 3.37), no section of the Wawa board exceeds or is even close to the yield strength of the Wawa board.

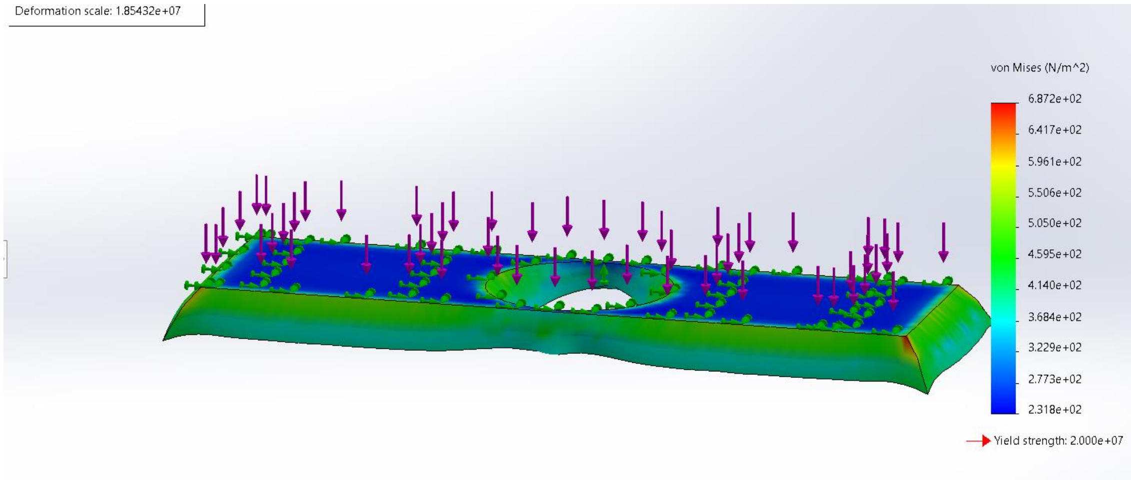

Figure 3.28:Wawa board von mises stress simulation study

CHAPTER FOUR

4.0 Experimental Results and Analysis

This chapter focuses on discussing the results obtained after simulating the various critical load-bearing systems of the filtration system as well as the results of filtering the polluted water sample through the various filtration systems.

4.1 Mechanical Results

4.11 Load bearing systems

After performing the compressive load analysis, the highest stress obtained on the steel frame was at a value of 9185e+04N/ms^2, way below the steel frames yield strength of 2.920e

+08 Newtons per meter squared This concludes that the steel frame can bear the load of the filtration system safely.

The same simulation was run for the Ceramic filter and it could comfortably hold the 29.4Newton load it is designed to carry with its yield strength of 2.236e+04N/m^2 with minimal displacement. The wooden Wawa boards were also subjected to a transverse loading simulation and they performed excellently with a yield stress of 2.0e+08N/m^2. This simply means that all load-bearing systems are safe to operate.

4.2 Filtration results

The 120-litre storage tank was filled to the brim by the centrifugal pump and a stopwatch was set to record the period it would take for all the water the be filtered into the filtrate storage tank. This setup was run three times and I obtained an average filtration period of 6 hours 12.4 minutes. This far outperforms the goals set at the beginning of this project.

At each stage of the filtration process, a water sample was taken and Ph, Turbidity, conductivity measurements were taken as part of the water quality analysis tests. Trace metal testing was also performed on water samples at each stage as part of the trace metal testing procedure.

4.2.1 Water quality analysis of the water samples

Figure 4.1: Contaminated water sample from River Pra

Figure 4.2: Water sample after ceramic filtration

Figure 4.3: Water sample after orange peel filtration **Figure 4.4**: Water sample after activated. carbon filtration

The values for the water quality analysis and trace metal analysis are provided in table 4.1 and table 4.2 respectively below

Table 4. 1: Water quality analysis results compared to W.H.O standard for drinking water

	Turbidity (NTU)	Ph	Conductivity (µs/cm)
A contaminated water sample from river Pra	670	6.58	132.9
Water sample after ceramic filtration	309.7	7.13	233.1
Water sample after orange peel filtration	272.8	4.75	240
Water sample after the activated carbon filter	223.4	6.6	255.6
WHO standard for Drinking water	5 – 25	6.5 - 9	1200

