PBL EAST AFRICA

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MAKERERE UNIVERSITY

THE VEPOX FILTER REPORT

VepoX

AN INTEGRATED ACTIVATED CARBON AND FUNCTIONALIZED SAND WATER FILTER PROJECT.

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LIST OF ABBREVIATIONS

AC ----------------------- Activated Carbon

BAC---------------------- bamboo activated Carbon

BC ----------------------- bamboo Carbon

F-SAND ---------------- Functionalized Sand

Mak-PBL --------------- Makerere Problem based Learning

MOCP ------------------ Moringa Oleifera Cationic Protein

NEMA ----------------- National Environment and Management Authority

NWSC ------------------ National Water and Sewerage Cooperation

PCM -------------------- pyrogenic carbonaceous material

WHO ------------------- World Health Organization

ABSTRACT

This report is a record for the eight weeks industrial training period I undertook with the Mak-PBL VepoX filter design project. It highlights activities carried out, the tools used and the skills obtained. These activities include; - Sieve analysis, Valley dam reconnaissance, Raw water quality tests, Bamboo activated carbon preparation, Functionalized sand preparation, Setup of lab analysis models, First and second material performance tests and Software schematic designing. It also includes the challenges faced, and their solutions, conclusions, recommendations and photos showing the different activities that were carried out during the industrial training. This document is not an invention; it's a collection of both theoretical and practical knowledge from different engineering literatures and can thus be further edited or become a future reference. As with writers of many reports, the desire of this writer is that, this report may impress the University, Mak-PBL, supervisors and anyone person(s) who reads this report. Enjoy and have fun as you read through.

Be blessed!

1 CHAPTER ONE

1.1 INTRODUCTION:

As part of Makerere University's School of Engineering four-year undergraduate curriculum, it requires students to undertake a two (2) months industrial training in which a student is attached to a firm practicing the trade of engineering so as to enable the him/her obtain hands on working experience in the field of engineering in which he/she specializes.

Internship gives a student the opportunity to apply the knowledge acquired from class in the field, carry out field tests and learn how to use machinery. Being in the field also helps the students to develop relationships, connections and even learn how to handle different people in an organization.

It's for this above reason that I was included to take on the Mak-PBL VepoX filter design project as my internship. I'm grateful for all the exposure I acquired in terms of the scientific approach to solving problems and creating something iconic!

1.2 OBJECTIVES OF INDUSTRIAL TRAINING

Besides being a requirement for the award of a bachelor's degree by Makerere University, industrial training has other objectives which include the following.

- To transfer theoretical knowledge learnt from class into practical skills.
- To expose students to civil engineering ethics and codes of practice.
- To help students of civil engineering to interact with other professionals.
- To acquire practical working, supervision and management skills as a future civil engineer.

1.3 THE MAK-PBL PROJECT

It sits under the umbrella arm called PBL East Africa, which develops best practices in problem-based education as a joint initiative between University of Dar es Salaam, University of Nairobi, Makerere University and Aalto University. It has been bringing together faculty, students and external partners in the four partnering countries to work on sustainable innovation challenges between 2017 and 2020.

The project operates as a piloting platform for testing, sharing and refining the implementation of problem-based education – while also building regional and global networks to share knowledge and deepen innovation capabilities in East Africa and beyond. Problem based learning was implemented since universities play an important role in developing the necessary skills, knowledge and tools to respond to both persistent and newly emerging societal challenges. Problem-based learning (PBL) – also known as project-based or challenge-driven learning – is a particularly powerful approach to seeking and applying in-depth knowledge from many disciplines. The approach centers the students and emphasizes their capabilities in communication, knowledge acquisition, reasoning, and teamwork. PBL also helps question the relevance and impacts of proposed solutions to clients, users and surrounding communities, leading to enhanced societal impact in the long run.

1.3.1 PBL PROJECT GOALS

The project aims at;

- Developing multidisciplinary PBL courses and curricula in East African universities
- Building regional and global networks to support PBL in innovation work
- Contributing to the development of sustainable innovation ecosystems by building the capacity of university students and faculty to respond to global challenges

1.3.2 PBL PARTNERS

PBL East Africa is a joint initiative between University of Dar es Salaam’s Innovation and Entrepreneurship Centre, University of Nairobi’s C4DLab, Makerere University’s CEDAT College and Aalto University from Finland. From Aalto University, involved are four multidisciplinary master’s programs and courses: International Design Business, Management (IDBM) master’s programme, Software and Service Engineering master’s programme, Sustainable Global Technologies (SGT) programme, Creative Sustainability Capstone course.

1.4 OVERVIEW OF THE WORKDONE

During internship, the VepoX filter project sought the use of naturally available materials like lake sand, bamboo, and moringa oleifera seeds; to design and implement a portable batch water flow purification device, which couples the filtration capabilities of sand with the antimicrobial and flocculating properties of the cationic protein found in Moringa Oleifera seeds, and the adsorption capabilities of bamboo activated charcoal to eliminate toxic substances like nitrates ions from valley dam water.

Below is a summary for a series of the activities carried out during the entire eight weeks training period.

1. Sieve analysis,
2. Valley dam reconnaissance,
3. Raw water quality tests,
4. Bamboo activated carbon preparation,
5. Functionalized sand preparation,
6. Setup of lab analysis models,
7. First and second material performance tests
8. And Software schematic designing.

2 CHAPTER TWO

2.1 BAMBOO ACTIVATED CARBON

Bamboo plants are identified as species of subfamily *Bambusoideae*, family *Gramineae*. They are distributed in many parts of the world. Bamboo grows rapidly and matures in 4 to 8 years. Generally sympodial species mature earlier than monopodial ones. Its specific gravity and mechanical strength remain in good status and it is the best time to utilize it during mature period (Jiang, 2004).

Bamboo charcoal, which is a sort of porous material with excellent adsorption properties is a pyrogenic carbonaceous material (PCM). It is produced by thermochemical conversion of carbonaceous feedstock (pyrolysis or/and activation) of bamboo. Pyrogenic carbonaceous materials are defined by Lehmann and Joseph (2015) to describe "all materials that were produced by thermochemical conversion and contain some organic content".

Bamboo charcoal (BC) has a particular pore structure, surface functional group, chemical stability, mechanical strength, acid resistance, alkali resistance and heat resistance, and can provide strong adsorption characteristics; as a result, it has been used extensively in water purification (Lin et al., 2003). In general, activated carbon (AC) is a good adsorbent for gaseous and liquid adsorption and is widely applied in the purification, decolorization, and removal of toxic substances, as well as the treatment of waste water (Manocha, 2003; Yorgun et al., 2009; Sun and Jiang, 2010). Hence, the BC, after being refined by activation, becomes bamboo activated carbon (BAC) that still retains the charcoal's characteristics, and its absorption capacity is higher than that of BC (Weng, 2010).

A previous study (Lin et al., 2015) reported that the AC with multiple micro/mesopores can be used as functional water purifying material (Chien et al., 2017). As AC has a developed pore structure, it can adsorb the trace amounts of organic contaminants in water (Kihn et al., 2000; Andersson et al., 2001), and significantly reduce the chemical oxygen demand and total organic carbon in water (Kunio et al., 2001; Seyed et al., 2004; Omri et al., 2013). It is also effective on the turbidity and chromaticity of the physical standards for drinking water (Anu et al., 2006). In addition, the AC has an inhibitory effect on total bacterial count and coliform in water (Ogawa et al., 2011).

According to Chien et al., 2017, Mutagenicity is a change in the hereditary property in the reproduction process of deoxyribonucleic acid storing gene information in biological stomatocytes caused by toxic chemical substances. If the source water is severely polluted, there may be mutagenicity, increasing the probability of cell mutation, and if the chlorine dosage is too high in the source water, there may be high carcinogenic risk.

2.1.1 CHEMICAL COMPOSITION

The macrostructure of bamboo stem is similar to many species of grass family with distinct nodes and internodes (Jiang, 2004). Analyzing chemical components of bamboo shows the bamboo is mainly composed of; -

- Cellulose, hemicellulose, lignin, carbohydrates, fat and protein, etc.

The cell wall mainly consists of cellulose, hemicellulose and lignin (Chen 1984). The cellulose of bamboo is a natural linear macromolecular compound which is jointed with β-D-glucose Ⅰ - 4 glycocidic. The cellulose content in bamboo varies from 40% to 50% with different species. The hemicellulose’s content is in the range of 20% to 30%. Lignin is an aromatic macromolecular compound together with cellulose and hemicellulose in lignified tissue, and it is concentrated in intercellular layers. In the lignified tissue, the lignin is mainly to stick the cellulose and hemicellulose and its content ranges from 15% to 35%.

Bamboo material can be burned to ash in high temperature. The ash content is in the range of 1% to 2%. The compounds of the ash exist in following forms: Potassium exists as potassium oxide which is in the range of 0.5% to 2%; Silicon exists as silica is about 1.3%; Phosphate exists as phosphorus pentoxide and is the range of 0.11%~0.24%. Besides these compounds, there are some metallic elements with little content such as copper, iron, calcium, magnesium and manganese. (Jiang, 2004).

