KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY, KUMASI

IDENTIFYING APPROPRIATE MICROFILTER MEDIA FOR SURFACE WATER TREATMENT IN RURAL COMMUNITIES

By

ANSAH, PHILIP

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DECLARATION

I do hereby declare that this submission is my own work towards the MSc. Chemical Engineering and that, to the best of my knowledge , it contains no material previously published by another person nor material which has been accepted for the award of any degree of the University, except where due acknowledgement has been made in the text.

Ansah, Philip (PG8319612)

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Student Name Signature Date

Certified by:

Nana Yaw Asiedu

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Supervisor's Name Signature Date

Certified by:

Mrs. Zsuzsanna Momade

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(Head of Department) Signature Date

DEDICATION

First and foremost, I dedicate this thesis to the Lord Jesus Christ for having paved the way for my academic pursuits.

Finally, to my elder brother, Mr. Charles Dubeng of AGA, Obuasi Mine for his steadfast support and encouragement.

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ABSTRACT

Almost 60 percent of Ghanaian population is rural peoples. Commonly improved water sources found in the rural communities are boreholes, protected dug wells, protected springs, and rain harvested water. A large proportion of the rural population continues to be dependent on surface water resources such as rivers, streams and dams. Obviously the surface water sources are contaminated with pathogens and other contaminants. Even the quality of the ―improved‖ water sources is questionable. There have been quite a number of efforts by Government (Community Water and Sanitation Agency) and non-profit organizations such as Community Water Solutions (CWS) and Pure Home Water Product (PHW) to provide safe water to rural inhabitants in the country. These organisations have used ceramic pot filters, bio-sand filters, cloth filters, chlorine tablets and alum for surface water sources purification. Clearly, economic sustainability, adaptability and flow performance for some of the filter media are always a problem. For these reasons it becomes imperative to identify appropriate filter media for Point-ofuse (POU) microfilters to increase safe water supply in the rural communities. It is perceived the filter would improve flow performance as well as water quality. A different study was conducted to determine fabrics pore size distribution using LEICA DFC290 and image J. it was found that nylon (Nyl) and polyester (POL) had the finest average pore size of 1.5µm and 1.7µm respectively. Pore size for locally twill weave polyester (LTW POL) was also found to be 1.9µm, close to both nylon and polyester. Another study was conducted to construct filter media from nylon (Nyl) and polyester (POL) fabric. The media was categorized into nylon, polyester, composite (polyester and nylon) and hybrid (activated carbon from bamboo and polyester). The filter media was used to treat raw water from GWCL, Mampong dam and river Offin. The treatment cycle time or run time was 5-10 minutes. Percent TSS removal for nylon was 62.46, the highest among the four filter media category, followed by composite filter. The composite filter percent removal of turbidity was 60.28, slightly

higher than hybrid and nylon filter. All filters were found to remove 100 percent fecal coliform and *e.coli* bacteria. However, percent total coliform bacteria removal for composite medium was 60, about 17% higher than polyester and nylon efficiency. In general, performance of hybrid medium in removals of heavy metals was better than any filter. The percent removal of Pb, Fe, Cu, Cd, Zn and Mn for hybrid medium are 61.25, 48.61, 69.64, 56.25, 61.31 and 87.5 respectively. Furthermore, aquatab chlorine was used for raw water treatment and also used to treat products of polyester, composite filter. It was again found that polyester and composite filter compete with raw water treatment with the aquatab in terms of pathogens removal. Percent removal of total coliform(TC) for polyester was 64.64 slightly higher than raw water treatment with aquatab chlorine(AQUATT). However, TDS, turbidity and conductivity for all aquatab chorine treatment surged. Interestingly, it was found that TSS in all aquatab treatment improved. The run time also improved the removal efficiency of pollutants in the raw water. In general, nylon media performance is better than polyester. However, when combined (composite) its effectiveness in removing pollutants in water is improved.

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LIST OF ABBREVIATIONS

A	“**A** solute component **A**‖
AAS	Atomic Absorption Spectrophotometer
AGMD	Air gap membrane distillation
AQUAT	Aquatab

AQUATT	Raw water treatment with aquatab
B	“**B** solute component **B**‖
CA	Cellulose acetate
CC	Coca Cola
CFFF	Composite Fabric Frame Filter
CFU	Colony forming unit
COD	Chemical oxygen demand
CSWFF	Circular Sheet Woven Fabric Filter
CWS	Community Water Solutions
CWSA	Community Water and Sanitation Agency
DCMD	Direct contact membrane distillation
E.coli	Escherichia coliform
ED	Electrodialysis
EPA	Environmental Protection Agency
GF	Gravity filtration
GNA	Ghana News Agency
GS	Gas separation
GSB	Ghana Standards Board
GSS	Ghana Statistical Service
GWCL	Ghana Water Company Limited
GWEP	Guinea Worm Eradication Programme
H	High
IMBR	Immersed Membrane Bioreactor
L	Low
L	Litre

Lab	Laboratory
LAN	Langary
LEICA DFC290	Model of electronic microscope
LPW POL	Local plain weave polyester
LTW POL	Local twill weave polyester
M	Medium
MD	Membrane distillation
MDG	Millennium Development Goal
MF	Microfiltration
MLSS	Mixed liquor suspended solids
MWCO	Molecular weight cut-off
NF	Nanofiltration
NGO	Non Governmental Organisation
NTU	Nephelometric turbidity
Nyl	Nylon
Nyl2	Nylon2
PAN	Polyacrylonitrile
PATH	Program for Appropriate Technology in Health
PC	Processing computer
PDMS	Polydimethylsiloxane
PE	Polethylene
PE	Polyimide
PEI	Polyetherimide
PET	Polyethylene tetraphthalate
PES	Polyethersulfone
PFA	Polyfurfural alcohol

PP	Polypropylene
POL	Polyester
POU	Point-of-use
PS	Polysulfone
PVC	Polyvinylchloride
PVDC	Poly vinylidene chloride
PVDF	Polyvinylidene fluoride
RO	Reverse Osmosis
SFFF	Symmetric Fabric Frame Filter
SGMD	Sweeping gas membrane distillation
SS	Suspended solids
Teflon	Polytetrafluoroethylene
TDS	Total dissolved solids
TSS	Total suspended solids
UF	Ultrafiltration
UNICEF	United Nations Children's Fund
VMD	Vacuum membrane distillation
WHO	World Health Organisation
WFACF	Woven Fabric Activated Carbon Filter
WF-IMBR	Woven Fabric Immersed Membrane Bioreactor
WT	Water treatment

NOMENCLATURE

cm centimeter ^{o}C degree celcius ^{o}F degree

farenheit

m	meter
mg/L	milligram per litre
ml mililitre mm millimeter	
MPa	mega pascal
Mw	molecular weight
m^3/m^2h	cubic meter per meter square hour psi
	pound square per inch
µm	micrometer
µS/cm	microsiemens per centimeter
#	hash (repeated)
<	less than
%	percent

CHAPTER ONE

INTRODUCTION

1.1 Background information

In a membrane-separation process, a feed consisting of a mixture of two or more components is partially separated by means of a semi permeable barrier (the membrane) through which one or more species move faster than another or other species (Seader & Henley, 2006). Almost all industrial membrane materials that serve as barriers are made from natural or synthetic polymers (macromolecules). However, due to instability of polymer membranes in harsh situations, inorganic materials have been recently developed and used for membrane applications. Aside specialized selective polymer or inorganic membranes being utilized for separation of mixtures, fabrics (woven or nonwoven) which principally serve as substrate for production of polymer membranes, are also commonly used to construct systems for low pressure membrane processes.