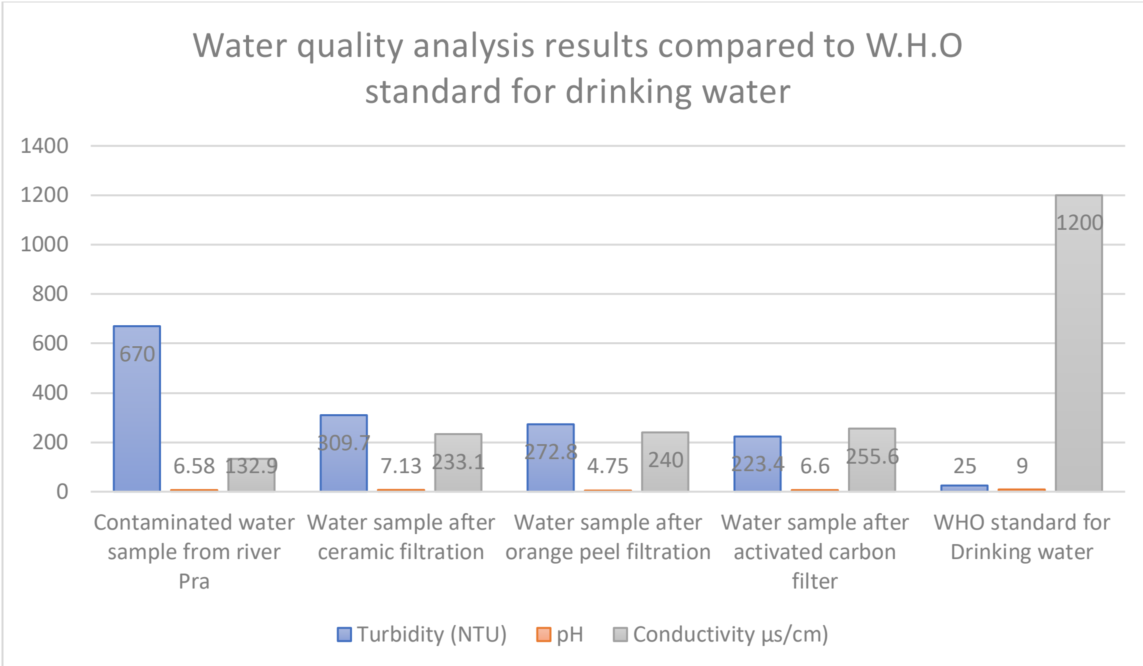

Figure 4.5: Water quality analysis results compared to W.H.O standard for drinking water

As seen in the data presented above, the filtration system was able to successfully able to reduce turbidity by 66.656716%, increase the conductivity by 92.32% and bring the pH of the water within the acceptable range for consumption. The turbidity and conductivity even though, they have been improved drastically still fall short of the W.H.O. standards for potable water.

Table 4. 2: Trace metal analysis results compared to W.H.O standard for drinking water

	Lead (mg/l)	Copper(mg/l)	Cadmium(mg/l)	Zinc(mg/l)

Contaminated water sample from river Pra	0.1	0.411	0.021	0.096
Water sample after ceramic filtration	0.097	0.024	0.02	0.064
Water sample after orange peel filtration	0.075	0.021	0.015	0.131
Water sample after activated carbon filter	0.066	0.006	0.004	0.016
WHO standard for Drinking water	0.015	1.3	0.005	5.0