Briefly, the Bamboo pyrolysis process can be divided into four stages according to temperature and products situation in a kiln or a pyrolysing kettle, that is; -

- dry, pre-carbonization, carbonization, and refining or calcinations

2.1.2 CLASSIFICATION

According to its shape, bamboo charcoal can be classified into round, slice, particle and powder charcoal.

Figure 1-Prepared bamboo charcoal (Internet file)

2.1.3 BAMBOO PYROLYSIS

Bamboo pyrolysis is a manufacturing method which makes bamboo heated to form many pyrolysis products under the condition of isolating air or letting little air in. The method includes; - bamboo carbonization, bamboo destructive distillation, bamboo activated carbon and bamboo gasification, etc

1. Bamboo carbonization: bamboo is heated in brick kilns or mechanical kilns with little air by means of the heat energy generated by burning firewood to pyrolyse bamboo and produce bamboo charcoal.
2. Bamboo destructive distillation: bamboo is heated in a pyrolysing kettle isolating air to produce bamboo charcoal and bamboo vinegar and so on.
3. Bamboo activated carbon: the bamboo material is heated in a brick kiln and activated kiln to get bamboo activated carbon.
4. Bamboo gasification: bamboo or bamboo residues resulting from the processing are heated to get bamboo gas in a gasification kiln (Huang 1996).

2.1.4 THE PYROLYSIS STAGES

Bamboo pyrolysis can be divided into four stages according to temperature and products situation in a kiln or a pyrolysing kettle.

- First stage – drying: the temperature is below 120℃ and the speed of pyrolysis is very slow in this stage. The applied heat evaporates the water in bamboo, the chemical composition of the bamboo is still intact. Consequently, this stage is endothermic reaction and water is the major product in this stage.

- Second stage – pre-carbonization: the temperature is in the range of 120℃ to 260℃ and there is a distinct pyrolysis reaction in bamboo during this stage. The unstable chemical compounds in bamboo (i.e. hemicellulose) began to decompose into carbon dioxide, carbon monoxide little vinegar, etc. this stage is also an endothermic reaction.

- Third stage – carbonization: the temperature is in the range of 260℃ to 450℃, and the bamboo is rapidly decomposed into many liquid and gas products. Liquid products contain much acetic acid, methanol and bamboo tar. Flammable methane and ethylene in gas products are increasing while carbon dioxide decreasing gradually during this stage. Because a lot of heat emits from bamboo, this stage is an exothermic reaction.

- Fourth stage – calcinations (refining stage): the temperature is over 450℃. The bamboo is becoming charcoal by means of providing a mass of heat, emitting the volatile substances in the charcoal and to enhance non-volatile carbon of charcoal carbon. There are few liquid and gas product in this stage. Refining stage is the key to upgrade the quality of bamboo charcoal (Huang 1996).

2.1.5 PRODUCTS OF PYROLYSIS

There are three groups of pyrolysis products, that is; - solid (bamboo charcoal), liquid (bamboo vinegar) and gas (bamboo gas). The bamboo destructive distillation carried out in a generic one-kilogram-retort in a lab, under a pyrolysis time interval of about 8 hours at a terminal temperature of 500^0 C yielded the following results summarized in the table below (Jiang, 2004). The percentage compositions for pyrolysis products are 30%, 51%, 18% and 1% corresponding to bamboo charcoal, bamboo vinegar, bamboo gas and losses respectively.

2.1.6 REQUIRED RAW MATERIALS

The bamboo culms must be matured (growing over 4 years) and fresh. For naturally air dried bamboo, the moisture content should within the range of 15% to 20% prior to insertion into the kiln.

Table 1-Summary of the entire process pyrolysis process

Bamboo sample weight	1.0 kg
Particle size	Half or quarter segment
Pyrolysis conditions	Air tight
Residence time	About 3 hours
Charcoal yield	30%
Pyrolysis temperature	450 - 500^{0}C
Initial moisture content	20 – 30% (air dried)
Heating rate	1^0 C per second

2.2 MORINGA OLEIFERA

Moringa Oleifera is a fast-growing, deciduous tree that can reach a height of 10–12 m and trunk diameter of 45 cm (Parotta, John A. 1993). The bark has a whitish-grey color and is surrounded by thick cork. Young shoots have purplish or greenish-white, hairy bark. The tree has an open crown of drooping, fragile branches and the leaves build up feathery foliage of tripinnate leaves. The flowers are fragrant and asexual, surrounded by five un equal, thinly veined, yellowish-white petals. The flowers are about 1.0–1.5 cm long and 2.0 cm broad (Parotta, John A. 1993)

Figure 2-Moringa oleifera seed Pods (internet file)

Flowering begins within the first six months after planting. In seasonally cool regions, flowering only occurs once a year between April and June. In more constant seasonal temperatures and with constant rainfall, flowering can happen twice or even all year-round, (Parotta, John A. 1993).

The fruit is a hanging, three-sided brown capsule of 20–45 cm size which holds dark brown, globular seeds with a diameter about 1 cm. The seeds have three whitish papery wings and are dispersed by wind and water. In cultivation, it is often cut back annually to 1–2 m (3–6 ft.) and allowed to regrow so the pods and leaves remain within arm's reach. (Parotta, John A. 1993)

2.2.1 POTENTIAL OF APPLICATION IN WATER TREATMENT

Loo et al. (2012) proposed a set of criteria and evaluation process for selecting a sustainable point-of-use water treatment technology during emergency situations 9S. These criteria include the cost of technology, performance, water throughput, potential acceptance and environmental impact. Satisfying all of these criteria is ideal however this is usually difficult to accomplish.

As an example, silver-impregnated ceramic filters effectively remove bacteria in the water but low water throughput and the release of silver ions into the treated water have been noted (Elefeldt, K. Kowalski, R. S. Summers). In another study, paper filters coated with copper nanoparticles have been shown to remove pathogens well but traces of copper were evident in the treated water (T. Dankovich, J. Smith). Even though both of these point-of-use technologies are effective at microbial disinfection, they also require further water treatment to remove the residual chemicals in the water. Hence they fail the sustainability-criteria.

Figure 3-Moringa Oleifera seeds (Internet file)

- A point-of-use water treatment that might potentially satisfy nearly all sustainability criteria involves the use of Moringa Oleifera (MO) seeds for coagulation and disinfection. The protein component of the MO seed is mainly responsible for these processes. The abundance of MO tree in low-income tropical regions lowers its cost of production.

Even if the tree is not actively cultivated, it is still able to produce enough seeds that can purify about 6000 liters of water at an average dosage rate of 50 mg/l (M. Pritchard, T. Craven, T. Mkandawire et al.) In addition, the inherent coagulation-flocculation properties of the MO seed do not limit its use to water disinfection.

In other studies, MO seeds have been shown to lower hardness and remove arsenic in drinking water (S. A. Muyibi, L. M. Evison), (P. Kumari, P. Sharma, S. Srivastave et al.). Also, various ethnicities are already aware and knowledgeable of the benefits of using MO seeds (J. Popoola, O. Obembe,). This supports the idea of using the seeds as point-of-use water treatment technology since it is widely accepted and is already in use. Collectively, these facts support the concept of using MO as a viable candidate in sustainable water treatment.

Earlier research findings of Crapper et al. (1973) and Miller et al. (1984) showed that the chemicals used for water purification can cause serious health hazards if an error occurs in their administration during the treatment process. These reports suggested that a high level of aluminium in the brain is a risk factor for Alzheimer's disease.

However, Davis (2006) found no conclusive evidence linking aluminium with Alzheimer's disease. Also, studies by workers (Letterman and Driscoll, 1988; Malle-vialle et al., 1984; Miller et al., 1984) have raised doubts about the advisability of introducing aluminium into the environment by the continuous use of aluminium sulphate as a coagulant in water treatment.

There is therefore the need to investigate the use of non-chemicals which would be available locally in most developing countries. The use of natural materials of plant origin to clarify turbid water is not a new idea (Bina, 1991; Folkard et al., 1989; Jahn, 1986, 1988; Kaser et al.,1990; Sani, 1990; Sutherland et al., 1992) cited by Ndabigengesere et al. (1995) and Madsen et al. (1987).

Among all the plant materials that have been tested over the years, powder processed from the seeds from Moringa Oleifera has been shown to be one of the most effective as a primary coagulant for water treatment and can be compared to that of alum (conventional chemical coagulant) (Madsen et al., 1987; Oslen, 1987; Postnote, 2002). It was inferred from their reports that the powder has antimicrobial properties. Earlier studies have found Moringa to be non-toxic (Grabow et al., 1985), and recommended it use as a coagulant in developing countries (Barth et al., 1982; Bhole, 1987; Jahn, 1988; Müller, 1980) cited by Ndabigengesere et al. (1995) and Olsen (1987).

The use of Moringa has an added advantage over the chemical treatment of water because it is biological and has been reported as edible. The cost of this natural coagulant would be less expensive compared to the conventional coagulant (alum) for water purification since it is available in most rural communities where treated water is a scarce resource.

It is in this light that this research was carried out to confirm the effectiveness of powder extracted from mature dried Moringa Oleifera seeds which is commonly available in most rural communities in Uganda. It is a well-established fact as proven in several publications that the quality parameters of drinking water include its turbidity, conductivity, pH and microbial load.
Moringa oleifera is known as the "miracle tree" because parts of the tree are rich in nutrients, have several medical benefits, and can be used to treat drinking water (Razis, A. F. A *et.al*). People in many developing nations treat drinking water by first shelling and grinding the seeds into a powder. Fatty acids are pressed from the grounds, collected, and sold as a commodity.

