DESIGN, CONSTRUCTION AND EVALUATION OF CHARCOAL, ACTIVATED CARBON, MORINGA SEED AND SAND WATER FILTRATION SYSTEMS

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ABSTRACT

The majority of human population especially in developing countries suffers from water-borne diseases such as skin abscesses, cellulitis, skin infections, and diarrhoea due to improperly treated water. Safe drinking water remains unavailable to a large portion of the global population and this is a global concern. This work focused on the design, construction and evaluation of charcoal, activated carbon, Moringa seed and sand water filtration systems with an objective of evaluating the performance of the filters using flow rate and water quality parameters and also compare the cost and the performance of the filters with an existing commercial imported filter. The filtration method was adopted for this work. Four different filters were designed using different materials (sand, charcoal, activated carbon and pulverized Moringa seeds) were used because of the cost and destruction of a large number of microbial especially bacteria, pathogens, etc. Some water quality test such as the potential of Hydrogen (pH), Electrical Conductivity (EC), Turbidity, Dissolved Oxygen (DO), Total Dissolve Solid (TDS) and flow rates were carried out. The results shows that sand filter has the best flow rate of 3.80mL/sec. followed by charcoal (1.91mL/sec), activated carbon (1.73mL/sec) then Moringa (0.51 mL/sec), in terms of turbidity Moringa is the best with the value of 11.8 NTU and sand is the worst with 33.6NTU and Moringa is still the best in terms of EC and activated carbon is the worst with the value of 270 µS/cm and 315 µS/cm respectively.

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DEDICATION

I dedicate this work to Almighty Allah (SWT) and my beloved Father; Late Alh. Ahmed Umar Farooq.

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AfDB: African Development Bank
AUST: African University of Science and Technology
BOD: Biochemical Oxygen Demand
COD: Chemical Oxygen Demand
COTS: Commercial-Off-The-Shelf
DO: Dissolved Oxygen
DNA: Deoxyribonucleic Acid
EC: Electrical Conductivity
EPA: Environmental Protection Agency
FGN: Federal Government of Nigeria
FMWR: Federal Ministry of Water Resources'
HAL: Health Advisory Level
IWRM: Integrated Water Resources Management
MF: Membrane Filter
MPN: Most Probable Number
MWCO: Molecular Weight Cut-Off
NTU: Nephelometry Turbidity Unit
OD: Oxygen Demand
pH: Potential Hydrogen
PLF: Protein-Like Fluorescence
Ppb: Parts Per Billion
PV: Photovoltaic
RNA: Ribonucleic Acid
SDG: Sustainable Development Goal
TDS: Total Dissolved Solids
THMs: Trihalomethanes
TMP: Trans-Membrane Pressure
TSS: Total Soluble Solid
UNICEF: United Nations Children's Fund
UV: Ultraviolet
WHO: World Health Organization

CHAPTER ONE

INTRODUCTION

1.1 Background

Water purification is the removal of contaminants from water regardless of the source (underground, surface, or recycled) in order to make it suitable for a certain purpose of use. Water purification includes the decontamination of surface and groundwater from sources such as lakes and streams but also includes reclamation from wastewater sources[1]. The purification methods used include physical processes such as filtration sedimentation and distillation, biological processes which involve the removal of solid particle and other impurities from contaminated or polluted water using physical means such as slow sand filters or biologically activated carbon, chemical processes such as flocculation and chlorination and the use of electromagnetic radiation such as ultraviolet light. other methods include boiling which has to do with heating water to its boiling point (100^oC), distillation is another method of water purification through heating, to distil water, simply means elevating its temperature beyond its boiling point and this will adequately increase the evaporation rate, and sunlight is one of several forms of heat energy that can be used to power that process.

These purification methods may reduce the concentration of contaminants including suspended particles, bacteria, parasites, viruses, fungi, algae, and many of dissolved materials from the contaminated water[2].

Water is the second most important natural resources after air. Water is one of the key resources to generate and sustain economic prosperity of any country or region. But, the availability and distribution of safe drinking water are limited by increasing population and industrialization. Water is mostly polluted or contaminated by bacteria, viruses, parasites and other harmful microorganisms that live in it. Surface water is susceptible to many contaminants from organisms in the environment, elements in the atmosphere, and even bedrocks. Microorganisms are generally present due to the waste products produced by humans in the area and animals which may live in or around the water[3].

Potable water is critically important in domestic and industrial use, agricultural use such as irrigation farming, areas which experienced the natural disaster such as earthquake, battlefield etc. The majority of human population especially in developing countries suffers from water-borne diseases such as skin abscesses, cellulitis, skin infections, and diarrhoea due to improperly treated water. In West Africa for instance, the borehole water system (BWS) is the source of water supply mostly used and this lacks the capability of monitoring chemical compound, filtration, and disinfection of potable water. As a result, there is not enough potable water to support a large-scale supply in most West African countries[4].

In Nigeria, many rural dwellers depend on surface water from rivers and lakes for their daily water need. Even in urban and peri-urban centres in Nigeria, access to potable water is a major challenge. If Nigeria is to achieve Sustainable Development Goal (SDG) No 6, access to potable drinking water must be assured. A major way to ensure this is to promote point of use water purification systems which do not require other inputs such as power and transportation for delivery. Several attempts have been made at developing water filters from local materials in order to make them affordable to the poor. Yet, most of the water filters in the market are imported and made from materials that are not easily available. This project focuses on how to design and construct water filters based on the use of local materials.

1.2 Problem Statement

Lack of safe drinking water is a global concern. The World Health Organization (WHO) estimates that about 780 million people worldwide lack access to clean water (WHO and UNICEF, 2010). Having access to clean water supply is essential not only to prevent fatal dehydration but also for sanitation purposes, as more than 3.4 million people die each year from water sanitation and hygiene-related cause [5]. Besides the achievements of Millennium

Development Goals, 783 million people still have no access to safe drinking water in 2015[6]. According to the World Health Organization, people living in low-income countries especially in Africa suffer more from lack of access to clean and safe drinking water due to the geographic, economic and social differences. Moreover, the majority of the areas having better water sources, a large percentage of water is contaminated. Furthermore, statistics show that about 1.8 billion people are using drinking water that is polluted with faecal material (WHO 2015). This work focused on the design and construction of water filtration systems using local materials.

1.3 Aim and Objectives

The aim of this work is to develop an efficient point of use water filtration system using local materials. The specific objectives are to:

i. Design and construct four different filter setups making use of charcoal, activated carbon, moringa and sand as filter media;
ii. Evaluate the performance of the filters using flow rate and water quality parameters;
iii. Compare the performance of the filters with an existing commercial imported filter.

1.4 Scope and Limitations

This work is limited to the design and construction of water filters using the four filter media named. Physical properties of purified water such as taste, colour, odour, COD, BOD, EC, P^H and Bacteria test were carried out and compared to that of clean water. The work is limited to proof of concept in the laboratory. Subsequent work will involve actual fabrication and manufacture of the filter using standard engineering materials.

1.5 Arrangement of the Thesis

The Thesis is arranged in four chapters. Chapter one covers the introduction including background, problem statement and scope. Chapter two is the literature review. Chapter three is research methods. Chapter four is results and discussions and Chapter five is conclusion and recommendation. The last section is a listing of references cited in the work.