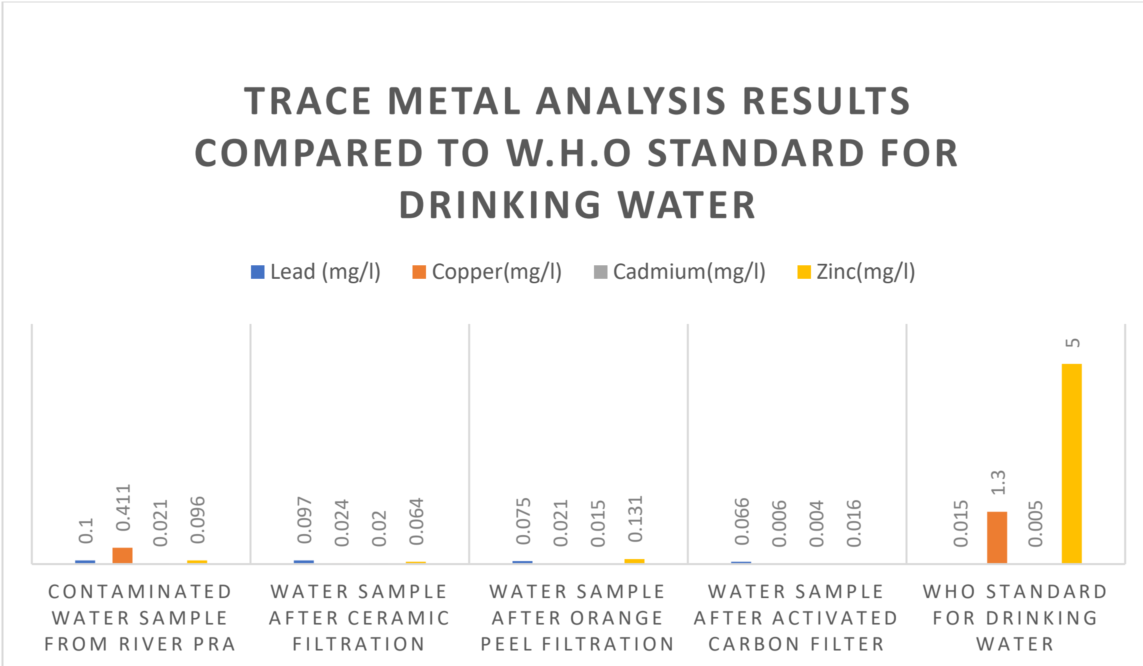

Figure 4.6: Trace metal analysis results compared to W.H.O standard for drinking water

Upon analyzing the trace metal results, it was found that the filtration system reduced the presence of lead by 34%, copper by 98.45%, cadmium by 80.95% and zinc by 83.33% in the water samples. The presence of trace metals in the final filtrate are all below harmful levels with the exception of lead which still poses a considerable amount of harm if consumed.

CHAPTER FIVE

5.0 Conclusion and notes for future works

5.1 Conclusion

This work contains the design, analysis, simulations and fabrication of a water filtration system for particulate adsorption and heavy metal removal. It also contains the experimental results and analysis obtained after running a water sample from the galamsey-polluted River Pra through the filtration system.

The steel framework and all other load-bearing parts have proven through SolidWorks simulations and mechanical testing to be robust and capable of serving their intended purpose. The filtration system has served its intended purpose by drastically reducing heavy metal traces in the water sample as well as improving the quality of contaminated water that was filtered. All objectives for this project have successfully been met.

5.2 Limitations

Due to the Coronavirus 2019 pandemic we currently find ourselves in, there were difficulties in obtaining some necessary components which stretched the duration of the project. The fact that most parts such as the welding machine used to put the steel frame together had to be outsourced also increased costs and increased the duration of the project because they would have been provided by the Ashesi University Engineering department under normal conditions. There was a difficulty in varying the flow rate of the filtrate which negatively affected the contact time between the water sample and the activated carbon and orange filters. This hindered the effectiveness of the particulate adsorption and biosorption process.

5.3 Future works

The main stakeholders in illegal mining activities in Ghana have shown little interest in halting their activities and as such, we the normal citizens have to take the cleansing of our water bodies into our own hands. The need for clean water is ever high due to the current pandemic we find ourselves in because clean water is required to keep sanitary and stop the spread of Covid-19

It is my hope that with enough funding and resources I will take on this project on a larger scale to aid in returning our contaminated rivers to their glorious pasts through cost-effective methods.

The current filtration system features a centrifugal pump that must be manually turned on and off, in future works, I intend on adding a water level sensor coupled with a circuit breaker that can automatically turn the pump on or off based on the water level in the storage tanks. This also reduces human contact with the system and can aid in stopping the spread of Covid-19.

APPENDICES

APPENDIX A**:** Tools and materials used in the fabrication of the filtration system

Figure 1: Conical funnel used for moulding the ceramic filter.

Figure 2: Welding machine used for welding steel frame together.

Figure 3: Mortar and pestle used for crushing orange peels

APPENDIX B**-** Tools used in taking water quality analysis test.

Figure 4: Turbidity sensor

Figure 5: Conductivity probe

Figure 6: pH meter

APPENDIX C: More pictures of the destruction caused to River Pra

Figure 8: River Pra

Figure 7: River pra

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