The defatted seeds are then added to a small container of water and shaken to extract cationic proteins that act as coagulants and antimicrobial agents. This protein solution is poured through a cloth into a larger container of water designated for drinking. This water is stirred and particulate matter is allowed to settle, at which time the water is potable.

Although Moringa oleifera cationic proteins are highly effective coagulants and antimicrobial agents (reducing water turbidity up to 99.5% 11–23 and achieving 1 to 4 log removal of microorganisms (Wilson, S. A.), this procedure provides only short term benefit.

Natural organic matter from the seeds remains in the treated water and supports the growth of residual microorganisms, causing the water to become unsafe to drink after 24 hours (Lea, M). In many developing nations, drinking water is scarce or difficult to obtain, so methods of reducing natural organic matter in Moringa oleifera treated water are of great interest.

Li and Pan (Li, L) found that sand modified by Moringa oleifera proteins can remove between 20-80% of algal bloom cells depending on the algae species. Nisha et al. found that a filter packed with Moringa oleifera cationic protein-coated sand (referred to as MOCP c-sand) was able to produce a reduction in water hardness of ~33% and a reduction in chloride ion concentration of ~43%. Williams et al. showed that E. coli will attach to f-sand packed in a column and that these microbes can be removed with a surfactant rinse.

Ion exchange has been employed to remove excess dissolved organic carbon in the form of non-cationic proteins (Gassenschmidt). It has also been used to isolate individual cationic protein fractions or various combinations of cationic protein fractions (Gassenschmidt). These studies used dissimilar chromatographic and micro-coagulation assay conditions, and therefore reported different fractions with varying levels of coagulation activity. The cationic proteins have been found to reduce water turbidity 50-99.5% depending on initial turbidity (Madsen).

2.3 THE IMPACT OF THE CHEMICALS IN WATER

Nitrates are more toxic than nitrites and can cause human health problems such as liver damage and even cancer (Gabel et al., 1982; Huang et al., 1998). Nitrate can also bind with hemoglobin and create an oxygen deficiency called methemoglobinemia in warm-blooded animals, especially in the young babies (blue baby syndrome) (WEF, 2005).

Meanwhile, nitrites have been associated with “brown blood diseases” in warm water fish (Kentucky Water Watch, 2008), and is carcinogenic when involved in chemical and enzymatic reactions with amines (Sawyer et al., 2003). In addition, both phosphorus and nitrogen species can trigger eutrophication, which occurs when excessive nutrients in a water body encourage the excess growth of plants such as algae and weeds. These plants consume available oxygen in the water, leaving less available for fish and other aquatic species. Ultimately this condition degrades both the aesthetics and ecosystem health of rivers, springs, and lakes. Compounds containing nitrogen and phosphorus are found in storm water runoff. While highways are a main source of these nutrients in storm water runoff (USEPA, 1999a).

Many other sources also contribute to increased nutrient contents in storm water and groundwater. These sources include agricultural fertilizers, untreated wastewater, insufficiently treated wastewater from septic tanks, and animal urine and droppings. Phosphorus is released from fertilizer, dead plants, animal waste, detergents, forest fires, synthetic materials, and decaying animal bones. Most phosphorus exists in the form of orthophosphate (PO_4^{3-}, OP) (Crites and Tchobanoglous, 1998)

Under existing hydrologic systems, the high nitrogen and phosphorus concentrations in storm water runoff, contaminated groundwater, landfill leachate, and domestic and industrial wastewater effluents will continue to increase surface and groundwater contamination and reduce the potential for water reuse. In water management, best-management practices include maintenance procedures and management practices aimed at preventing or reducing water pollution. Bamboo charcoal can be treated to make activated carbon. It is produced by heat treatment where a unique internal pore structure is creating, thus providing it with adsorptive properties. Activated carbon is a carbonaceous adsorbent with high porosity

2.4 THE VEPOX WATER FILTER

From the above literature, we see that bamboo activated carbon, Moringa Oleifera, and sand have been potential ways of cleaning and removing all impurities from dirty water. The only challenge is that using explicitly one of the above mechanisms doesn't eliminate all the impurities contained in the water. For example;

- Sand used in filtration can reduce the turbidity and pathogens in water to a large extent but can't remove dissolved chemicals like nitrates and chlorides which cause health issues when taken in excess.
- The Moringa Oleifera is good at the elimination of pathogens but not quite for dissolved chemicals.
- The activated carbon to a large extent only eliminates dissolved ions by adsorption, but not quite effective in the removal of pathogens.

Therefore, combining the three independent parts into one, with each having a role to play in the elimination process would perfectly clean the contaminated water. This is exactly the idea behind the VepoX water filter, that is; - The Integrated Bamboo activated carbon and Functionalized Sand Water Filter.

3 CHAPTER THREE

This chapter describes in full detail all the activities carried out during the training, to design and prepare the filter materials used.

3.1 TEAM GOALS RESTATEMENT

- To design and implement a batch water flow purification device, which couples the filtration capabilities of sand with the antimicrobial and flocculating properties of the cationic protein found in Moringa Oleifera seeds, and the adsorption capabilities of bamboo activated charcoal to eliminate toxic substances like nitrates ions from valley dam water.

- To design and implement an end User friendly water purification device at a comfortable price, through use of locally available materials for the filter media and product modelling.

3.2 ACCOMPLISHMENTS

During the internship period (which officially started on 10th June 2019), the Vepo filter team went through a series of dynamic activities, with the Wabbale valley dam located in Nakasongola district as the study case; to align all events with the team's final goals. Below is a breakdown of the executed activities, followed by the detailed descriptions for each stage.

1. Sand sieve analysis
2. Wabbale valley dam reconnaissance
3. Laboratory tests on first six water samples
4. Software schematic designing
5. Preparation of Bamboo activated carbon
6. Preparation of functionalized sand
7. Setup of lab scale analysis models
8. Analysis of filter material performance on second and third water sample sets
9. Conclusions from laboratory analysis
10. Final prototype design adjustments

3.2.1 SIEVE ANALYSIS

We carried out dry sieve analysis of sand in the soil mechanics laboratory under the guidance of Mr. Mukasa, who granted us access to the lab's sieving media.

The sand used in the analysis was Lake sand obtained from Gerenge grounds along the shores of Lake Victoria. We obtained approximately 10kg of sand. Procedure for sieve analysis

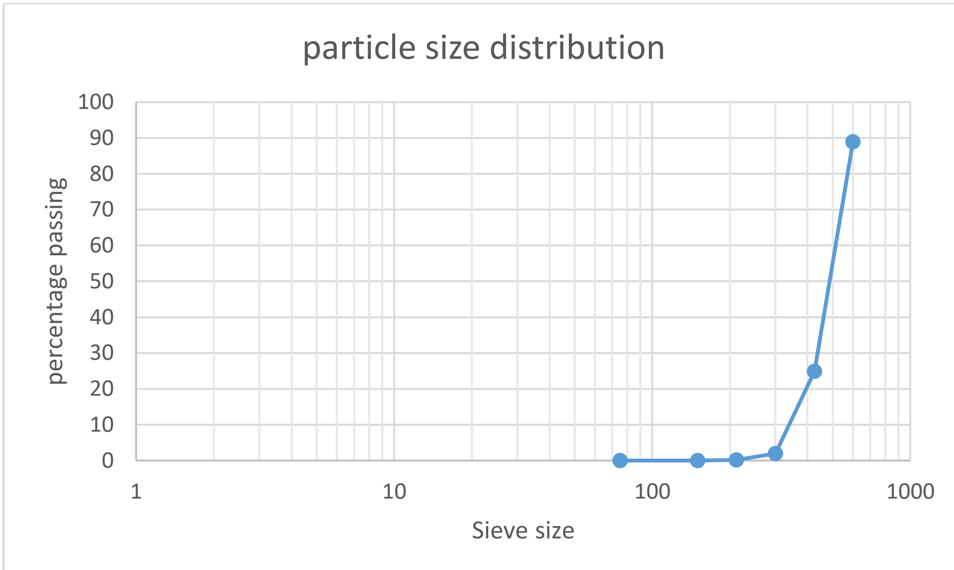
1. The sand (wet) was first dried under the sun for 12 hours to reduce the moisture content, and make it efficient for dry sieving
2. A sand sample was passed through a riffle box for uniformity consistency of the particles.
3. Of the above sample, we measured a representative fixed amount of sand and determined its initial weight using an electronic balance.
4. The sieves were then stacked in increasing diameter including the pan and cover
5. The sand was then poured into the stack of the sieves from the top. The cover was placed, and the stack was mechanically shaken by hand means for 10 minutes.
6. The shaking was then stopped and the mass of sand retained on each sieve was measured.
7. The grading curve (log sieve Vs percentage finer). Corresponding to 10%, 30% and 60% finer, diameters were obtained from the graph which were used to determine the sand coefficients of uniformity and curvature respectively.