CHAPTER TWO

LITERATURE REVIEW

2.1 Importance of Water

Water is the most common liquid on the earth. It is one of the most important compounds that profoundly influence life[7]. Water seems, at first sight, to be a very simple molecule, consisting of two hydrogen atoms attached to an oxygen atom[8]. It covers about two-thirds of the earth and human require water to live therefore, pure drinking water is necessary for human survival. Water is the most remarkable substance and has many uses, some of which includes drinking, washing, cooking, swimming, fishing, etc. although probably not all at the same time. We are about It is a known fact that life cannot go without water just like droughts cause famines and floods cause death and disease. Because of its clear importance, water is the most studied material on Earth[8]. Water, although an absolute necessity for life both plants and animals, it can also be a carrier of several diseases. The availability of water makes it possible for the personal hygiene measures that are necessary to prevent the transmission of any enteric diseases. The water related diseases can be classified as waterborne, water-hygiene, water-contact and water-habitat vector diseases.[9]

The sustainable development goal number six (SDG 6) includes eight global targets that are universally applicable and aspirational. However, each government must decide how to incorporate them into national planning processes, policies and strategies based on national realities, capacities, levels of development and priorities. They cover the entire water cycle including: provision of drinking water (target 6.1) and sanitation and hygiene services (target 6.2), treatment and reuse of wastewater and ambient water quality (target 6.3), water-use efficiency and scarcity (target 6.4), integrated water resources management (IWRM) including through trans boundary cooperation (target 6.5), protecting and restoring water-related ecosystems (target 6.6), international cooperation and capacity-building (target 6.a) and participation in water and sanitation management (6.b).[9]

The Federal Ministry of Water Resources' (FMWR) 2000 National Water Supply and Sanitation Policy defined the roles of the different tiers of government in Nigeria: The three levels of government; federal, state, and local share statutory responsibility for the delivery of water and sanitation services[10]. The federal government is responsible for formulating and coordinating national water policies and managing water resources. It is also responsible for data collection, resource and demand surveys, monitoring, evaluation, and coordination of water supply development and management, research and development, national funding and technical support. State government are responsible for the establishment, operation, quality control, and maintenance of urban and semi-urban water supply systems and in some cases for rural supply. They are also responsible for licensing and monitoring private water suppliers, monitoring the quality of water supplied to the public, and providing technical assistance to local governments. Local government councils are responsible for establishing, operating, and maintaining rural water supply and sanitation facilities in conjunction with the beneficiary communities[10]. Nigerians derive their water from surface water (springs, stream and rivers), hand dug wells, rain harvesting, pipe borne water, boreholes, and vendors (FGN, 2000). An estimated 224 billion cubic meter of water is available, annually, from run-off of rivers in the eight hydrological zones of the country. Groundwater resources in aquifers, however, are yet to be quantified[11]. No one can go ahead to tap groundwater sources without recourse to geophysical tests or the obtaining of necessary permits from regulatory bodies but majority of Nigerians cannot afford drilling cost and additional costs attached to that. It is estimated that 48% of Nigerian population make use of surface water for their domestic needs, 57% use hand dug wells, and only 14% have access to borehole water sources (FG 2017). Another interesting statistic informs that 54.6% Nigerians use pit latrines, exclusively, 13.71% use water closet, exclusively, 0.58% use the bucket system, and 31.16% Nigerians use other unsanitary methods[11]. Some of these unsanitary methods include defecating in open fields and disposal into surface water bodies. When rain falls, all the defecations disposed on land could also get washed down with the runoff into the surface water bodies as non-point source pollution. This is, beside the pollution, being discharged into surface water bodies by industries. The immediate problems result in a string of further consequences, which has direct or indirect effect on the quality of life of the ordinary Nigerian (poor).

2.2 Water Purification

Water purification is the process of removing undesirable chemicals, biological contaminants, suspended solids and gases from contaminated water[7] by filtration, sedimentation, distillation or desalination. Water purification can be achieved using several methods. These include one or combination of solar pasteurization, reverse osmosis (RO), Sand/carbon filtration, ceramic filters and ultraviolet (UV) lamp sterilizer system with power supplied by photovoltaic (PV) modules. The United Nations reports that two-thirds of humanity will suffer from “moderate to severe water stress” within thirty years if growing trends of pollution continue.[6][12]. Pollution can come in the form of rapid expansion of wastewater by residents, industries, hospitals and commercial establishments and its ‘disposal’ to bodies of water downstream.[6]. Some of the important factors which gained much popularity that contributes to water scarcity and lowering water quality are pathogen concentration in water, salinity level, global warming, etc. Solar water purification is an antique way of converting impure or contaminated water into safe drinking water. The first time, this technique was used by Arabal chemists in 1551. In 1872, the first modern solar still was built in Chile, which consists of64 basin and supplied up to 20000 litres of water per day.US Navy during world war II, created 20000 stills for the navy.[13]. Another work was carried out by Rai and

Tiwari (1983) which presented the performance of single basin solar still coupled with a flat plate collector. The results show that the average daily production of distilled water has been found to be 24%higher than that of simple single basin solar still.[13]

2.2.1 Water Filtration

Filtration is one of the oldest and simplest methods of removing contaminants pose a threat to human health. Filtration is the process of removing suspended solids from water by passing the water through a permeable fabric or porous bed of materials[14]. Filtration is essentially a physical and chemical process, the actual removal mechanisms are interrelated and rather complex, but the removal of colour and turbidity is based following factors

- ✓ chemical characteristics of the water being treated (particularly source water quality)
- ✓ nature of suspension (physical and chemical characteristics of particulates suspended in the water)
- ✓ type and degree of pre-treatment (coagulation, flocculation, and clarification)
- ✓ Filter type and operation.

Some particles, not all can be removed in the filtration process by physical straining, which may be defined as the removal of particles from a liquid (water) by passing the liquid through a filter or fabric sieve whose pores are smaller than the particles to be removed[15]. A number of interrelated removal mechanisms within the filter media relied upon high achievement removal efficiencies. These removal mechanisms include the processes like sedimentation on media (sieve effect), adsorption, absorption, biological action and straining.

Filtration technologies have been categorized into four majorly: Granular Media Filtering, Barrier Media Filtering, Disinfection Treatments, and Carbon Adsorption[15]. These broad sections classify all eight filtration methods researched and analyzed, by underlying technology employed.

2.2.2 Granular Media Filtration

Granular filtration is the process of passing water through a medium to remove particulate and other impurities. These impurities include suspended particles such as fine silts and clays, biological matter such as bacteria, plankton, spores, cysts or other matter and floc. The material used in filters for public water supply is normally a bed of sand, or any other granular substance such as coal. This type of filtration processes can generally be categorised as being either slow or rapid granular filtration. Slow sand filters are the original form of filtration. The first one was built in 1804 by John Gibb of Paisley, Scotland to treat water for his Bleachery, with the surplus treated water sold to the public. Slow sand filters were first used in London in 1820 to treat water from the River Thames.[15].

2.2.3 Slow Sand Filtration

A slow sand filter is one of the means of treating water for drinking and other domestic and industrial purposes and involves filtering water through a bed of 'media' (usually sand). Slow Sand Filtration has been in used for more than 200 years as a relatively simple and easy-to-operate process that allows raw water to pass through a sand medium. As the water passes through the sand, solids particles, microorganisms and heavy metals (such as. Cu and chromium (Cr)) are removed.[16]. Research and other observations show that slow sand filtration can effectively remove cysts and coliform bacteria from raw or contaminated water, and the process is found to be an innovative, cost-effective, low maintenance treatment process and other silent advantages. A slow sand filter is comprised of a bed of graded sand which is supported by a layer of gravel. This filter media is confined in a box made up of any material that is inert to the water and the contaminant with openings at both ends allowing water to flow in and out while operating on a top to bottom, gravity basis. A filtration process is a form of natural and biological water treatment used to remove solids, precipitates, turbidity (muddiness) and in some cases bacterial particles that produce bad taste, odour and colour [17]. A slow sand filter is primarily a biological treatment process and provided the basic rules are followed when designing, constructing and operating this type of filter, this can be very effective at removing disease-causing micro-organisms from water (98-99% removal rates, WHO, 1996).[18]. Treatment of water in a slow sand filtration is largely achieved by ecological processes. Micro-organisms colonise the surface areas of the sand grains and feed on impurities in the water as it filters passed. The initial water that filters through the bed may need to be discarded (run to waste). A so-called 'ripening period' is required before treated water meets the required water quality standards. This is because water treatment by the filter is primarily undertaken by the biological community established in the sand bed, and operational procedures such as skimming will have disturbed this community. Water monitoring during the ripening period is important in determining when treated water is of drinking water quality. The sketch for the typical slow sand filter (reprinted from Huisman & Wood, Slow Sand Filtration, Copyright (1974), with permission from the publisher, World Health Organisation, WHO) is shown in Fig.1.