The common synthetic materials used for fabric and polymer based purification systems are Polysulfone, Polyisoprene (natural rubber), Polytetrafluoroethylene (Teflon), Polystyrene, Polyester, and Polyimide.

Membranes separation methods are used on large scale to produce potable water, to clean industrial and municipal effluents and recover valuable constituents, to concentrate, purify, or fractionate macromolecular mixtures in food and drug industries, and to separate gases and vapors in petrochemical processes (Strathman *et al*., 2006).

Conventional separation processes for concentration and purification such as distillation, centrifugation, extraction, adsorption, absorption, can also be supplemented by membrane processes (Strathmann *et al*., 2006). The advantages of membrane processes include low energy and chemicals requirement, greater flexibility in designing systems, greater efficiency for raw materials usage and potential for recycling of by-products. In addition, the products are of high quality and it is relatively easy for scale up.

Membrane processes are categorized based on the separation mechanism which mainly consists of size exclusion, solubility and diffusivity, and charge. The common industrially important membrane separation operations are: reverse osmosis (RO), ultrafiltration (UF), microfiltration (MF), nanofiltration (NF), dialysis, pervaporation (PV) and gas separation (GS).

Different configurations of membrane modules are available for various membrane separation processes. These include spiral wound, flat sheet (plate and frame), hollow fiber, and tubular module. Hollow fiber and spiral modules are largely applied to reverse osmosis (RO), ultrafiltation and nanofiltration separation processs. Although plate and frame, and tubular modules have low packing density, they are built to be used in application where fouling is severe.

Membranes with a pore size of 0.1 – 10 µm perform microfiltration. Membrane modules usually applied to microfiltration process are plate and frame, and spiral wound module. These modules can be built either as cross flow or submerged or immersed microfilters. Microfilters are commonly used in wastewater and water treatment. They remove protozoa (for example *Cryptosporidium*, *Giardia*), bacteria (for example *Campylobacter*, *Salmonella*, *Shigella*, *E. coli*)(CDC, 2012), suspended solids and colloids in water. Aside industrial applications of microfiltration technique, microfilters are designed and constructed for house hold water treatment which primary serve as health intervention. A growing number of studies suggest that point-of-use water purification translates into reductions in diarrheal disease at a level that is comparable to other water, sanitation, health and hygiene interventions(CookClean, 2010). Other applications of microfilters include cold sterilization of beverages and pharmaceuticals, clearing of fruit juice, wines and beer, separation of oil/ water emulsions, pre-treatment of water for nanofiltration or reverse osmosis.

1.2 Problem statement

Almost 6.1 billion people, 89 per cent of the world's population, were using an improved water source in 2010(WHO & UNICEF, 2012). This is a clear indication of tremendous improvement in the activities that have led to meet MDG drinking water target. In Ghana a population of about 24.7 million in 2010 (GSS, 2012), proportion of people who have access to improved water source is between 76 and 90 percent (WHO & UNICEF, 2012). Ghana's rural water coverage is now 63 per cent showing an increase of 5.86 per cent from 2008 (GNA, 2011). The common improved water sources in the rural areas are boreholes, dug–out wells, and springs. A large population in rural areas depend on surface water. Over 30 percent of the rural population relies on surface water from rivers, lakes, ponds or dams. The use of surface water stands at a surprisingly high 3 per cent of the global population, or 187 million people(WHO & UNICEF, 2012). Most of these people – 94 per cent – are rural inhabitants, and they are concentrated in sub-Saharan Africa(WHO & UNICEF, 2012). In Ghana, surface water sources are entirely unimproved. Indeed their quality are questionable. Vegetative plants grow in them and are highly polluted by waste materials from the communities. Animals in the wild and cattle use the same streams and rivers. These lead to high water–related diseases. These include diarrhea, hepatitis A, typhoid, cholera and guinea worm (CookClean, 2010). Rural inhabitants in Ghana have been dependent on simple household water treatment technologies. Commonly used home water treatment systems are ceramic candle filter, ceramic clay pot filter under the brand name kossim, fiber-carbon filter and bio-sand filter.

These technologies are less expensive and are adaptable to rural communities. However, the major problem is their low capacities. The kossim has slower flow rate(PATH, 2009). It can produce 10L of potable water per day (Ghanaweb, 2012). Community Water Solution (CWS), an NGO operating in Ghana, uses the technology now, and accordingly, in first three years they have provided a permanent source of safe drinking water to approximately 20,000 people including over 4,000 children in thirtyfive villages in northern region of Ghana (CWS, 2012). All these call for the essence of indentifying a suitable filter medium for construction of point-of-use microfilters for rural surface water treatment.

The filter system would be used to treat river water and probably other unimproved water sources. It would be applied to ―Ankore: or ―Jerri‖ cans which are commonly used in rural areas in Ghana. No energy would be required since permeate flow is due to gravity. The filter will produce a product free of suspended solids, colloids, and most pathogens, and that can be easily disinfected. This study focuses on fabrics selection and development of these materials into filter media for river source water treatment. The treated water (product) quality is measured thus to determine the performance of the filter media.

1.3 The scope of the study

The scope of the study includes the following: material search and selection, design and construction of the filters (modules), and piping and tank system, raw water treatment and water quality measurement.

1.4 Objectives of the study

The objectives of the study are the following:

1. To select appropriate fabrics and other materials for microfilters
2. To construct immersed microfilters

3. To treat raw water (river source) using the microfilters
4. To measure the performance of the microfilters

CHAPTER TWO

LITERATURE REVIEW

2.1 Materials for membrane separation processes

A membrane material for separation is a sermipermeable barrier (Salleh *et al*., 2011; Seader & Henley, 2006; Wang and Zhou, 2013; Strathmann *et al* ,2006), which basically separate two phases and control the transport rates of components (ions, molecules) in the mixture in a selective manner (Wang and Zhou 2013a; Feng *et al*, 2008). It can also allow some components to cross while hindering others (Wang & Zhou, 2013b). The most general membrane process is shown in Figure 2.1, where the feed mixture is separated into a retentate (that part of the feed that does not pass through the membrane) and a permeate (that part of the feed that does pass through the membrane) (Wang and Zhou 2013c; Seader & Henley, 2006). A membrane can be homogenous or heterogeneous, symmetric or asymmetric in structure, solid or liquid, can carry a positive or negative charge or be neutral or bipolar (Strathmann *et al*, 2006). The thickness of membranes generally varies from a fraction of a micrometer to several millimeters. Membranes can be natural or synthetic. Biological membranes carry out complex tasks in living organisms (Strathmann *et al*., 2006). Almost all industrial membrane materials that serve as barriers are made from natural or synthetic polymer macromolecules (Seader & Henley, 2006). Natural polymers include wool, rubber, and cellulose (Seader & Henley, 2006). Common synthetic polymers for membrane applications are indicated in Table 2.1.