Table 2: Results from sieve analysis

Sieve size (microns)	mass of sand retained (kg)	cumulative mass retained (kg)	% cumulative retained	% finer or % passing
600	0.134	0.134	11.04	88.96
425	0.778	0.912	75.12	24.88
300	0.278	1.19	98.02	1.97
212	0.022	1.212	99.84	0.16
150	0.002	1.214	100	0
75	0	1.214	100	0

From the above results we opted for the sand size retained on the 425-micron sieve because of the large percentage of sand which was retained.

<u>Resultant particle distribution graph.</u>



Analysis of results: From the graph above,

D_{30} = 430 D_{60} = 505 D_{10} = 340

coefficient of curvature	Coefficient of uniformity
$\boldsymbol{C_c = \frac{{D_{30}}^2}{D_{60}\ x\ D_{10}} = 1.08}$	$C_u = \frac{D_{60}}{D_{10}} = 1.485$

For a well graded sand, C_c varies between 1 – 4 and $C_u > 4$. Since the sand sample doesn't satisfy the criteria, then it poorly graded.

Also the sand porosity was calculated and averaged to 0.4

3.3 WABBALE VALLEY DAM RECONNAISSANCE

Nakasongola District is located in the Central Region of Uganda, bordering Apac District to the north-west, Amolatar District to the north-east, Kayunga District to the east, Luweero District to the south, Nakaseke District to the south-west, and Masindi District to the north-west. Nakasongola suffered from relative neglect due to the distance from the then district headquarters, which became the basis for its creation in 1997.

The district covers 4,909 square kilometers (1,895 sq. mi), of which 4.6% is permanent wetland.

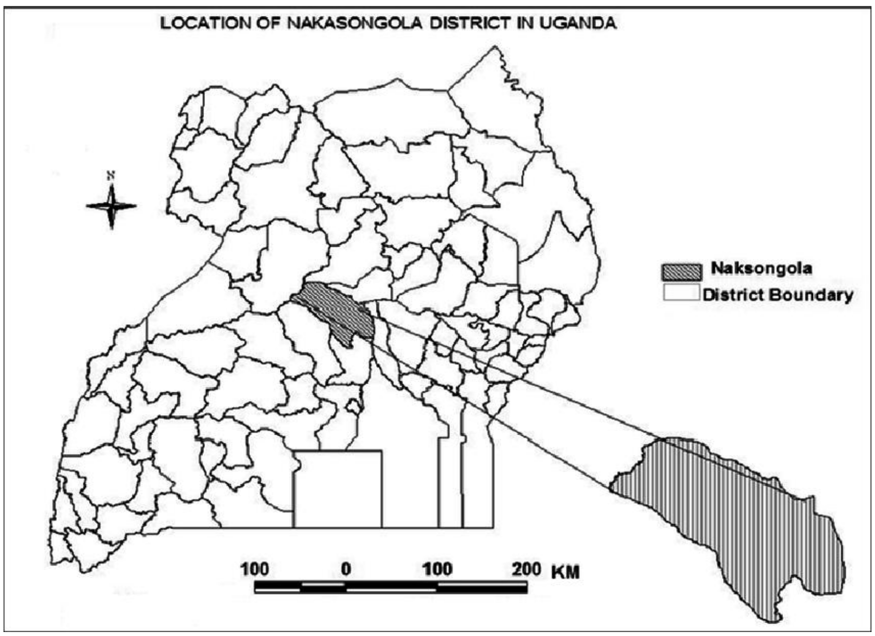


Figure 4-Location of Nakasongola district on the map of Uganda (internet file)

3.3.1 GEOGRAPHICAL LOCATION

The Valley dam we visited during reconnaissance is located in Wabbale village in Nakasongola District. The geographical coordinates of the valley dam are, Latitude: 1.315967° (1°18'57.89"N); Longitude: 32.450054° (32°27'00.09"E). Access to the valley dam from Bwaise Roundabout is by way of Kampala-Gulu Highway for approximately 114.22km to reach Nakasongola loop sign post. Turn right onto Valley Road for about 7.39km to reach Nakasongola town, turn left and continue for about 1.96km and finally turn right for about 150m to reach the Valley dam on the right hand side.

Figure 5- Aerial location of the valley dam (Google maps image)

Interactions with the locals who had come to fetch water revealed that the dam served as the main water source in the village, providing for both domestic and animal use (cattle, which used the separate extension of the dam on the opposite side of the road), and also serving the neighboring villages.

3.3.2 AREA OF THE VALLEY DAM

The valley dam is approximately 46,886sq.m (11.6 acres) with approximately 60% of the water surface exposed to the environment. This is because the dam is rarely maintained through the cutting and removal of the water weeds.

Figure 6-Ground extent of the valley dam

The available tap water in the area is at the Nakasongola prison. However, piping tap water is expensive for the locals, which is why most of them opt for the free valley dam water.

Our observations indicated that men with at least four jerry cans came fetching water in approximate intervals of five to ten minutes. The valley dam derives it water entirely from rainfall in its large catchment area. An interaction with one of the locals who has been using the valley dam water since 2002 revealed that the dam doesn't run dry even in dry seasons. He further clarified that it only happened once when the dam dried up, because of water overuse by large illegal trucks, which used to fetch water and transporting it to far distances.

3.3.3 METHODS OF CURRENT WATER TREATMENT

The fetched water is first boiled (by some) to make it safe and ready for drinking, whilst others are used to taking it raw! New locals in the area find it hard to sustain their health with un boiled water and therefore opt to boiling it.

Figure 7-Physical engagement with Locals at the valley dam

3.3.4 WATER FETCHING POINTS

The valley dam has a total of six (6) potential fetching points, which are used by the locals according to the nearest direction of the dam from place residence. Water is mainly fetched in 20-liter jerry cans.

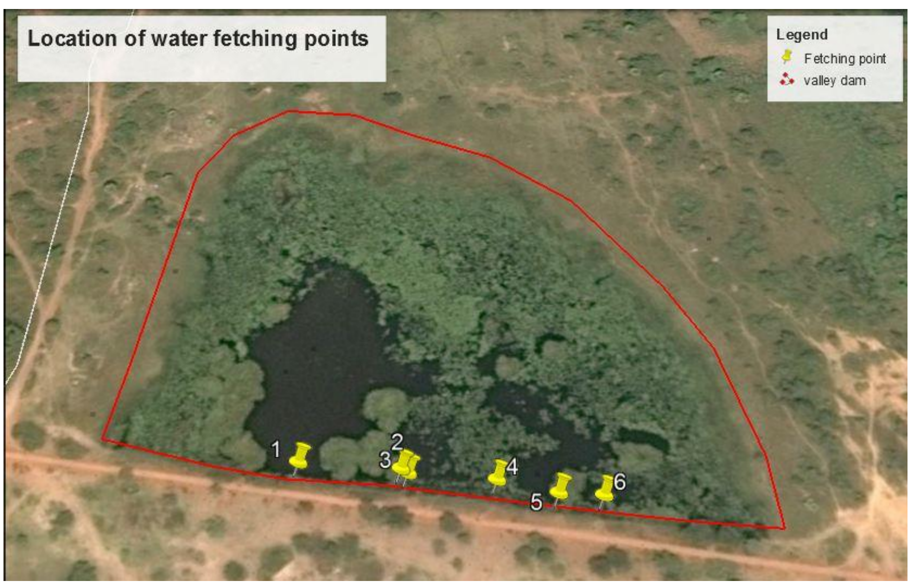


Figure 8 - Aerial view of the dam's 6 fetching points (Google maps image)

3.3.5 DAM NAVIGABILITY

Our ground observations and interactions with revealed that the dam tapers from the shallow end at its shores, becoming deeper few meters towards its center. There were no available boats or canoes to allow for navigation midway the valley dam.

Figure 9 - Locals fetching water at the dam

Since the valley dam was relatively large, with no local or available means of navigation, we deduced to carry out water sampling two meters from the shore line. This in theory would give us a fair approximation for the raw water quality in the valley dam, which we could use as the basis for the VepoX filter design.

This valley dam was a potential study case for our VepoX filter project, since it served a relatively large number of people in Wabbale village and the neighboring areas with potential health implications due to natural contaminations caused by microorganisms and chemicals. However, this valley dam was quickly accessible since it lies less than 200 meters from the kampala-gulu highway.