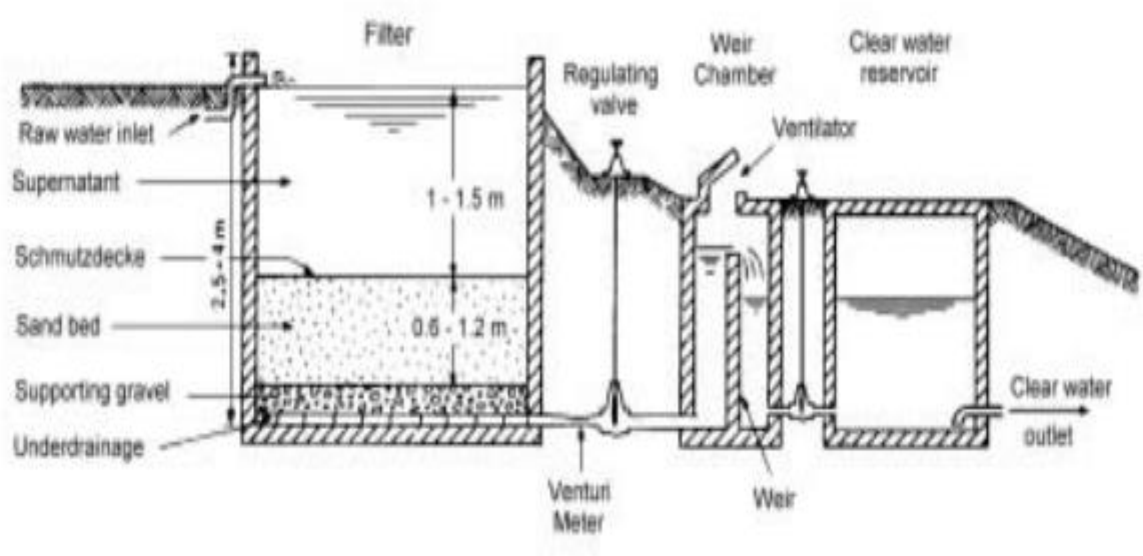

Fig.1: Sketch of a Slow Sand Filter

There are four basic components of the slow sand filter these can be identified as:

- ✓ Supernatant
- ✓ Filter bed
- ✓ Under-drainage system.
- ✓ Flow control systems i.e. regulating valves, weir etc.[18].

The filter bed is also known as the ‘media bed’ or ‘bed’ usually comprises a uniform mixture of sand grains throughout its depth (Kiely, 1998). Its depth will typically vary between 0.6 and 1.2m [18][19]. The sand grains are effective at capturing particulates. They provide a large surface area for attachment and microbiological growth and the comparatively small interstitial spaces (pores, spaces between the sand grains) which encourage sedimentation[18][20].

2.2.4 Rapid Gravity Filtration

Generally, gravity filtration systems the water level or pressure (head) above the media forces the water through the filter media. The rate at which water passes through the granular filter media (the filtration rate) may vary widely, depending on the purpose for which the water is required[21]. In rapid filtration, sand is commonly used as the filter medium but the process is quite different from slow sand filtration. This is so because much coarser sand is used with an effective grain size in the range 0.4-1.2 mm and the filtration rate is much higher, generally the filtration rate for this process between 5 and 15 m^3 /m^2 .h (120-360 m^3 /m^2 .day). Due to the coarse sand used, the pores of the filter bed are relatively large and the impurities contained in the raw water penetrate deep into the filter bed[22].

2.2.5 Membrane Filtration Technique

The Membrane Filter (MF) Technique was introduced in the late 1950s as an alternative to the most probable number (MPN) procedure for microbiological analysis of water samples. The membrane filtration technique offers the advantage of isolating discrete colonies of bacteria, whereas the Most Probable Number procedure only indicates the presence or absence of an approximate number or organisms (indicated by turbidity in test tubes). The membrane filtration technique was accepted by the U.S. EPA for microbiological testing of potable water in the 11th edition of Standard Methods for the Examination of Water and Wastewater. In the 1978 publication, Microbiological Methods for Monitoring the Environment, the U.S. EPA stated that the membrane filtration technique is preferred for water testing because it permits analysis of larger samples in less time.[23].

A membrane is a thin layer of material that will only allow certain compounds to pass through it. The material that will pass through the membrane is determined by the size and the chemical characteristics of the membrane and the material being filtered[19]. Transport through the membrane can occur under the action of various driving forces, in case of membrane filtration, it is trans-membrane pressure (TMP) difference. Separation effect of the membrane is based on two factors which are sieving effect and physical or chemical interactions of separated components with the membrane.[24]. Membrane processes are increasingly used for removal of bacteria, microorganisms, particulates, and natural organic material, which can impart some physical properties such as colour, tastes, and odours to water and react with disinfectants to form disinfection by-products. As advancements are made in membrane production and module design, capital and operating costs continue to decline. The membrane filtration processes include microfiltration, ultrafiltration, Nano-filtration, and reverse osmosis[16].

2.2.6 Microfiltration

Microfiltration can be defined as a membrane separation process using membranes with a pore size of approximately 0.03 to 10 microns and a molecular weight cut-off (MWCO) of greater than 1000,000 Daltons and a relatively low feed water operating pressure of approximately 100 to 400 kPa.[21]. Materials removed by microfiltration include sand, silt, clays, Giardia lamblia and Cryptosporidium cysts, algae, and some bacterial species.

Microfiltration is not an absolute barrier to viruses. However, when used in combination with disinfection, Microfiltration appears to control these microorganisms in water.

2.2.7 ULTRAFILTRATION

Ultrafiltration has a pore size which is less than that of ultrafiltration. It has a pore size of approximately 0.002 to 0.1 microns, and molecular weight cut-off (MWCO) of approximately 10,000 to 100,000 Daltons, and operating pressure of approximately 200 to 700kPa.[21]. Ultrafiltration will remove all microbiological species removed by microfiltration but only partial removal of bacteria, as well as some viruses (but not an absolute barrier to viruses) and humic materials. Disinfection can provide a second barrier to contamination and is therefore recommended.

2.2.8 Nanofiltration

Nano-filtration membrane has a nominal pore size of approximately 0.001 microns and molecular weight cut-off (MWCO) of 1,000 to 100,000 Daltons. Pushing water through these smaller membrane pores requires a higher operating pressure than either microfiltration or ultrafiltration. Operating pressures are usually near 600 kPa and can be as high as 1,000 kPa.[21]. This system can remove virtually all cysts, bacteria, viruses, and humic materials.

2.2.9 Reverse Osmosis

Reverse osmosis as the name implies, it has to do with the movement of fluid from the region of higher concentration to the region of lower concentration and this process can effectively remove nearly all inorganic contaminants from water. Reverse osmosis can also effectively remove radium, natural organic substances, pesticides, cysts, bacteria and viruses. Reverse osmosis is particularly effective when used in series with multiple units. Disinfection is also recommended to ensure the safety of water for drinking and other domestic and industrial purposes. Reverse osmosis is essentially important and some of its advantages include: removal of nearly all contaminant ions and most dissolved non-ions, the process is relatively insensitive to flow and total dissolved solids (TDS) level and suitable for small systems with a high degree of seasonal fluctuation in water demand, Reverse osmosis operates immediately, without any minimum break-in period not only that it also has low effluent concentration possible. Furthermore, operational simplicity and automation allow for less operator attention and these make reverse osmosis suitable for small system applications. Despite all the advantages stated reverse osmosis has some limitations which are; High capital and operating costs, managing the wastewater (brine solution) is a potential problem since it produces the most wastewater at between 25-50 percent of the feed and also membranes are prone to fouling[12].