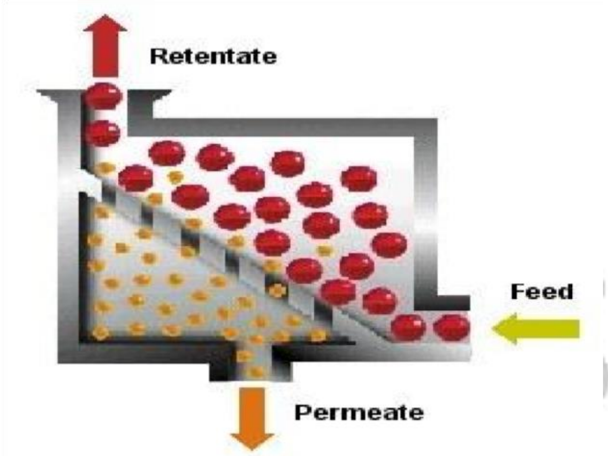


Figure 2.1:General Membrane Process(Sharma,2001)

are Polystyrene, Polycarbonate ,Polysulfone Polytetrafluoroethylene and Polyimide. Table 2.1 lists examples of synthetic polymers and their corresponding membrane processes. Sometimes copolymers are formulated and used for separation. Polymeric membranes dominate the market because they are less expensive and more versatile than inorganic membranes (Wang & Zhou, 2013). Swelling, that occur in polymeric membranes also tends to alter the membrane properties and generally leads to higher permeability and lower selectivity (Wee *et al.*, 2008). The application of polymer membranes is generally limited to temperatures below about 200°C and to the separation of mixtures that are chemically inert (Seader & Henley, 2006). Inorganic membranes have rapidly received global attention, and these have been considered as one of the potential candidates to replace available polymeric membranes (Salleh *et al.*, 2011). The advantages of inorganic membranes over polymeric types are their higher temperature stability, good resistance to fouling, narrower pore size distribution, and their relative to swelling. (Coulson *et al.*, 1991; Wee *et al.*, 2008).

Table 2.1: Commonly Used Polymers For Membrane Separation Processes(Wang & Zhou, 2013)

Polymer	Membrane Type

Polyamide	RO,NF,UF,MF
Celluse Acetate (CA)	RO,UF,MF
Polysulfone (PS)	UF,MF
Polyethersulfone (PES)	NF,UF,MF
Polyvinylidene fluorode (PVDF)	UF,MF
Polyimide (PE)	NF
Polyetherimide (PEI)	UF,MF,GS
Polethylene (PE)	UF,MF
Polypropylene (PP)	UF,MF
Polyacrylonitrile (PAN)	UF,MF,PV
Polyethylene tetraphthalate (PET)	MF
Polydimethylsiloxane (PDMS)	NF,PV,GS

Inorganic membranes are made of ceramics such as aluminum, titanium or silica oxides , silicon carbide or some glassy material and carbon; largely produced by pyrolysis of polymer materials such as poly(vinylidene chloride) or PVDC, poly(furfural alcohol) or PFA, cellulose triacetate, polyacrylonitrile or PAN, and phenol formaldehyde, silica, zeolite, various oxides (alumina, titania, zirconia) and metals such as palladium, silver and their alloys. Inorganic membranes are also produced by deposition of colloidal metal oxide on to a supporting material and high temperature sintering. These membranes are applied in MF, NF, gas separation, pervaporation. Organic and inorganic membranes can be amorphous and crystalline in nature. They can also be porous or non porous. Porous inorganic membranes exhibit high permeabilities relative to dense membranes and high thermal stability relative to organic membranes (Wee *et al*., 2008). Synthetic membranes can be classified as symmetric, asymmetric and composite thin film. Symmetric membranes are not largely applied for separation because of their high permeance and low selectivity. Most membranes used in industry have an asymmetric structure (Feng *et al*. 2008; Wang and Zhou 2013). Figure 2.2 shows schematically a typical cross-sectional view of an asymmetric membrane. It consists of two layers; the top layer being very thin and dense (also called the top skin layer), and the bottom one is a porous layer (Feng *et* *al*., 2008).The top dense layer governs the performance (permeation properties) of the membrane; the porous sub layer only provides mechanical strength to the membrane(Feng *et al*., 2008). The membranes of symmetric structures do not possess a top dense layer(Feng et al., 2008). In the asymmetric membrane, when the material of the top layer and porous sublayer are the same, the membrane is called an integrally skinned asymmetric membrane. On the other hand, if the polymer of the top skin layer is different from the polymer of the porous sublayer, the membrane is called a composite membrane. Symmetric polymer membranes are produced by: track etching and precipitations from vapour phase while asymmetric types are largely produced by phase inversion technique. Membranes have been produced in the following forms: sheets, tubes, films and fibers.

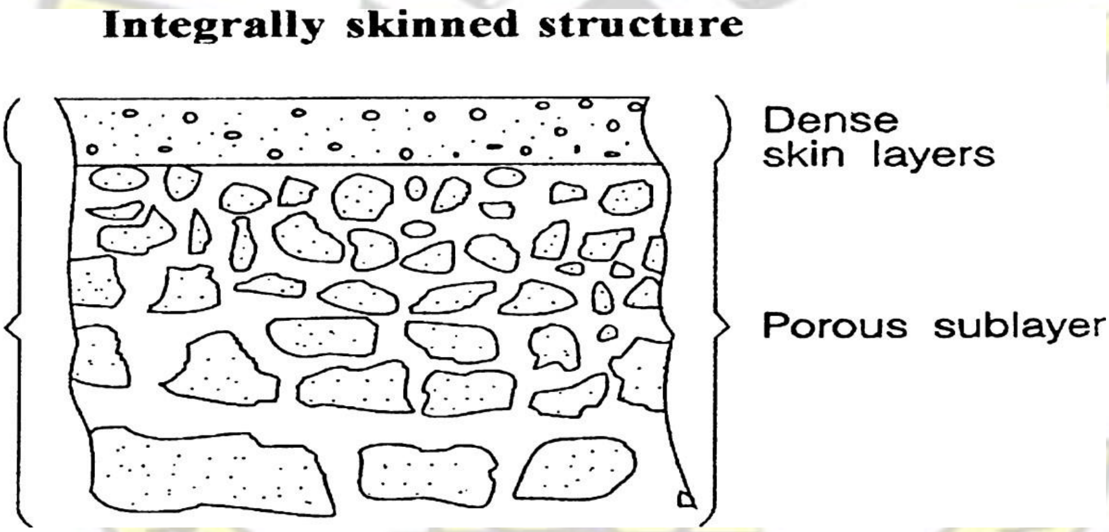


Figure 2.2:Crosssectional View Of Asymmetric Membrane(Feng *et al*., 2008)

2.2 Fabrics for separation processes

Fabrics are also termed as textiles. They are principally produced from yarns or strands made from fibers. Fabrics can be produced from natural and man-made fibers. Natural fibers come from plants like cotton or flax, a silk worm's cocoon, the leaves of pineapple plants, or from animals, like sheep or even camels (Phipps, 2008). Man-made fibers are fibers in which either the basic chemical units have been formed by chemical synthesis followed by fiber formation or the polymers from natural sources have been dissolved and regenerated after passage through a spinneret to form fibers (Needles, 1986). The synthetic man-made fibers include the polyamides (nylon), polyesters, acrylics, polyolefins, vinyls, and elastomeric fibers, while the regenerated fibers include rayon, cellulose acetates, regenerated proteins, glass and rubber fibers(Needles, 1986). Fabrics, either synthetic or natural have a wide range of properties. Tables 2.2 and 2.3, show the properties of some common fabrics. Synthetic fibers are more widely used today than natural fibers because they can operate at higher temperatures and better resist chemical attack. Polypropylene is the most inexpensive and widely used polymer in liquid filtration.(Hardman, 1997) Nylon is considered to surpass all other fibers in abrasion resistance(Wang *et al*, 2005). Most commonly used synthetic fabrics for separation processes can be found in Table 2.7.