3.4 LABORATORY TESTS ON FIRST SIX WATER SAMPLES

After meeting up with the mentors to present the reconnaissance data, we were assigned to pick six water samples at approximately spaced intervals all-round the valley dam, at a distance of 2 meters from the shore line, whilst obtaining the GIS coordinates for each point, and the vertical depth at each corresponding point. Our laboratory analysis targeted both the physical and biological properties of the raw water. The parameters of our study included the following; -

- pH
- electrical conductivity
- Turbidity
- Apparent color
- True color
- E-coli
- Nitrates & nitrites
- TDS & TSS
- Ammonia
- Total iron

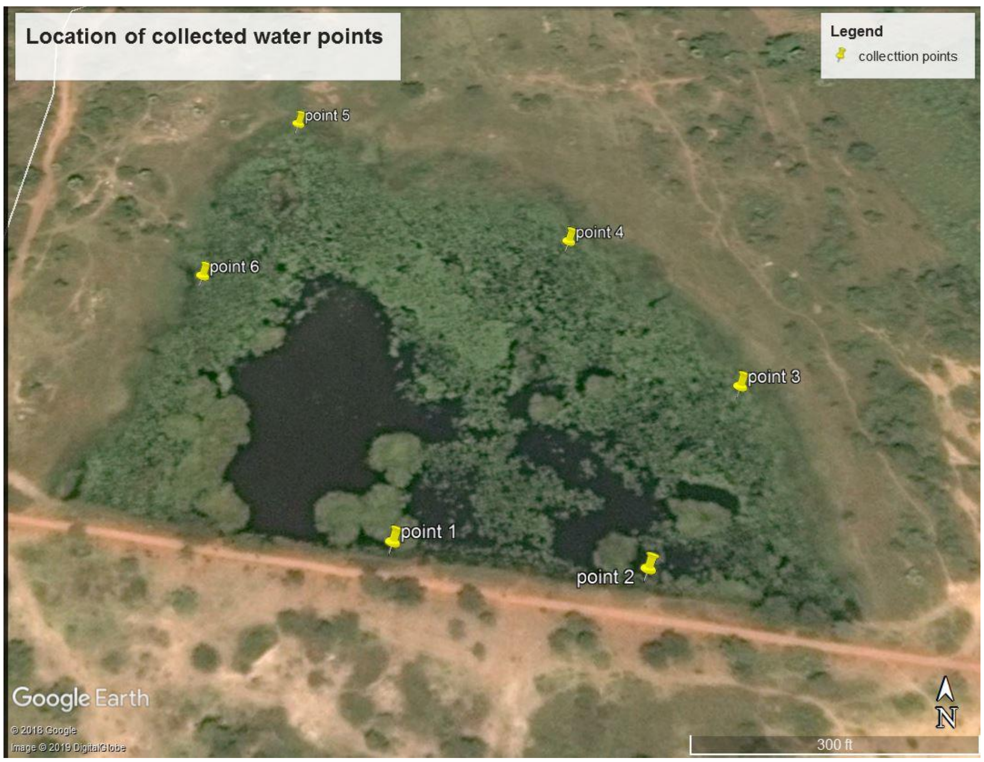


Figure 10-Image showing the various Sampling points at the Valley dam. (Google maps image)

We carried out water sampling from points 1, 2, 3, 4 and 5, whose corresponding vertical depths were; 1.6m, 1.4m, 1.2m,0.6m, 1.2m and 0.5m respectively

The table below summarizes the results for the laboratory analysis on the raw water.

Table 3-Raw water quality laboratory results

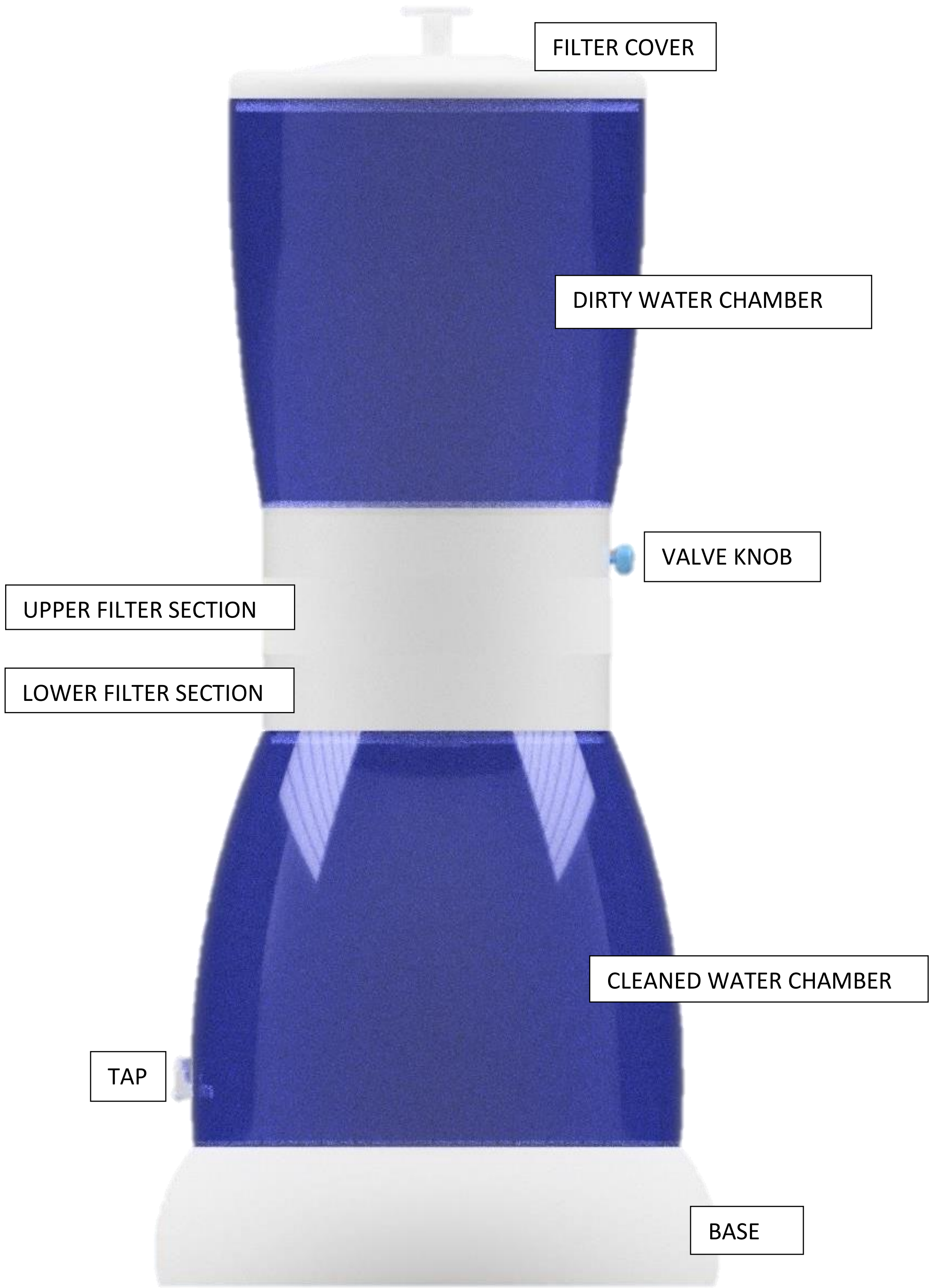
PARAMETERS												
Fetching points	pH	EC (µS/cm)	Turbidity (NTU)	Apparent color (Pt-Co)	True Color (Pt-Co)	Nitrates (mg/l)	Nitrites (mg/l)	Ammonia (mg/l)	Total Iron (mg/l)	E-Coli (CFU/100ml)	Total Dissolved solids, TDS (mg/l)	Total suspended solids, TSS (mg/l)
1	7.28	198.3	17	147	57	0	0.005	2	1.8	140	130	24
2	7.25	195.5	13	128	60	12.6	0.002	3	0.6	290	150	34
3	7.62	195	8	69	14	9.7	0	7	0.07	440	134	0
4	7.94	189.8	8	86	36	1.8	0.002	4	1.11	265	184	0
5	7.46	134	60	642	492	6.5	0.04	40	2.28	260	230	20
6	7.39	193.1	8	120	89	2.5	0.005	4	0.48	370	174	0
WHO standards (fourth edition)	6.5 - 8.5	1500	5	5	_	50	3	1.5	0.3	0	500	0
mean	7.5	184.3	19.0	198.7	124.7	5.5	0.009	10.0	1.1	294	167.0	13.0
standard deviation	0.24	22.63	18.64	165.87	199.96	4.51	0.01	13.50	0.77	93.83	34.29	13.65