2.2.10 Ultraviolet Disinfection

Ultraviolet (UV) irradiation is a common disinfection option for water treatment in the developed world. A sufficient dose of ultraviolet light inactivates most microorganisms. Ultraviolet light is produced by an electric arc struck in mercury, or more recently, xenon vapour much like ordinary fluorescent bulbs. The UV spectrum runs from 100 and 400 nanometers (nm) with the optimal wavelength for bacterial disinfection occurring between 200 and 280 nm.[25].The germicidal properties of UV light were discovered in 1887. The first application of UV light in drinking water occurred in 1910 at Marseilles, France[26]. In 1955, the first modern installations of UV disinfection systems using low-pressure UV lamps in water treatment plants occurred in Switzerland and Austria[25]. Since then, UV light is used in drinking water systems worldwide primarily for disinfection. Currently, there are only one Commercial-Off-The-Shelf (COTS) individual water purification devices using UV light for disinfection. UV Light Description In drinking water, UV light is used for disinfection. The use of UV for disinfection involves some steps which are: the generation of UV light with the desired germicidal properties, and the delivery (or transmission) of that light to microbial pathogens. As Figure 2 shows, UV light lies between x-rays and visible light in the electromagnetic spectrum. The UV spectrum covers the wavelength range from 100-400 nm as mentioned earlier. UV light at certain wavelengths can inactivate microorganisms. UV light with wavelengths from 200-300 nm inactivates most microorganisms, with the greatest amount of inactivation occurring around 260 nm.[26]. The typical wavelength ranges are shown in figure 2.

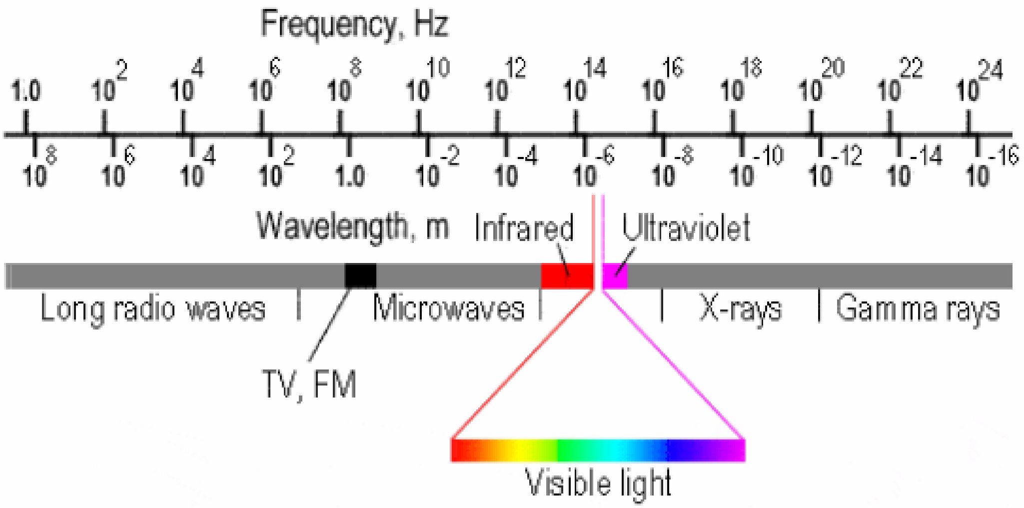

Fig. 2: Typical Wavelength

Typical UV disinfection systems involve the flow of water through a vessel containing a UV lamp. As the water passes through this vessel, microorganisms are exposed to intense ultraviolet light energy which causes damage to genetic molecules (i.e. nucleic acids: DNA or RNA) needed for reproductive functions. This damage prevents the microorganism from multiplying or replicating in a human or animal host. Because the microorganism cannot multiply, no infection can occur. Disinfection of water is achieved when UV light causes microbial inactivation.[27].

2.3 Water Filtration Principles and Materials

There are two basic types of water filters: sediment (or mechanical) filters which filter particles by size and adsorptive or reactive filters which contain a medium that adsorbs or reacts with a water contaminant. For instance, Activated carbon filtration is an adsorptive process in which the contaminant is attracted to and held (adsorbed) onto the surface of the carbon particles. The efficiency of the adsorption process is influenced by medium characteristics (particle and pore size, surface area, density and hardness) and the contaminant characteristics (concentration, the tendency of a chemical to leave the water, the solubility of the contaminant, and contaminant attraction to the carbon surface).[28]. Water treatment can be done with different materials such as charcoal, activated carbon, pulverized moringa seeds, sand, gravel, alumina etc., this research will focus on charcoal, activated carbon, pulverized Moringa seeds, sand bed and gravel.

2.3.1 Activated Carbon Filtration

Carbon filtering is one method of filtering water that uses a bed of activated carbon to remove contaminants and impurities, using chemical absorption. In this method, each particle (granule) of carbon provides a large surface area (pore structure) this allows contaminants to have the maximum possible exposure to the active sites within the filter media (activated carbon)[29]. Carbon filtering is commonly used for water purification; it works by adsorption process, it which a pollutant or Contaminants such as benzene, chlorobenzenes, trichloroethylene, carbon tetrachloride, methylene chloride, and vinyl chloride in the water to be treated are trapped inside the pore structure of the carbon substrate. The particle sizes that can be removed by this type of filters range from 0.5 to 50 micrometres[29]. The efficacy of a carbon filter is determined by the flow rate regulation. Households are always concerned about contaminants in their water supply that may affect their wellbeing or cause taste and odour problems. Some sources of these contaminants might include solvents, pesticides, industrial wastes, or contaminants from leaking underground storage tanks[9].

Contaminants such as benzene, chlorobenzenes, trichloroethylene, carbon tetrachloride, methylene chloride, and vinyl chloride in drinking water may pose health risks if they are present in quantities above the health advisory level (HAL). Pesticides, such as Atrazine, also can pose a health risk if present in quantities above is above the specified standard such as the US The Environmental Protection Agency (EPA). Activated carbon filtration can effectively reduce some in not all of these organic chemicals as well as certain harmless taste- and odour-producing compounds. Some drinking water may be disinfected with chlorine or chloramines. During disinfection, the reaction of chlorine with organic matter can produce compounds such as trihalomethanes (THMs) as by-products. These disinfection byproducts may increase the risk of certain cancers. The Environmental Protection Agency (EPA) mandates that public systems have less than 80 parts per billion (ppb) of THMs in their treated water. AC filtration can be effective in removing chlorine, chloramines, and some disinfection by-products.[30]. No one piece of treatment equipment which manages all contaminants with high efficiency. All treatment methods have limitations and often a combination of treatment processes is required to effectively treat the water. Activated carbon filters will not remove microbial contaminants (such as bacteria and viruses), calcium and magnesium (hard water minerals), fluoride, nitrate, and many other compounds[9].

2.3.2 Moringa Oleifera Seed Filtration

Moringa Oleifera is a special multipurpose, medium- or small-sized tree which has been used for centuries due to its medicinal properties and health benefits. It also has some outstanding properties such as antifungal, antiviral, antidepressant, water purification and anti-inflammatory properties. It is drought tolerant and has nutritional, medicinal, and water-cleaning attributes. Maringa is indigenous to many parts of Africa, Asia, and South America. Its pods have been used as an inexpensive and effective sorbent for the removal of organics, and coagulant for water treatment in many ways[29]. Moringa seeds are reported to have multifunctional roles. The seeds at some points are used as an ordinary or normal water purifier, which has both antioxidant and antimicrobial properties and these properties make it a very good candidate for water purification.[18]. Moringa seeds are used as a coagulant for the replacement of Aluminium Sulphate (Alum) which is known for used in conventional water treatment plants. It is reported by Eilert (1978), that the *Moringa seeds have* very significant properties such as water-soluble proteins (low molecular-weight proteins), this carries positive charge when the pulverised seeds are added to contaminated or wastewater, such proteins produce positively charged ions which act like magnets and attracting the predominantly negatively charged particles (such as clay, silt bacteria as, and other toxic particles in water). The flocculation process occurs when the proteins bind the negative charges forming flocs through the aggregation of particles which are present in water. These flocs are then easily removed by settling or filtration, a situation that gave rise to this study on Moringa seed application.[31].