Table 2.2: Fiber Properties

Property	Examples
Abrasion resistance: its ability to resist damage from rubbing or surface contact	Abrasion resistant: nylon, polyester Sensitive to abrasion: acetate,lyocell
Absorbency: percentage of moisture a dry fiber will absorb from the air	Absorbent fibers: cotton, wool, rayon Nonabsorbent fibers: polyester, olefin
Chemical reactivity: effect of acids, alkalis, oxidizing agents, solvents, or other chemicals	Resistant to chemicals: polyester, olefin Harmed by acid:cotton, rayon, lyocel Harmed by alkali:wool, silk
Mildew resistance: resistance to growth of mold, mildew or fungus	Resistant:wool, nylon, polyester Sensitive:cotton, rayon, lyocell
Oleophillic: fiber with strong attraction for oil	Oleophillic fibers:nylon, polyester
Shrinkage resistance: ability to retain original dimensions during cleaning	Prone to shrinkage:wool Resistant to shrinkage:polyester, nylon
Strength:ability to withstand a pulling force	Strong fibers:nylon, polyester Weak fibers:rayon, acetate

(Kadolph, 2013)

Table 2.3: Fiber Properties Related To Fabric Performance

Fiber	Strength(g/d)	Absorbency (%)	Density(g/cc
Glass	9.6 (H)	0(L)	2.48(H)
Aramid	4-5.3(H)	6.5(M)	1.38-1.44(M)
Lyocell	4.8-5(H)	11.5(H)	1.56(H)
Silk	4.5(H)	11(H)	1.26(L)
Nylon	3.5-7.2(H)	2.8-5(M)	1.14(L)
Flax	3.5-5(M)	12(H)	1.52(H)
Olefin	3.5-4.5(M)	0.01-0.1(L)	0.9-0.91(L)
Cotton	3.5-4.0(M)	7.0-11(M)	1.52(H)
Polyester	2.4-7.0(M)	0.4(L)	1.34-1.38(M)
Acrylic	2.0-3.0(M)	1.0-1.5(L)	1.17(L)
Wool	1.5(L)	13-18(H)	1.32(L)
Acetate	1.2-1.4(L)	6.4(M)	1.32(M)
Rayon	1-2.5(L)	11.5-12.5(H)	1.48(M)
Spandex	0.7-1.0(L)	0.75 - 1.3(L)	1.2(L)
Rubber		0.8(L)	1.1(L)

L: Low M: Medium H:High

(Kadolph, 2013)

2.3 Methods for identification of fibers

Several methods are used to identify fibers and to differentiate them from one another (Needles, 1986). The most common methods include microscopic examination, solubility tests, heating and burning characteristics, density or specific gravity, and staining techniques (Needles, 1986). Microscopic appearance is most useful for natural fibers (Kadolph, 2013). Solubility tests and the more sophiscated procedures (including burn test, staining test, etc.) are most effective for manufactured fibers (Kadolph, 2013). Color tests or staining tests for fibers are also applied using special stains (Katz, 2005).

Figure 2.4 shows Textiles Identification Stain (TIS) numbers and fiber colors. T.I.S. Stain no. 1 is recommended for use with natural fibers whilst T.I.S. Stain no. 3A is

Figure 2.4: T.I.S. numbers(Nos) And Fiber Colors (Katz, 2005)

recommended for synthetic fibers(Katz, 2005). Tables 2.4, 2.5 and 2.6 give the general fiber behavior in burn test, microscopic appearance of fibers and effect of acids and alkalis.

Table 2.4: Fibers Behavior In Burn Test

Fibers	when nearing flame	When in flame	When out of flame	Ash	Odor
Cellulose(cotton, flax, lyocell,rayon)	Does not shrink or fuse from flame	Burns with light gray smoke	Continues to burn, after glow	Gray, feathery, smooth edge	Burning paper odor
Protein(silk,wool)	Curls away from flame	Burns slowly	May selfextinguish	Crushable black ash	Burning hair odor
Acetate	Melts and pulls away from flame	melts and burn	Continues to burn and melt	Brittle, black hard bead	Acrid, harsh sharp odor
Acrylic	Melts and pulls away	Melts and burn	Continues to burn and melt	Brittle, black hard bead	Chemical odor
Glass	No reaction	Does not burn	No reaction	Fiber remains	No odor
Nylon	Melts and pulls away	Melts and burn	May selfextinguish	Hard gray or tan bead	Celery-like odor
Olefin	Melts and pulls away	Melts and burn	May selfextinguish	Har tan bead	Odor
Polyester	Melts and pulls away	Melts and burn	May selfextinguish	Hard black bead	Sweet odor
Spandex	Melt but does not pull away from flame	melts and burn	Continues to melt and burn	soft black ash	Chemical odor

(Kadolph, 2013)

Table 2.5: Microscopic Appearance Of Fibers

Fiber	Lengthwise appearance	Cosswise Appearance
Cotton	Convolutions	Kidney bean shape with central lumen
Bast fibers(flax, hemp, ramie	Thick and thin fibers, nodes fiber clumps	Polygorial, lumen
Wool	Scales	Round shape; medula in some wools
Silk	Slightly irregular	Triangular or trilobal shape
Rayon	Strations	Multilobed or flower-petal shape
Lyocell	Slight strations	Almost round
Acetate	Strations	Multilobed or flower-petal shape
Melt spun fibers(Nylon, polyester, olefin	Very smooth and regular, may have dark flecks	Varies with end use
Acrylic	Very smooth and regular, dark flecks	Round, dog-bone, or other
Elastomeric fibers(spandex, rubber,	large compared to most other fibers, often mono-Filament	Usually round
Aramid	Very smooth and regular, dark flecks	Usually round
Glass	large compared to most other fibers	Usually round

(Kadolph, 2013)