3.5 SOFTWARE SCHEMATIC DESIGNING

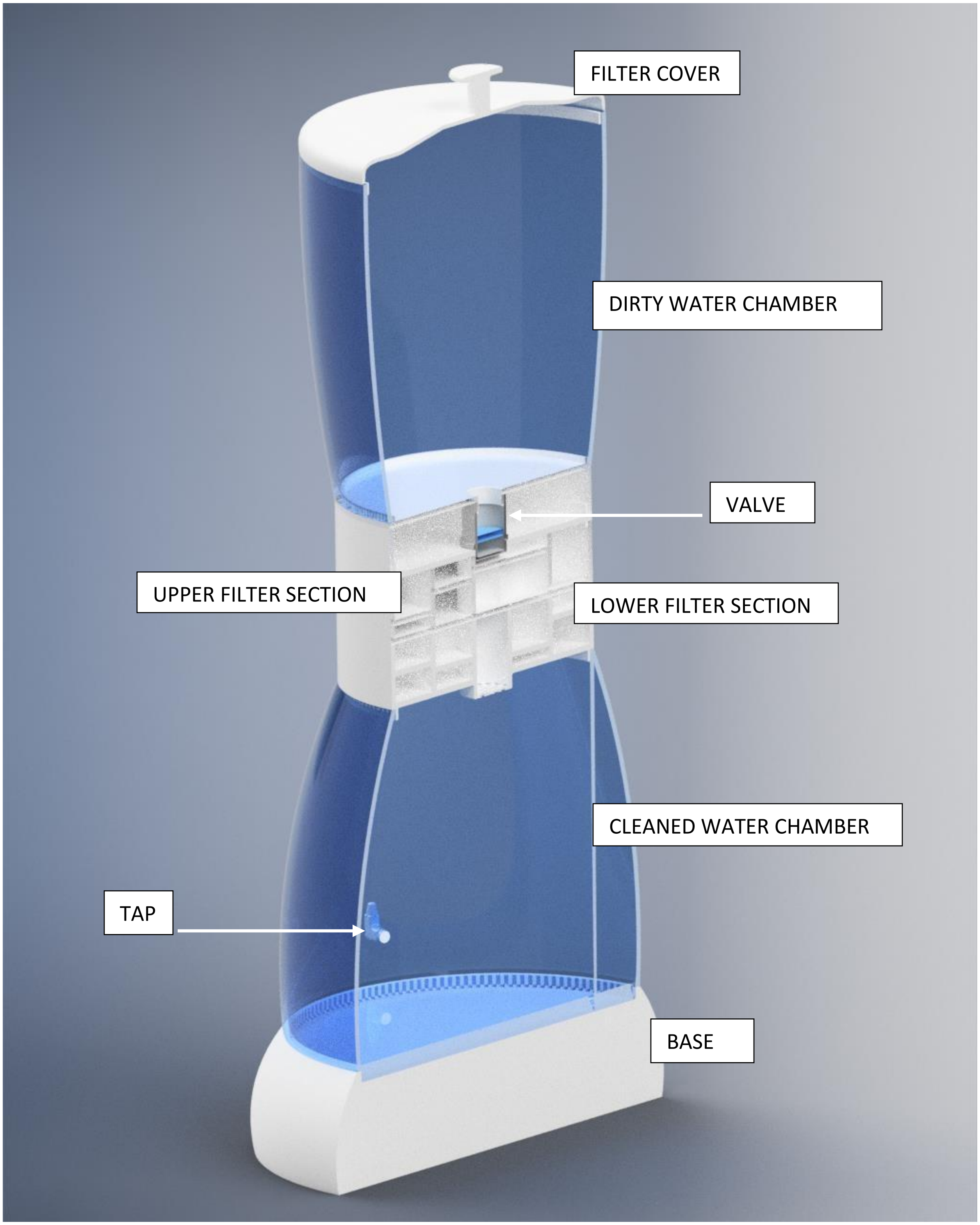
The filter works by combining the natural adsorption capabilities of bamboo activated carbon and the anti-microbial mechanism of functionalized sand (f-sand) to eliminate, dissolved ions, turbidity and pathogens (especially E-coli) contained in dirty water respectively. f-sand is made by the process of adhering the cationic protein extracted from the moringa oleifera seeds onto the sand grains surface, giving it a positive electric surface potential to attract irreversibly the negatively charged E-coli bacteria.

Figure 11-Artistic impression of the VepoX filter

FIGURE SHOWING THE VEPOX FILTER PARTS



LONGITUDINAL SECTION THROUGH THE FILTER



3.5.1 FILTER MEDIA SECTION

This is the most important part of the design. It is designed such that water flows downwards by gravity, whose flow rate is controlled by the inlet valve just before entering the upper filter section.

HOW IT WORKS

When water emptying from the dirty water enters the upper filter section, it gradually flows through it in a spiral-like movement, of increasing diameter from the center (A) constantly, downwards a spiral inclination to the extreme end (B)

At the extreme end (B), water flows into the lower filter section, and gradually flows through it in a spiral-like movement, of reducing diameter from the extreme at a constant and downward spiral inclination to the center, where it finally drops out into the cleaned water container.

NB: The inclination is necessary to avoid stagnation of water whilst in the filter chamber thus reducing head loss.

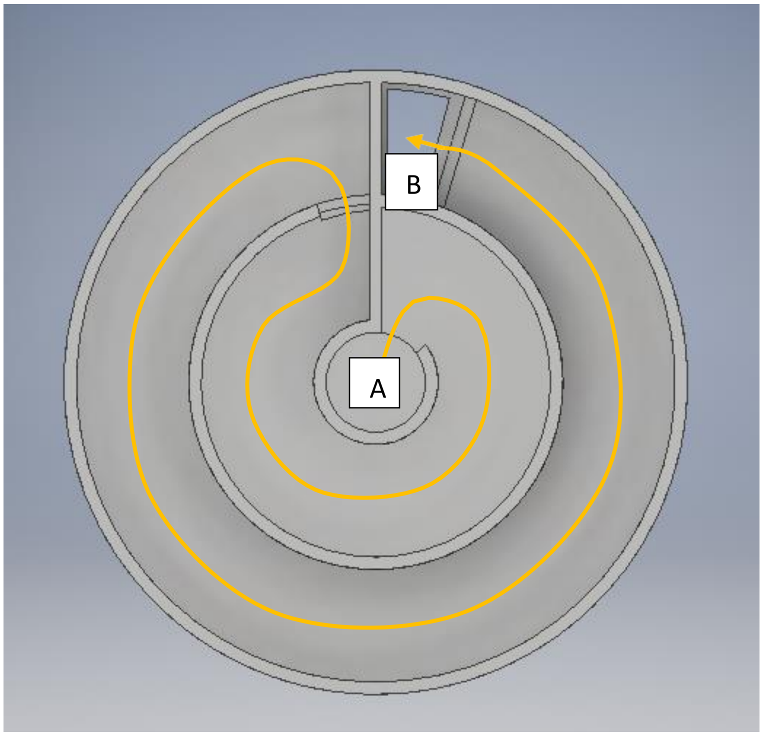


Figure 1-Upper Filter Chamber

Water flows in the orange spiral pattern of increasing diameter outwardly from point A to point B, and flows to the lower filter section via the opening at B.

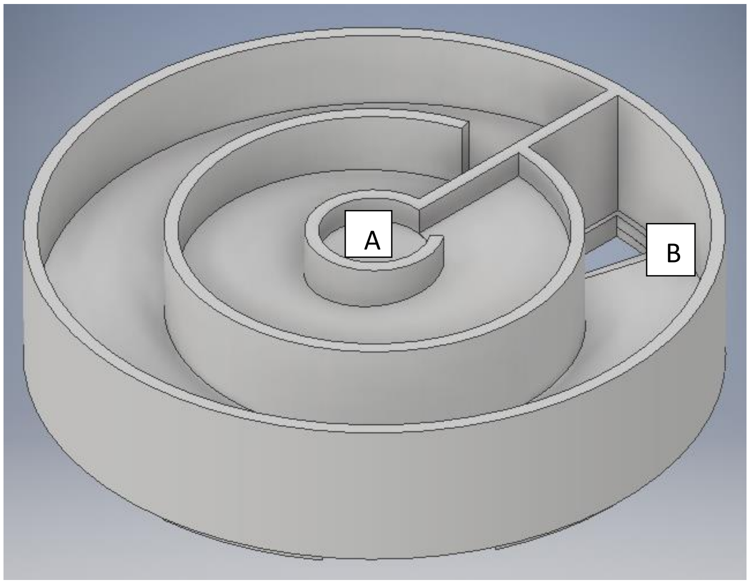


Figure 2-Upper Filter Chamber

The 3D rendering depicts the fall of gradient from point A (at a highest point) to the exit at point B (the lowest point). Therefore, water will flow by gravity.

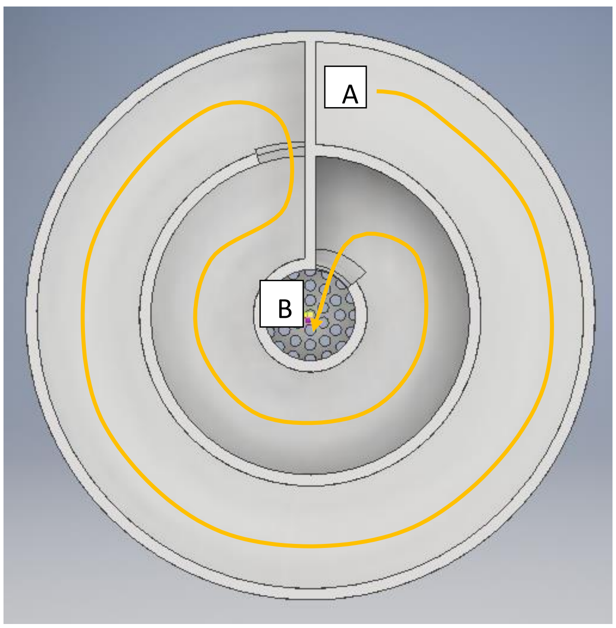


Figure 3-Lower filter chamber

Water flows in the orange spiral pattern of decreasing diameter inwardly from point A to point B, and flows into the cleaned water chamber through the openings at B.