2.3.3 Charcoal Water Filtration

Charcoal is carbon and activated charcoal is charcoal that has been treated with oxygen to open up millions of tiny pores between the carbon atoms[32]. Charcoal filters have several uses. The most common use is water purification to eliminate impurities in a fluid through the process called adsorption, whereby contaminant molecules in the fluid to be treated are trapped inside the pore structure of the carbon substrate. These filtration systems are most effective at removing sediment, odour, chlorine, taste and other volatile organic compounds from contaminated or polluted water. They are not effective at removing minerals, salts, and dissolved inorganic compounds. The typical particle sizes that can be removed by this type of filter range from 0.5 to 50 micrometres [32].

2.3.3 Ceramic Water Filtration

Ceramic water filtration is one of the methods of water purification which involves the use of locally available natural material majorly clay, rice husk and water, the ceramic water filtration systems are unique and special because of their low cost due to local materials involved ease of fabrication and their effective bacteria removal from water. Ceramic water filter is a clay-based system usually produced by mixing of clay, water and sawdust (woodchips). Other combustible organic materials, such as rice husk, coffee husk, or flour can also be used [33]. The process of making this type of filter includes mixing clay, sawdust and water at an appropriate ratio, drying and firing, the ceramic water filters are usually coated with a layer of colloidal silver, which is used because of its antimicrobial activity[33].

2.3.4 Sand Water Filtration

Sand Water Filtration is one of the earliest methods of water filtration used by man as a relatively simple method and it has an easy-to-operate process that allows raw water to pass through a sand medium (bed of sand). On the surface of sand there is a thin slimy matting of material called majorly organic origin called *schmutzdecke* (filter skin) this consist of a threadlike algae and numerous other forms of life including protozoa, diatoms, plankton, rotifers and bacteria.[34] These microorganisms play and important function of digesting, trapping and breaking down of organic matter present in the water passing through. The dead algae and bacteria present in the raw water are consumed within this filter skin of sand.[34] Depending on the filtration velocity the heavy particles are also entrapped within the bed of sand arranged in different particle sizes. As the water passes through the sand, solids particles, microorganisms and heavy metals (such as. Cu and chromium (Cr)) are removed.[16][34]

2.4 Water Quality and Water Testing

Water quality concerns increase rapidly from public complaints about odour or taste, an outbreak of waterborne illnesses or widespread death of aquatic species such as fish kills in cases most. Because many water quality concerns do not have such obvious or dramatic consequences, it may not be readily apparent that there is a problem. Instead, many important water quality parameters are routinely monitored and compared with water quality standards adopted for these parameters[29]. All living organisms on earth need water for their survival and growth. The most widely used definition of water quality is that which defined the chemical, physical and biological characteristics of water, usually in respect to its suit ability for the designated use. Water has many uses, primary ones are, for recreational, drinking, agricultural and industrial uses. Each of these designated uses has different defined chemical, physical and biological standards necessary to support that use. For example, we expect higher standards for water we drink and swim in compared to that used in agriculture and industry.[30]. It is necessary that the quality of drinking water should be checked at regular time interval because due to use of contaminated drinking water, the human population suffers from varied of water-borne diseases. It is difficult to understand the biological phenomenon fully because the chemistry of water revels much about the metabolism of the ecosystem and explain the general hydro - biological relationship[35]. The availability of good quality water is an indispensable feature for preventing diseases and improving quality of life. Natural water contains different types of impurities which are introduced into the aquatic system by different ways such as weathering of rocks and leaching of soils, dissolution of aerosol particles from the atmosphere and from several human activities, including mining, processing and the use of metal-based materials.[36]. It is very crucial to test the water before it is used for drinking, domestic, agricultural or industrial purposes. Water must be tested with different physic-chemical parameters. Selection of parameters for testing of water solely depends upon for what purpose is the water going to be used and to what extent its quality and purity are needed. Water contains different floating, dissolved, suspended and microbiological as well as bacteriological impurities. Some physical tests of water include testing of its physical appearance such as temperature, taste, odour, colour, turbidity, total dissolved solids (TDS), pH, etc, while some of the chemical tests include Biochemical Oxygen Demand, Chemical Oxygen Demand, dissolved oxygen, alkalinity, hardness and other characters. For obtaining more quality and purity water, a trace of metal, heavy metal contents and organic i.e. pesticide residue tests can also be carried out. It is obvious that drinking water should pass these entire tests and it should content required amount of mineral level. The following different physic-chemical parameters are tested regularly for monitoring the quality of water.

2.4.1 Temperature

In an established system the water temperature controls the rate of all chemical reactions, and the low oxygen values coincided with high temperature especially during the summer months.

2.4.2 P^H

The p^H is essential in determining the corrosive nature of water, for instance, the lower the P^H value the higher the corrosive nature of water. P^H is positively correlated with electrical conductance and total alkalinity[37][38]. The P^H of the solution is taken as the negative logarithm of H_2 ions for practical purposes. The p^H scale value ranges from 7 to 14 for alkalinity and from 0 to 7 for acidity and 7 is neutral. The P^H value for good drinking water lies between 4.4 to 8.5 [9].

2.4.3 Electrical Conductivity

Conductivity is the capacity of water to carry an electrical current and it with varies both with number and types of ions the solution contains. But, the conductivity of distilled water is less than 1umhos/cm. This conductivity depends on the presence of ions, their total concentration, mobility, valence and relative concentration and on the temperature of the liquid. Solutions of most inorganic acids, bases, and salts are relatively good conductors.[38]. Conductivity is a numerical expression of a solution's capacity to carry an electric current. This ability depends on the presence of ions, their total concentration, mobility, valence and relative concentrations, and on the temperature of the liquid[36].

2.4.4 Turbidity

Suspension of particles in water interfering with the passage of light is what defined turbidity. Turbidity is caused by a wide variety of Suspended particles. Turbidity can be measured either by its effect on the transmission of light which is termed as Turbiditymetry or by its effect on the scattering of light which is termed as Nephelometry. As per IS: 10500-2012 the acceptable and permissible limits are 1 and 5 NTU respectively.[9]

2.4.5 Microbial (Bacteria) Detection

High levels of bacteria are a concern for many marines, brackish, and freshwater environments. Elevated levels of bacteria in coastal waters are associated with the increased risk of gastrointestinal symptoms for recreational swimmers.[39]. Water supplies have to be constantly monitored for a variety of materials bacteria, nitrates, pesticides, metals, etc. Coliforms are bacteria that are naturally occurring in animals and in the environment: they are indicators of other potentially harmful microorganisms in drinking water. Membrane filter technique: Filtering 100 ml of water through a Millipore filter with holes smaller than the bacteria causes the bacteria to be trapped on top of the filter. The filter pad is then placed on special coliform media which allows a coliform count to be done. There are different procedures which involve using different standards in detecting bacteria in the water but the most common one is by using Petrifilm. The methodology for the Petrifilm plate's method involves three major steps which are:

(i) Inoculate and spread 1 mL of water on the gel (Stock solution).

(ii) Incubate the plate at a temperature of 35 ±1^{o}C for 24 ±2 hours.

(iii) Counting the number of blue colonies associated with a small gas bubble.

2.4.6 Total Alkalinity

Alkalinity is the sum total of components in the water that tend to elevate the p^{H} to the alkaline side of neutrality. It is measured by titration with standardized acid to a p^{H} value of 4.5 and is expressed commonly as milligrams per litre as calcium carbonate (mg/l as $CaCO_3$). Commonly occurring materials in water that increase alkalinity are carbonate, phosphates and hydroxides. Limestone bedrock and thick deposits of glacial till are good sources of carbonate buffering[9].