Table 2.6: Effect of Acids and Alkalis on Fibers

Fiber	Effect of acid	Effect of alkali
Acetate	Unaffected by weak acids, Soluble in acetic acid, decomposed by strong acids	Saponified, little effect from cold weak alkalies
Acrylic	Resistant to most acids	Destroyed by strong alkalies at a boil, resists weak alkalies
Aramid	Resistant to most acids	Resistant
Cotton	Disintegrates in hot dilute and cold concentrated acids	Swells when treated with caustic soda but is not damaged
Flax	Harmed	Resistant
Glass	Resists most acids. Etched by hydrofluoric acid and hot phosphoric acid	Attacked by hot weak alkalies and concentrated alkalies
Lyocell	Harmed	Resistant
Nylon	Decomposed by strong mineral acids, resistant to weak acids	Little or no effect
Olefin	Very resistant	Highly resistant
Polyester	Resistant to most mineral acids; disintegrated by 96% sulfuric acid	Resistant to cold alkalies, slowly decomposed at a boil by strong alkalis
Rayon	Disintegrates in hot dilute and cold concentrated acids	No effect by cold, weak alkalies, swells and loses strength in concentrated alkalies
Silk	Harmed by strong mineral acids, resistant to organic acids	Harmed
Spandex		Resistant

(Kadolph, 2013)

2.4 Woven and non woven fabrics

Fabrics can be woven, non-woven and knitted. Both woven and non-woven fabrics are usually used as substrate for production of thin film membranes. The majority of membrane elements utilize a polyester fabric as the base substrate, whereas polypropylene fabric substrates are used when chemical resistance and/or inertness is essential, especially when aggressive cleaning agents are employed(Gregor, 2008). The fabrics provide the coating surface, dimensional stability, strength, tear resistance and durability(Gregor, 2008).

Woven fabrics are produced in different fiber content, weight, style of weave, and sheen. Woven fabric media is commonly applied to surface filtration as shown in figure 2.5A. Woven fabrics filtration becomes more effective when cake is formed on the media surface. The cake-forming approach to the process of filtration means that the fabric itself serves as the filter media in the initial stage of the process, after which the built-up cake will itself become the (very fine) filter in the following process cycles(SEFAR, 2008). The fabric then mainly functions as a support for the filter cake(SEFAR, 2008). Woven media are used in low-energy devices (Wang *et al*., 2005). The basic woven fabric styles are plain, twill, and satin weave as shown in figure 2.6. The plain weave is the simplest and least expensive. This weave is usually the tightest, having the smallest pore openings in the fabric. Consequently, it retains particles very quickly. This weave is not frequently used, because it is associated with a higher pressure drop. Twill weave fabric is bulkier and warmer than plain weave. The twill weave does not retain particles as well as the plain weave, but does not tend to blind as fast. The twill weave allows good flow rates through the filter and high resistance to abrasion.

The nonwoven is felt fabric or membrane. Felt fabrics are tighter in construction (i.e., less porous), and for this reason, they can be considered to be more of a true filter medium

(Wang *et al*., 2005). Felt media are normally used in high-energy cleaning systems; felt or nonwoven is a typical media of depth filtration depicted in figure 2.5 B.

A

B

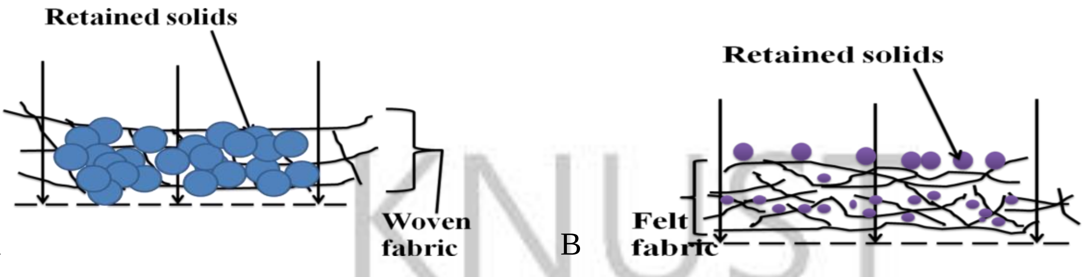
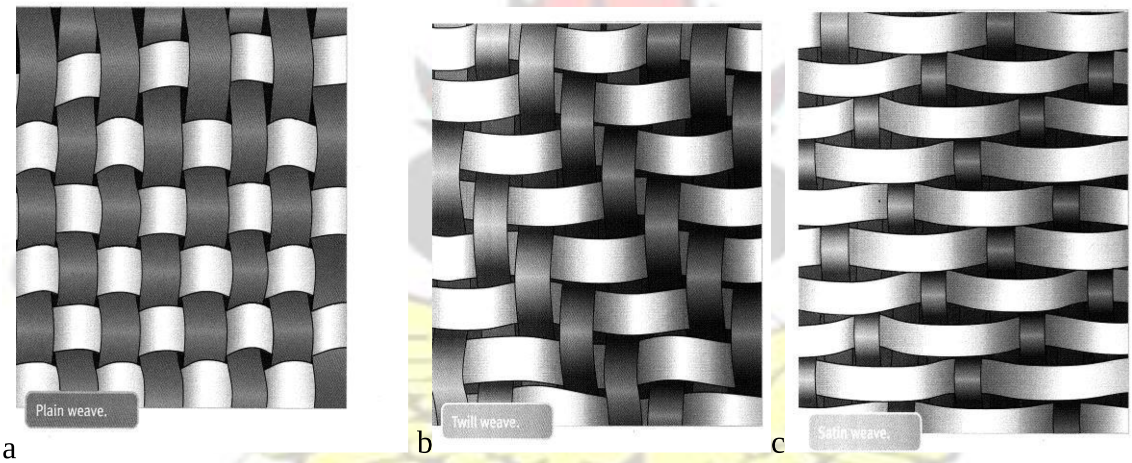


Figure 2.5: (A) Depth Filtration and (B) Surface Filtration



a b c

Figure 2.6: (a) Plain weave: the weft yarn passes over one and then underneath one warp yarn at a time. (b) Twill weave: the weft yarn passes over two and then underneath two warp yarn forming a diagonal surface pattern. (c) Satin weave: the weft yarn travels over three or four warp yarns and then underneath one warp.

2.5 Applications of woven fabrics

Fabrics are also commonly used as filter media for solid – gas, solid – liquid, liquid – liquid or solid – solid mixtures (Lucica & Ioan, 2011). They are largely used to construct baghouses, and filter presses as well as membrane modules for microfiltration processes.

Pillay used woven fibre developed by Chris Buckley's PRG at UN for Point-of-use (POU) microfilters and Woven Fabric Immersed Membrane Bioreactor (WF-IMBR). The POU system was used to treat raw water from river and dam. The POU system consistently produced a product of < 1 NTU, and generally around 0.5 NTU, for raw feeds ranging from 20 NTU to > 300 and complete disinfection (*e-coli* up to 100,000 cfu/ml)(Pikwa *et al*., 2010).

WFM-IMBR was designed based on Wiese pilots scale system and it was used to treat municipal waste water. The sludge and hydraulic retention time was 30 days and 24 hour respectively. In terms of the performance of the system, COD and MLSS removal was found to be above 95% an100% respectively. The permeate turbidity was found to be less than 1 NTU (Cele *et al*., 2010). Woven cloth water filter is one of the household water treatment systems in developing countries. It takes less than one minute to filter enough water to fill a standard 44-liter metal bucket but the cloth filters have a tendency to tear and need frequent replacement (PATH, 2009). A woven fabric has been used for treatment of oil-in-water emulsion : Under optimal condition, more than 90% of surfactant stabilized emulsified oil could be removed (Zhang *et al*., 2014). Table 2.7 shows typical fabrics that have been exploited in separation processes.