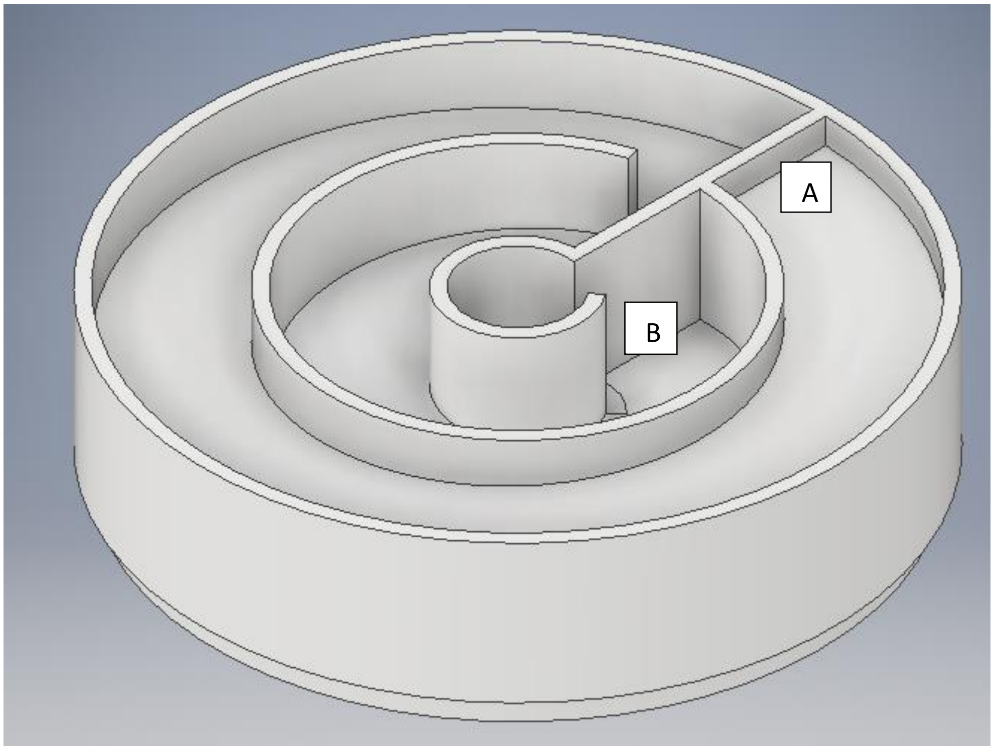


Figure 4- Lower filter chamber

The above 3D rendering depicts the fall of gradient from point A (at a highest point) to the exit at point B (the lowest point). Therefore, water will finally flow by gravity and exit the filter via point B into the clean water container.

3.6 PREPARATION OF BAMBOO ACTIVATED CARBON

This process involved three stages which were performed at MTSIFA, Kyambogo University Art section and the Mechanical Lab at CEDAT.

The first stage involved cutting of raw bamboo sticks from the MTSIFA and drying them under room temperature. This was done during the final month of the last semester and kept under room conditions to dry for about a month's time.

The second stage was the thermo-Pyrolysis of Bamboo, which involved the following processes; -

1. The bamboo was first chopped by an electric saw into small cylindrical pieces with an average height of 9cm. They (cylindrical pieces) were then crushed manually lengthwise into rectangular pieces, to reduce their volume occupied in the container.
2. The pieces were then packed into a ceramic pot and fired at 500 ^{0}C for 3 hours. The pot was left to cool and the carbonized material removed at 50 ^{0}C.

The third and last stage was the activation stage, which involved the chemical activation of bamboo Charcoal using Zinc chloride as the activator. The following is the series of the processes involved; -

1. The obtained bamboo charcoal was first crushed into small particles ranging from dusty fines to coarser particles.
2. Using the knowledge of sieve analysis and under the highway engineering lab, we sieved out the right size of our choice (0.2 – 1.18 mm) and used it as the raw material for the activation process.
3. 100 g of bamboo charcoal were added to 300g of zinc chloride powder (ratio 1:3) and mixed using deionized water until a uniform paste was formed.
4. The resultant paste was left to stand for 24 hours to allow for the soaking and penetration of zinc chloride ions into the deep porous fabric of bamboo carbon.
5. After 24 hours, the paste was oven dried at 105 ^{0}C in the highways laboratory to eliminate the excess moisture to a dry state (This was necessary to avoid destruction of the oven's heating elements at the later extreme activation temperatures).
6. Then, the dry (uniform mixture of charcoal and activator) was fired in the mechanical labs electric oven at 500 ^{0}C for 2 hours for the chemical activation process to occur.

7. After cooling from the oven, the sample was then washed with deionized water to eliminate the zinc chloride until the Electrical conductivity of the runoff cleansing water fell to below 400 µS/cm.
8. The product was then oven dried at 105 ^{0}C for 24 hours to completely eliminate water moisture. At last we obtained a dry sample of bamboo activated carbon.

Figure 12-Sieve analysis of bamboo charcoal

3.7 PREPARATION OF FUNCTIONALIZED SAND

Detailed methodology

1. The moringa seeds (kernel) were ground using a bender and the resultant powder mixed with 96% ethanol liquid for 30 minutes using a magnetic stirrer.
2. The solids were then separated by filtration through a muslin cloth and dried at room temperature, to eliminate the volatile ethanol
3. 3.416 grams of the dried solids were ground in a grinder to form a fine powder which then mixed uniformly with deionized (DI) water of 660ml for 10 minutes forming a suspension.
   The 3.416g of seed was used so as to obtain a seed concentration of $0.05\ g/ml$ and a seed loading of $5.6 g/m^2$ (Jerri, H. A., Adolfsen et.al)

Figure 13: weighing of dry moringa seeds

4. The solution was left to settle for 12 hours and then passed through a 2.5µm Whatman Filter Grade 5 using a suction pump to quicken the process.

Figure 2: Filtration of the solution through the 2.5µm

5. The filtrate was then passed through a 0.22µm cellulose acetate filter (Millipore) to obtain an extract containing the dissolved moringa cation. (*Boya Xiong, et al)*
6. The extracted solution of 660ml was then mixed with 100g of sand (425 microns) for charge reversal, from a sand surface potential of -42mV to about +10mV (8.2 ± 2.4mV). The mixing period ranged from 5 to 10 minutes. (Ziyuhan Wang, et al)

Figure 3: Mixing of sand the moringa cationic oleifera filtrate.

7. Afterwards the supernatant (lying above the mixture) was discarded off the resultant sand slurry washed with DI water at least three times to remove organic residues. This resultant combination is the **functionalized sand** (f-sand).
8. This f-sand was then packed into columns for further examination of the materials performance through various experimentations and model development.

Figure 14- Prepared Functionalized sand

Figure 15-Functinalised sand and Bamboo activated carbon

3.8 SETUP OF LABORATORY SCALE ANALYSIS MODELS

We set both vertical and horizontal flow models to analyze and optimize the performance of each set up.

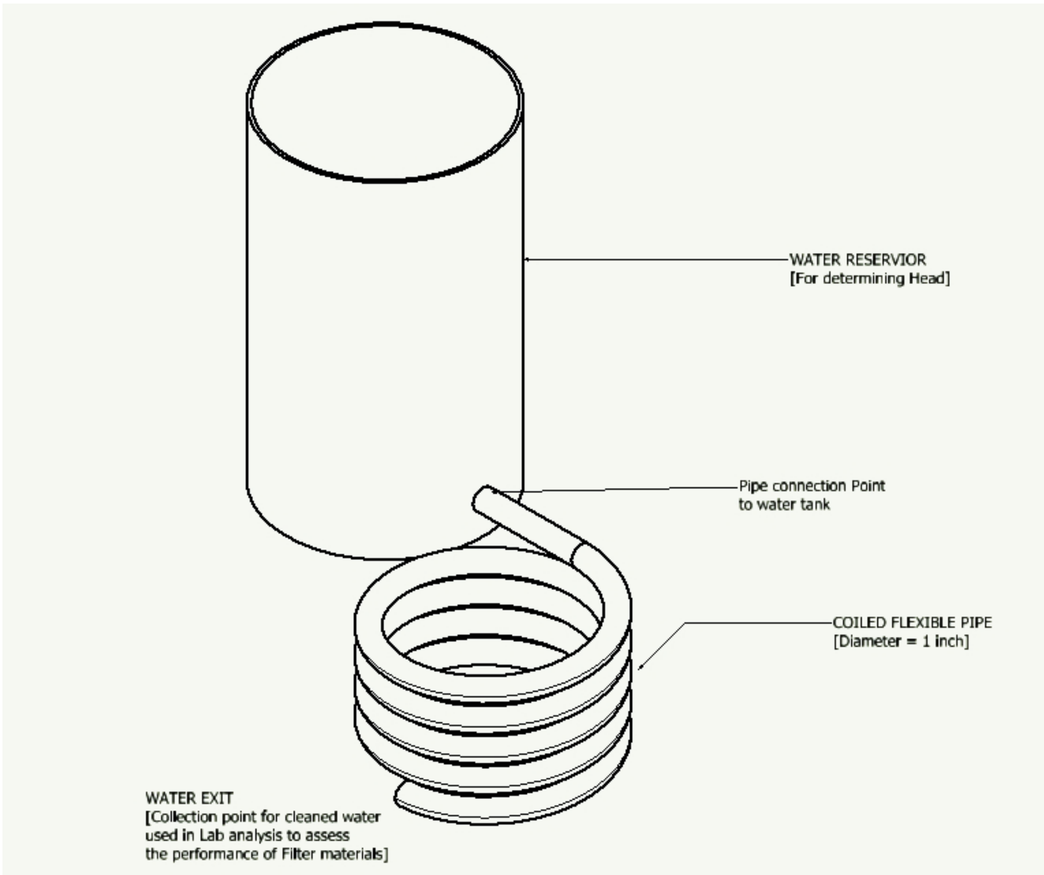


Figure 16-Laboratory scale model for horizontal flow

1. The Raw water reservoir of approximate height 50cm, was used in controlling the water head, and determination of the water flow rate through the coiled tubes.
2. Coiled flexible pipes (of diameter 2.54 cm and 1.6 cm) were coiled at a constant coil diameter of 25cm and filled with Filter materials (activated carbon and functionalized sand) in a ratio of 1:1.
3. Experiments were run to ascertain the flow rate through each of the columns and the water quality analyzed.
4. 2.54 cm diameter coils performed optimally in the previous experiment, and therefore used as the best choice for this next series of setups.
5. The experiments were then repeated with different coiled lengths of the flexible pipes ranging from; 0.5m, 1.0m, 1.5m and 2.0m. This is necessary to investigate the optimum coiled length to use in the finally designed Product.