2.4.7 Dissolved Oxygen

Dissolved oxygen is one of the most important parameters in water quality determination. Its correlation with water body gives direct and indirect information about the bacterial activity, photosynthesis, availability of nutrients, stratification etc.

2.4.8 Chemical Oxygen Demand (COD) and Biological Oxygen Demand (BOD)

Chemical oxygen demand is a measure of the oxygen required for the chemical oxidation of organic matter with the help of strong chemical oxidant. Biological Oxygen Demand (BOD) is the amount of oxygen required by microorganisms to degrade the organic matter in the water and COD is the total measurements of all chemicals (this includes both organic and inorganic) present in the water, the COD is always higher than BOD since BOD measures only organic chemical and mostly have only biodegradable substances while COD has both biodegradable and non-biodegradable substances. High chemical oxygen demand may cause oxygen depletion on account of decomposition of microbes to a level detrimental to life. Biochemical oxygen demand (BOD) and chemical oxygen demand (COD), indirect indicators of organic matters, are representative parameters for sewer water quality. However, it is very difficult to obtain continuous water quality data because of the scarcity of accessible space within the sewer systems and the necessity of separate laboratory experiments. Moreover, at least five days are required to acquire BOD data from the experiment and BOD itself may be biased by the presence of toxic substances that might cause the inhibition of the oxidizing bacteria. Chemical oxygen demand determination has an advantage over biochemical oxygen demand determination in that the result can be obtained in about 5 hours as compared to 5 days required for biochemical oxygen demand test. Recently, optical techniques such as UV-visible spectroscopy and fluorescence measurements were suggested as fast and versatile monitoring tools for BOD and COD in water samples[40]. It is well known that Ultraviolet absorbance at 250–300 nm is correlated with the concentrations of organic matters in sewage water samples. It is reported that protein-like fluorescence (PLF) intensity is linked with fluorescent biodegradable organic compounds such as tryptophan and tyrosine[41].

2.4.9 Total Hardness

The desirable limit and Permissible limit for hardness are lies between 200 and 600 mg/l respectively. The effect of hardness is Scale in utensils and hot water system in boilers etc. soap scum’s Sources are Dissolved calcium and magnesium from soil and aquifer minerals containing limestone or dolomite. The Treatment of hard Water is Softener Ion Exchanger and Reverse Osmosis process. The degree of hardness of drinking water has been classified in terms of the equivalent $CaCO_3$ concentration as follows: Soft - 0-60mg/l, Medium - 60-120 mg/l, Hard - 120-180 mg/l, Very hard - >180 mg/l.[9].

2.5 WHO Standards for Water Quality

Physicochemical parameter study is very important to get exact idea about the quality of water in terms of physical and chemical properties physiochemical parameters have an acceptable standard values. The physicochemical parameters for drinking water like p^H, EC, TDS, TSS, BOD, COD and many other parameters are given by World Health Organization (WHO), it is found that some of the water samples are non-potable for human being due to high concentration of one or the other parameter. Some of the WHO standard for water quality is summarized in table 2.1.

Table 2.1: WHO standards for water quality parameters

S/N	Parameter	Accepted Technique	WHO Standard
01	Temperature	Thermometer	_
02	Odour	Physiological sense	Acceptable
03	p^H	pH meter	6.5 – 9.5
04	Total Hardness	Complexometric titration	200 ppm
05	Turbidity	Turbidity meter	1-5
06	Ammonia	UV Visible Spectrophotometer	0.3 ppm
07	Biochemical Oxygen Demand (B.O.D.)	Incubation followed by titration	6
08	Chemical Oxygen Demand (C.O.D.)	C.O.D. digester	10
09	Chloride	Argentometric titration	250 ppm
10	Magnesium	Complexometric titration	150 ppm
11	Nitrate	UV Visible Spectrophotometer	45 ppm
12	Nitrite	UV Visible Spectrophotometer	3 ppm
13	Sodium	Flame Photometer	200 ppm
14	Sulphate	Nephelometer / Turbidimeter	250 ppm

CHAPTER THREE

RESEARCH METHODS

3.1 Equipment and Materials

The following equipment and materials were used.

- pH meter
- EC meter
- TDS meter
- Turbid meter
- Blender
- Petri film
- Retort Stand and Clamp
- Sand (0.50mm, 1.00mm,2.43mm particle size)
- Gravel
- Charcoal
- Activated Carbon
- Sample bottles
- Pulverized Moringa seeds
- Cotton
- PET Transparent Plastic bottles (150cm)
- Jaw crusher
- Sieve
- Beakers

3.2 Design of the Water Filters

Criteria for design

The following criteria guided the design of the water filters

- A filter with an acceptable flow rate
- Ability to remove the impurities and contaminants in water
- Small scale and affordable filter

Four different rapid sand filters were designed and constructed using 150 cm PET Transparent water bottles (Fig 3A) using charcoal (Fig 3H), activated carbon (Fig 3G), pulverised Moringa seed (Fig 3I), sand bed of different particle sizes (Fig. 3A, 3C, 3D, 3F) and gravel (Fig 3E). The sand (the filter bed) has a strong influence on the effectiveness of the filtration and it should be at least 45 cm in depth. Bacteria and viruses are trapped in the Schmutzdecke. Bacterial and biological activity maximizes in the Schmutzdecke but will continue up to 20 cm deep in the sand of the filter bed. A certain minimum level of dissolved oxygen should be present to support the aerobic actions that occur in the bed, after the initial installation of the Sand Filter. The soil sample for the filter bed was collected from the river bed, washed, sun-dried and sieved to 0.5mm, 1.00mm and 2.35mm. The gravel was collected and crushed to 3.00mm using a jaw crusher at AfDB Laboratory at AUST. The wood charcoal (Fig.3H) was made by burning the locally available wood obtained from dried trees in an open environment for about 15 minutes and allowed to cool in an open space then the resulted charcoal shown in Fig. 3H was collected and resized to 2.00mm using grinding machine in AfDB laboratory AUST. Activated carbon was obtained from AfDB laboratory AUST and it was bought from South Africa as said by my Co Supervisor (Dr Bello Abdulhakeem). Moringa Seed was collected from the Moringa tree, sun-dried for three day, crushed using crusher in AfDB laboratory AUST and pulverized as shown in Fig. 3I.

Fig. 3A: PET Transparent Plastic bottles (150cm) Fig. 3B: Sand (2.35mm particle size)

Fig. 3C Sand (1.00mm particle size) Fig. 3D: Sand (>2.35mm particle size)

Fig.3E: Gravel Fig.3F: Sand (0.5mm particle size)

Fig. 3G: Activated carbon

Fig.3H: Charcoal

Fig. 3I: Pulverized moringa seed

Fig.3J: Cotton

The first filter was built using gravel, sand bed with a particle size of 0.5mm, 1.00mm, and 2.35mm, cotton and charcoal with a layer thickness of 10 cm each. The second filter was made of the same material of same layers except that the charcoal was replaced with activated carbon but the layer is less than 10cm due to the limited availability of activated carbon. The third filter was constructed in the same manner but Moringa seeds were used to replace charcoal. Moringa seed was used with a layer thickness of 10cm. The fourth filter is sand bed of 0.25mm, 0.5 mm, 1.00mm, 2.35mm, greater than 2.35mm as shown in figure 3B and gravel in figure 3E.

3.3 Raw Water Sample Collection and Water Filtration

Raw water sample was collected at different periods from the stream located in AUST. Figures 4A, 4B, 4C show the raw water source and the collected raw water.

Fig. 4A: Raw water (AUST River)

Fig. 4B: Raw water sample

Fig. 4C: Raw Water

Four different filters setups were designed as shown in Figure 5, using sand, charcoal, pulverised Maringa seeds and activated carbon respectively from left.

Fig. 5: Four Filters Setups

The filter set ups were washed by running clean water through the filter to make sure the filtering media are properly washed. This was done until the system reached ripping time when which is a time taken to start getting the clean water as filtrate. At this point, the filtration was started at the same time for the four filters as shown in Figure 6 and the time was recorded. The flow rate was calculated and tabulated.