Table 2.7: Typical Fabrics Used For Filters

Fabric	Properties	Applications
Polypropylene (woven or felt)	: Acid-resistance, Alkali-resistance, Small specific gravity, high tensile strength, abrasion proof low temperature Inexpensive	Liquid-solid separation and dust collection foundries, coal crushers, and food industries, chemical industry, Pharmaceutical,etc equipments: frame filter press, belt filters, centrifuge filters,disc filters, drum filters, etc
Nylon (6 and 66)	Excellent abrasion resistance Fair resistance to: organic acids, mineral acids, Excellent reistance to: alkalies and solvents max operating temperature: 200°F	mainly used for liquid-soild separation industries of chemical,coal mining, building maerials,melting for equipments in the strong alkali operating conditions, such as frame filter press, disc filters, and centrifuge filters.
Polyester	Very good abrasion resistance Good resistance to: organic acids, alkalies and mineral acids Excellent solvent reistance Inexpensive Max temperature:275°F	Dust collector or liquid-solid separation Mainly used in food and beverage industry, pharmaceutical industry, non-ferrous metallurgy, chemical plant, building section , and mining industry,etc. for the equipment of filter presses,centrifuge filters, vacuum filters , belt filter presses, etc.
Fiber glass	Fair-Good abrasion reistance Good resistance to: organic acids, alkalies and mineral acids Excellent resistance to solvent Max temperature operating:275°F	dust collection cloth widely used in the bag filter systems to recycle the valueable industrial products, : Widely used in industry of carbon black, steel and non-ferrous metal processing, cement industry, chemical plant, power plant, etc

(Hardman, 1997; SUITA FILTERS, 2011; Wang *et al*., 2005)

2.6 Membrane separation processes

Membrane-based separation technologies have a broad range of applications, including process water treatment, wastewater treatment and reuse, metal and catalyst recovery, solvent recovery, gas separation, and concentration of heat sensitive biological macromolecules and proteins, among others (Wang & Zhou, 2013). Currently conventional separation processes for concentration, purification, etc such as distillation, centrifugation, extraction, adsorption, absorption, have been supplemented by membrane processes (Strathmann *et al*., 2006) Membrane filtration replaces the conventional sedimentation unit for separation of the treated water from the sludge and also serves as an advanced treatment unit for coliform bacteria and suspended solids (SS),which cannot be removed completely by conventional processes *(Kim et al*., 2004). Membrane separation processes have been seen to offer many advantages over existing separation processes such as ―higher selectivity, lower energy consumption, moderate cost to performance ratio and compact and modular design (Chapman *et al*., 2008). Most membrane separation processes do not use chemicals and for this reason they are environmentally friendly. Membranes do not require regeneration, unlike the adsorption or the absorption processes (Raavanchi *et al*., 2009). In most of the membrane processes, the driving force is a pressure difference or a concentration(or activity) difference across the membrane (Raavanchi *et al*., 2009). Others include temperature and electrical potential difference. Membranes are manufactured in different forms such as hollow fibres or flat sheets, which are incorporated into compact ,housing modules and cartridges designed to produce optimal hydrodynamic conditions for separation (Coulson *et al*., 1991; European Union, 2010).

2.7 Principles or mechanisms of membrane processes

There are different mechanisms by which membrane can perform separations. These mechanisms include sieving (steric hindrance), Knudsen flow, solution-diffusion, electrostatic repulsion, donnan exclusion, sorption and liquid-vapour equi;ibruim. Sieving is one of the basic mechanisms in material transport. Conventional filtration processes have been operated based on this mechanism. In this mechanism, larger size solutes or components are rejected in membrane pores whilst smaller ones are passed through the pores. Sieving effect is used in MF, UF and NF for separations. Sieving mechanism is greatly exploited and combined with sorption and diffusion, in carbon membranes for gas separation.

Knudsen"s diffusion occurs in a porous membrane, whose pore sizes are smaller than the mean free path of the gas molecules (Sridhar *et al*., 2002.). In Knudsen flow mechanism gas molecules interact with the pore walls much more frequently than colliding with one another which allows lighter molecules to preferentially diffuse through pores(Sridhar *et al*., 2002.). Knudsen"s diffusion principally takes place in membranes with a pore diameter in the range of 50-100Å (Sridhar *et al*., 2002.).

Solution-diffusion is also counted as a fundamental transport mechanism. It occurs in nonporous media, where preferential solutes first dissolve in the membrane and secondly diffuse through the membrane to the other side. The solution-diffusion effect is seen in RO, GS, PV and dialysis.

Electrostatic repulsion mechanism occurs when the membrane surface is negatively charged to repel anions and allow cations to be permeated.NF is usually operated based on electrostatic effect. All ion exchange membrane modules are dependent of donnan exclusive principle which is similar to electrostatic repulsion. In a typical ion exchange membrane, once co-ions are completely rejected then donnan exclusion effect is achieved.

Sorption mechanism in membrane transport has been effective in gas molecules separation using carbon membranes and PV-separating azeotropic mixtures. It occurs when fluid mixture is in contact with the filter media. Components are preferably adsorbed to the surface of the membrane prior to diffusion through the membrane to the otherside for desorption.

Solute membrane affinity is another mechanism that contributes to solute rejection. Here, the affinity of the solutes towards the membrane determines the potential to partition into the membrane surface and therefore to permeate through the membrane (Quach, 2011). Hydrophobic surfaces tend to attract hydrophobic solutes while rejecting hydrophilic ones (Quach, 2011). Hydrophobic solutes can therefore partition more easily and permeate through hydrophobic membranes (Quach, 2011). This mechanism is largely seen in membrane distillation (MD). Vapour-liquid equilibrium mechanism or principle in membrane is not different from conventional distillation processes. Here a preferred component vapour composition is in equilibrium with its liquid composition. This mechanism is also seen in MD. One of the characteristics of MD membrane is that membrane must not alter the vapor equilibrium of the different components in the process liquids (Camacho *et al*., 2013).

2.8 Membrane configurations or modules

Quite a number of membrane modules or sytems are available for a range of membrane processes. The common ones are plate and frame, spiral wound, all made from flatsheet membranes. Others are hollow fibres and tubular modules.

Plate and-frame modules are circular, square, or rectangular in cross-section (Seader & Henley, 2006). They were among the earliest types of membrane systems and the design is principally based on conventional filter press. Figure 2.7 shows plate and –frame module. It consists of a series of annular membrane discs placed on either side of support plates which also provide channels through which permeate can be withdrawn (Coulson *et al*., 1991).The sandwiches of membrane and support plate are separated from another by spacer plates which have central and peripheral holes, through which the feed liquor is directed over the surface of the membranes (Coulson *et al*., 1991). These modules have found wide application in food, pharmaceutical as well as in water desalination industries (Tiwari *et al*., 2003).