Figure 17-Laboratory setup for Horizontal flow

Figure 18-Tubes used for vertical Flow experiments.

The brown upper half constitutes functionalized sand and the Lower dark section is Activated carbon

3.9 ANALYSIS OF FILTER MATERIAL PERFORMANCE ON SECOND AND THIRD WATER SAMPLE SETS

EXPERIMENTATION 1 (**VERTICAL FLOW**) - PARAMETERS												
Water sample	pH	EC (µS/cm)	Turbidity (NTU)	Apparent color (Pt-Co)	True Color (Pt-Co)	Nitrates (mg/l)	Nitrites (mg/l)	Ammonia (mg/l)	Total Iron (mg/l)	E-Coli (CFU/100ml)	Total Dissolved solids, TDS (mg/l)	Total suspended solids, TSS (mg/l)
Raw Water	7.61	213.9	17	122	35	5.2	0.007	0	0.4	1650	102	0
Filtrate Sample A	6.66	369	1	0	0	0	0	0	0.09	0	95	28
Filtrate Sample B	6.76	269	5	18	0	0	0.005	0	0.13	0	74	0
WHO standards (fourth edition)	6.5 - 8.5	1500	5	5	_	50	3	1.5	0.3	0	500	0

Sample A -30cm length material

2.54 Column diameter

Sample B – 60cm length Material

1.4cm column diameter

EXPERIMENTATION 2 (**HORIZONTAL FLOW**)- PARAMETERS												
Water sample	pH	EC (µS/cm)	Turbidity (NTU)	Apparent color (Pt-Co)	True Color (Pt-Co)	Nitrates (mg/l)	Nitrites (mg/l)	Ammonia (mg/l)	Total Iron (mg/l)	E-Coli (CFU/100ml)	Total Dissolved solids, TDS (mg/l)	Total suspended solids, TSS (mg/l)
Raw Water	7.38	227	28	-	-	12	0.028	0	0.54	130	-	-
Filtrate Sample A (1m)	6.96	250	2	-	-	1.0	0.004	0	0.00	0	-	-
Filtrate Sample B (1.5m)	6.77	269	1	-	-	0	0.021	0	0.00	0	-	-
WHO standards (fourth edition)	6.5 - 8.5	1500	5	5	_	50	3	1.5	0.3	0	500	0

Diameter used for both setups in experimentation 2 were 2.54 cm.

Sample A -1m length material

Sample B – 1.5 length Material

On comparison, the performance of the filter media in the experiment 1 was for vertical flow, used as a control for experiment 2, which was designed and worked as horizontal flow.

The flow rate for vertical flow was 0.015422 litres/s while the flow rate for horizontal flow was 0.0011 litres/s. Both gave positive results judged against the W.H.O standards concerning the water quality.

In both experiments, the Electro conductivity values are greater than found in the raw water. This is because of the erosion of the remnant zinc chloride which had remained adsorbed onto the activated carbon porous surface.

Contrasting the flow rates, we are to opt for the 30cm length, 2.54 cm diameter, and vertical flow columns. Although the horizontal flow mechanism yielded the expected results, the flow rates were very low. (we waited for about 30 minutes for a drop of water to transit through from the inlet to the collection point under horizontal flow, compared to the vertical flow system that is faster and yielding intelligible results!)

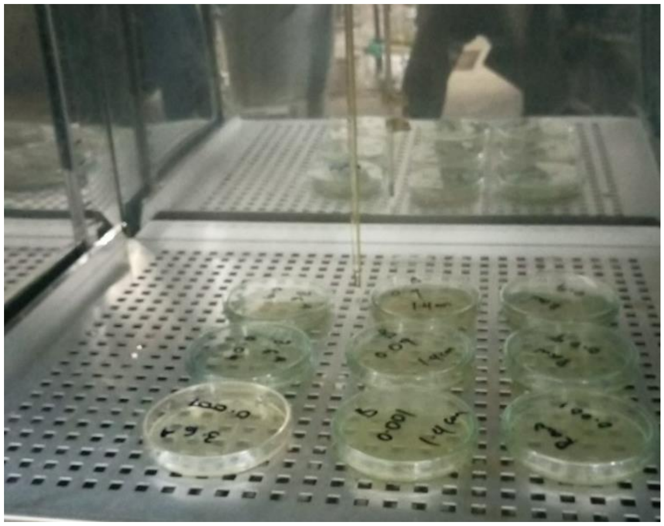


Figure 19-Incubation of agar plates during the E-Coli test experiment

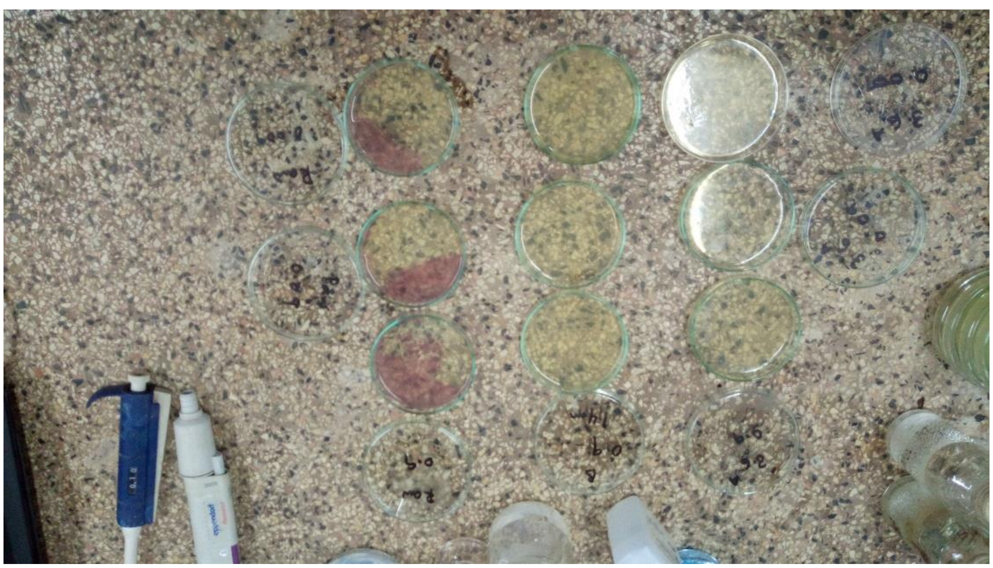


Figure 20- E-Coli results after 24 hr. incubation.

The leftward agar plates are for raw water. The reddish-purple signature indicates the presence of E-Coli in the sample. The rightward agar plates are for the Filtered water. There is no E-Coli signature colour.

4 CHAPTER FOUR

4.1 CONCLUSIONS FROM LABORATORY ANALYSIS

Following the above lab analysis of the materials, the following conclusions can be made; -

1. The functionalized sand performed as expected. This is evidenced in experiment 1 on its anti-microbial effect, by Epically reducing the E-Coli levels from 1650 CFU/100 ml in the raw water sample to 0 CFU/100 ml in the obtained filtrate!
2. The activated carbon performed as expected, due to the significant reduction in the ionic concentration in the raw water.
3. The filter media worked as expected in reduction of the raw water turbidity from high values to stringent values as low as 5 FAU, and even 1 FAU in the laboratory experiment 1.
4. The process of physical activation would have been better in comparison to the chemical activation method we applied in the production of bamboo activated carbon. This is due to Increase in electro conductivity values in filtered water than raw water; Caused by of the erosion of the remnant zinc chloride Activation agent which had remained adsorbed onto the activated carbon porous surface
5. The vertical flow system is optimally better in comparison horizontal flow, considering the flow rates. (Moreover, an end user in real life wouldn't be comfortable with a product which is not optimized)
6. The product will work as expected.

Figure 21-Figure showing two filtrate samples against the raw water

There is a clear distinction in the actual color of the filtrates and the raw water samples

4.2 FINAL⁺ PROTOTYPE DESIGN AND/OR ADJUSTMENTS*

The product will be adjusted for the vertical mechanism, which has experimentally proved to better than the horizontal flow for this typical design.

4.3 NEXT TARGET TO ACCOMPLISH

We intend to start the fabrication of the final end user product. This is because of the expected performance of the filter media, in reaching our target goal.

4.4 CURRENT DIFFICULTIES

- The pump used in the extraction of the filtration containing moringa oleifera cationic protein is inefficient (slow) taking us long periods of time to extract filtrates used to produce just a few hundred grams of f-sand.
- Limited accessibility to the PHEE lab (especially on weekends), which caused us to project some of our activities forward.

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