Fig. 6: Washing the filters

3.4 Water Quality Measurements

Some water quality tests were carried out before and after filtration using each filter. The measured parameters were pH, electrical conductivity (EC), oxygen demand (OD), turbidity chemical oxygen demand (COD), biological oxygen demand (BOD), microbial (Bacteria) detection. Filtration rate was also measured. The raw water was also filtered using an industrial filter which was bought from the market and the results ware compared with that of the designed filters to know which filter is more effective to use for both domestic and industrial applications. The p^H, electrical conductivity (EC) and Dissolved Oxygen (DO) were measured using a p^H kit as shown in Figure 7A and 7B, turbidity was measured using turbidity meter as shown in Figure 7C, and total dissolve solid was measured using TDS meter as shown in Figure 7D. The temperature under which every reading was taken was also noted.

Fig. 7A: p^H Kit

Fig.7B: p^H, EC an DO Readings

Fig.7C: Turbidity Measurement

Fig. 7D: TDS Measurement

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 The Water Filters

Figure 8 shows the filtration set ups in operation. The filtered water from each of the filters are shown with the raw dirty water in Figure 9. The engineering drawings with the dimensions showing the depth of each of the filter medium are shown in Figures 10A, 10B, 10C and 10D.

Fig. 8: The water filters in operation

Fig.9: Filtered Water Samples (clear) and the Raw Dirty Water (coloured).