Flat sheets are also fabricated into spiral-wound modules shown in figure 2.8, it consists of several flat membranes separated by turbulence-promoting mesh separators (Coulson *et al*., 1991). It is constructed by rolling the assembly around a central, perforated, collection tube to form a module that is inserted into a pressure vessel (Seader & Henley, 2006). The process feed enters at one end of the pressure tube and encounters a number of narrow, parallel feed channels formed between adjacent sheets of membrane (Coulson *et al*., 1991). The feed flows axially in the channels created between the membranes by the porous spacers. Permeate passes through the membrane, traveling inward in a spiral path to the central collection tube (Seader & Henley, 2006). These modules make better use of space than tubular or plate and frame types, but are rather prone to fouling and difficult to clean (Coulson *et al*., 1991). So far standard sizes of 2.5 ― and 4.0‖ diameter and12‖, 25‖ and 40‖ long elements are made and tested (Tiwari *et al*., 2003).

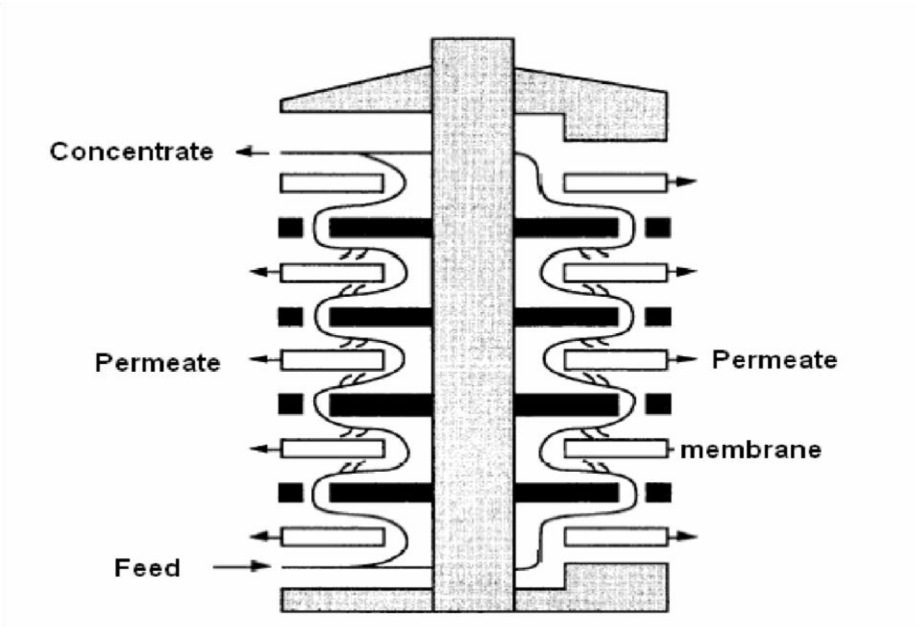


Figure 2.7: Plate and Frame Membrane Module

(Shakaib, 2008)

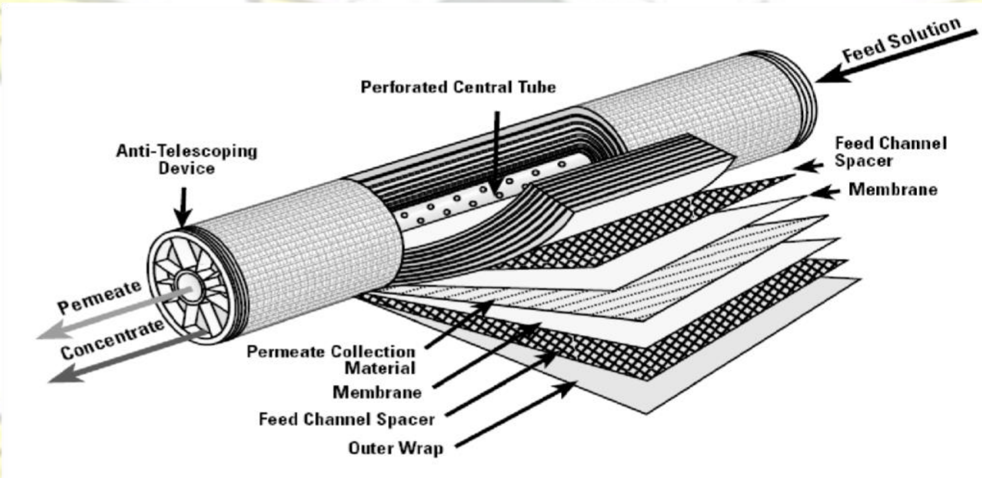


Figure 2.8: Spiral Wound Membrane Module

The hollow-fiber module shown in figure 2.9 resembles a shell-and-tube heat exchanger (Seader & Henley, 2006). It also consists of bundles of fine fibers, 0.-2.0mm in diameter and sealed in a tube (Coulson et al., 1991). The pressurized feed enters the shell side at one end. While flowing over the fibers toward the other end, permeate passes through the fiber walls into the central fiber channels (Seader & Henley, 2006). These modules though offer highest membrane packing density in the range of 6550 – 26199 m^2/m^3 but their productivity is not too far different from that of spiral wound module because of low flux densities (Tiwari et al., 2003). Hollow fiber cartridges can operate either with feed flow through the lumen (inside the hollow fiber) and permeate collection from the shell (inside-out), or with feed flow from the shellside and permeate collection from the lumen (Wang & Zhou, 2013) .A commercial module might be 1 m long and 0.1 to 0.25 m in diameter and contain more than one million hollow fiber (Seader & Henley, 2006).

A tubular module is shown in figure 2.10. The membrane is cast on the inside of a porous support tube which is often housed in a perforated stainless steel pipe (Coulson *et al*., 1991) . This module also resembles a shell-and-tube heat exchanger, but the feed flows through the tubes (Seader & Henley, 2006). Permeate passes through the wall of the tubes into the shell side of the module (Seader & Henley, 2006). Unlike plate and frame and hollow fiber modules, it works in turbulent zone. The typical membrane densities in tubular form are in the range of 60 – 160 m^2/m^3 (Tiwari *et al*., 2003). Membrane modules either flatsheet types or cartridge types are operated on dead-end and cross flow mode for membrane processes. Major membrane processes and applications are outlined in Table 2.8