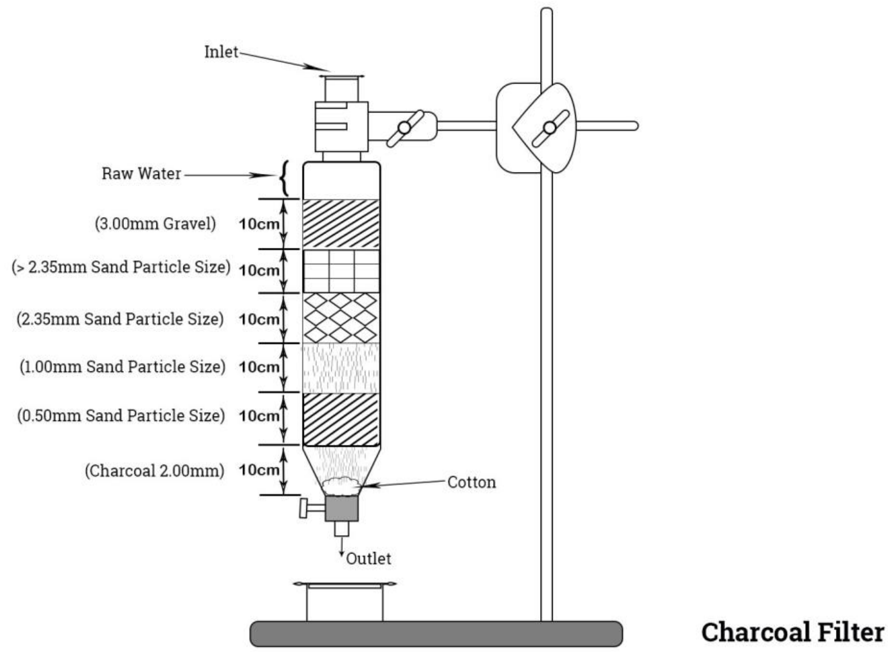

Fig. 10A: Charcoal water filter

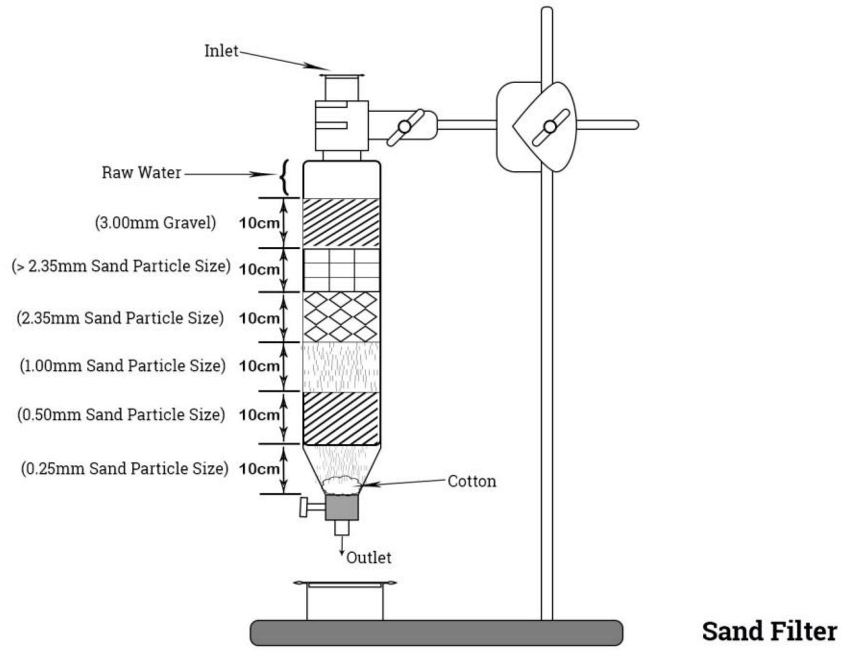

Fig. 10B: Sand water filter

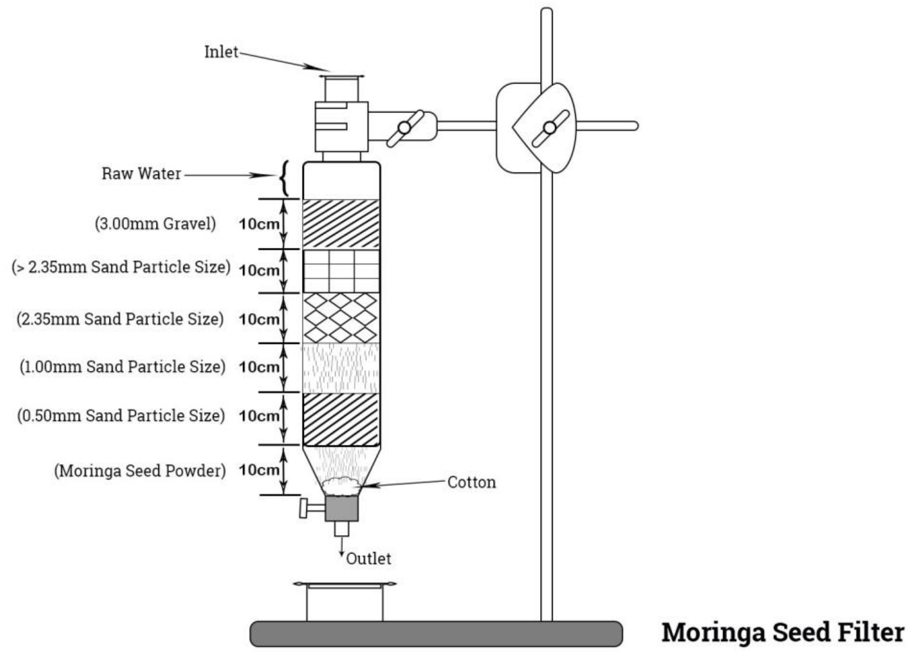

Fig. C: Moringa filter

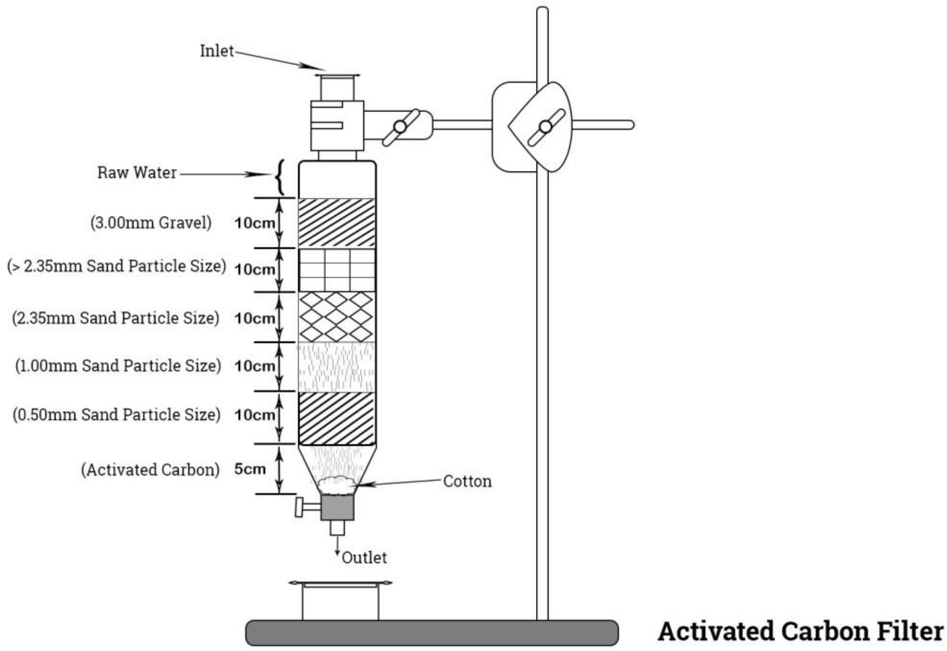

Fig. 10D Activated carbon filter

4.2 Water Quality

The p^H is essential in determining the corrosive nature of water, for instance, the lower the P^H value the higher the corrosive nature of water. The p^H value ranges from 7.04 to 7.67 which is within the range of drinking water 6.5 to 8.5 (WHO), it was observed that the filter with Moringa is the best with turbidity values of 5.24 NTU which reduces from 97.60 for day one, for day two it drops from 147 NTU to 5.25NTU and turbidity measures the amount of the degree of water cloudiness, the accepted value for turbidity is I the rage of 1-5 NTU. Therefore out of the four filters, that of Moringa filtered water more effectively in terms of EC, DO, TDS and turbidity then followed by charcoal then activated carbon then sand. EC is an Electrical conductivity and this conductivity depends on the presence of ions, their total concentration, mobility, valence and relative concentration and on the temperature of the liquid which for this case is water. Looing at the overall performance of EC in table 4.4 the values are 312 µS/cm for charcoal, 315 µS/cm for activated carbon , 270 µS/cm for Moringa and 308 µS/cm for Sand filter. This shows the presence and total concentration of ions in the water after filtration and it can be seen the Moringa filter has less ions after filtration because of its water purification ability and activated carbon has relatively much ions because the activation carbon used is an industrial one obtain from AUST Lab. The EC value of obtained from using Moringa filter meet the requirement of EC value for drinking water which has to be less that 300 µS/cm but that of activated carbon, charcoal and sand does not because the values are out of the acceptable range.

4.3 Filtration Rate

Three different filtrations (day; 1, 2 and 3) were carried out at different times and the results were tabulated in Table 4.1, 4.2 and 4.3. During filtration it was observed that the sand filter was the fastest with the flow rate of 5.43ml/sec., 3.47ml/sec. and 2.49ml/sec. for day one, day two and day three respectively. The slowest was that of Moringa with 0.60 ml/sec, 0.57 ml/sec, and 0.37 ml/sec. for day one, two and three respectively. The overall performance of the filtration rate is shown in table 4.4 which was calculated by taking the average of day 1, 2 and 3. The result shows that the sand filter has 3.80 ml/sec and is the highest filtration rate followed by charcoal 1.91 ml/sec. then activated carbon 1.73 ml/sec then that of Moringa 0.51 ml/sec. the difference in filtration rate is due to the particle sizes of the materials used as a filtration bed. The finest(Moringa) slow down the filtration velocity of the water while the Sand has a bigger particle size compared to Moringa, Charcoal and Activated Carbon as such water tend to pass very fast in a very short time. The filtration rate of a commercial filter is in the range of (2.5 – 5.0) ml/sec. this shows that, the Moringa filter has a filtration rate that is within the acceptable value.

Table 4.1: Day One Results

Parameter	Raw Water	Charcoal	Activated Carbon	Moringa (Seed)	Sand
p^H	7.506	7.65	7.53	7.67	7.18
EC(µS/cm)	372	287	312	261	290
DO(mg/L)	7.20	7.27	7.06	6.85	6.93
Turbidity (NTU)	97.60	14.3	11.1	5.24	24.7
TDS(ppm)	150	163	159	137	151
Flow rate (mL/sec.)	_	1.84	2.15	0.60	5.43

All the readings were taken at 26.2^{o}C

Table 4.2: Day Two Results

Parameter	Raw Water	Charcoal	Activated Carbon	Moringa(Seed)	Sand
p^H	7.63	7.158	7.58	7.04	7.6
EC (µS/cm)	267	314	305	271	326
DO (mg/L)	7.59	7.16	7.00	5.93	7.20
Turbidity (NTU)	147.00	12.8	10.7	5.25	19.5
Flow rate (ml/sec.)	-	2.27	1.66	0.57	3.47

All the readings were taken at 27.2^{o}C

Table 4.3: Day Three Results

Parameter	Raw Water	Charcoal	Activated Carbon	Moringa (Seed)	Sand
p^H	7.50	7.79	7.709	6.90	7.82
EC(µS/cm)	305	335	327	279	309
DO(mg/L)	7.41	6.60	7.51	6.31	7.63
Turbidity (NTU)	214.00	27.1	28.9	24.9	56.6
TDS(ppm)	150	163	159	137	151
Flow rate (ml/sec.)	_	1.66	1.37	0.37	2.49

All the readings were taken at 26.8^{o}C

Table 4.4: Overall performance of the filters

Parameter	Raw Water	Charcoal	Activated Carbon	Moringa (Seed)	Sand
p^H	7.55	7.53	7.60	7.20	7.53
EC(µS/cm)	315	312	315	270	308
DO(mg/L)	7.4	7.0	7.19	6.36	7.25
Turbidity (NTU)	152.87	18.07	16.90	11.80	33.60
TDS(ppm)	150	163	159	137	151
Flow rate (ml/sec.)	-	1.91	1.73	0.51	3.80

4.4 Overall Performance

The overall performance of the four filters is shown in table 4.4 and is obtained by calculating the average of the day one, day two and day three results of each parameter shown in table 4.1, 4.2 and 4.3 respectively, looking at the table 4.4, the p^H of the four filters falls within the WHO standard range (6.5-9.5), Sand filter has the best filtration rate with the value of 3.80 ml/sec. and that also falls within the range of commercial filters (2.5 – 5.0) ml/sec. Moringa also has relatively the best turbidity value of 11.80 NTU when average is taken but looking at the turbidity values of table 4.1 and 4.2 for day one and day two respectively is 5.24 NTU and 5.25 NTU the value is very closed to that of WHO standard, the possible reason for slight deference could be from the raw water used, the Moringa filter also has the best EC result with the value of 270 µS/cm which meet the requirement of less than 300 µS/cm. the only problem observed when using Moringa filter is that it generates odour over time which is possibly due to the bacterial growth within the filter, in terms of colour (neatness) as observed physically Moringa is the best in colour removal. Using all the parameters it can be concluded that Moringa filter is the best in terms of water purification but the slowest in terms of filtration rate.

CHAPTER FIVE

CONCLUSIONS AND FUTURE WORK

Moringa is acknowledged as the best water filtration material among the other materials used (sand, charcoal and activated carbon) because of its local availability which makes it easily accessible and affordable and also it's unique water purification ability. The Moringa water filter removes most impurities and contaminant in raw, dirty or contaminated water though it is slow and takes a lot of time. The Moringa water filter is associated with bacterial growth. This generates an odour in the water over time. Therefore, the elimination of the bacterial growth in Moringa water filter is recommended for further work.

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