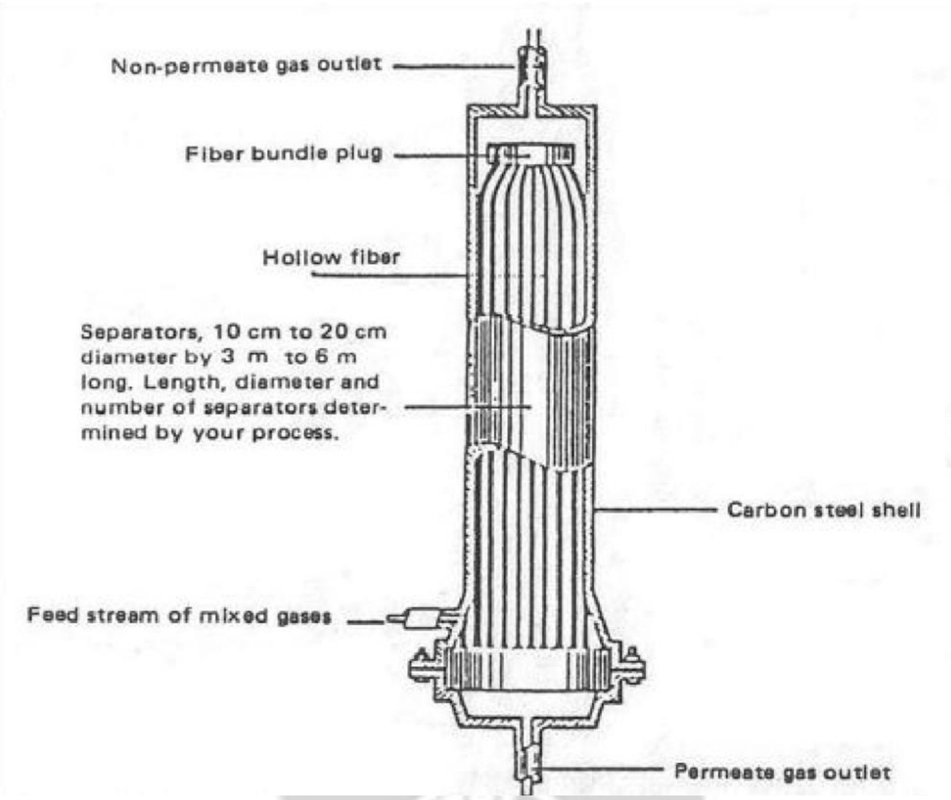


Figure 2.9: Hollow Fiber Module with Closed-End Design

(Keong, 2007)

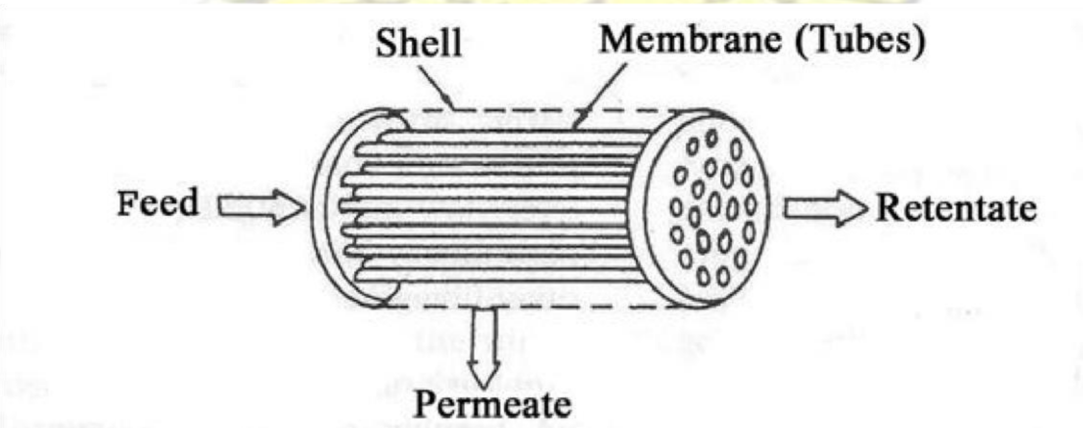


Figure 2.10: Tubular Membrane Module

(Keong, 2007)

Table 2.8: Membrane Modules and Their Applications

Membrane module	Separation processes
Spiral wound	RO, UF, NF,D, RO, GS, ,MF
Plate and frame	RO,UF,D, PV, MF

Hollow fiber	GS,D, RO, UF,MF
Tubular	RO, UF

2.9 Pressure driven membrane processes

The most widely used membrane separation technologies are pressure driven processes- reverse osmosis (RO), nanofiltration (NF), microfiltration (MF), and ultrafiltration (UF). Pressure driven processes are well established large scale industrial processes. Pressure driven membranes are housed in a vessel and the flow is fed from a pump. Vacuum-type systems are membranes submerged in non-pressurized tanks and driven by a vacuum created on the product side (EUROPEAN UNION, 2010).

2.9.1 Microfiltration

Microfiltration is a process by which suspended solids and large colloids are rejected, while dissolved solids and macromolecules pass through the membrane (Wang & Zhou, 2013). In terms of pore size, MF fills in the gap between ultrafiltration and granular media filtration. Many membrane manufacturers rate their MF membranes according to the nominal pore sizes, which are in the range of approximately 0.1-10µm (Seader & Henley, 2006a; Sirkar, 1997; Wang & Zhou, 2013), and a molecular weight cut-off (MWCO) of greater than 1000,000 Daltons. MF membranes are suitable for the removal of total suspended solids, flocculated materials, bacteria (Wang and Zhou 2013; Sirkar 1997), blood cell and other microbial cells and very large and soluble macromolecules (Seader & Henley, 2006b) from gas streams and liquid suspensions.. MF is not an absolute barrier to viruses. MF processes operate at very low pressure, typically 10psi or less (Wang & Zhou, 2013). MF membranes can operate in either crossflow separation or dead-end filtration (EUROPEAN UNION, 2010). There are also two pump configurations, either pressure driven or vacuum-type systems. They are also used as a pretreatment to desalination technologies such as nanofiltration and reverse osmosis (EUROPEAN UNION, 2010).

2.9.2 Ultra filtration

UF membranes are commonly used to retain relatively large dissolved materials(e.g. proteins, starches, polymers, sugars) and suspended solids(e.g., colloids, viruses) while allowing salts and smaller dissolved organic compounds to permeate (Coulson *et al*., 1991; Seader & Henley, 2006; Wang & Zhou, 2013d). The solutes retained or rejected by UF membranes generally have MWCO values between 1,000 and 300,000 Daltons (Coulson *et al*., 1991; Wang & Zhou, 2013e) and pore diameters in the range of 10nm to0.1µm (Wang & Zhou, 2013f). The pressure difference applied across the membrane is usually in the range 14.5-101.5psi and membrane permeation rates are typically 0.010.2m^3/m^2h(Wang & Zhou, 2013; Coulson *et al*., 1991a). In industry UF is always operated in cross flow mode (Coulson *et al*., 1991b). UF membrane processes are widely used in biopharmaceutical protein separation, virus clarification and whey protein concentration and isolation in the dairy industry.

2.9.3 Nanofiltration

Nanofiltration (NF) membranes are a kind of pressure driven membranes with separation characteristics between reverse osmosis (RO) and ultrafiltration (UF) membranes(Liu *et al*., 2007). Nanofiltration membranes have pore sizes ranging from 0.005 microns to 0.001 microns. NF removes multivalent ions and small molecules in the nanometer range(e.g., sulfate ions**,** sugars) (Wang & Zhou, 2013). NF membranes can fractionate small compounds, such as salts and small organic molecules, and are commonly used to permeate monovalent ions while retaining divalent ions (Wang & Zhou, 2013). In NF processes, salts with divalent anions(e.g., sulfate) have rejection rates in the range of 90% to more than 99% while salts with monovalent anions (e.g., sodium chloride) have rejection rates of 20-80% (Wang & Zhou, 2013). Solvent-resistant NF membranes are also used to separate organic compounds in an organic solvent (Wang & Zhou, 2013).

The operating pressures of NF processes are typically in the range of 50-225psi (Wang & Zhou, 2013). Their advantages over RO membranes in water and wastewater treatment include low operation pressure, high permeation flux, relatively low capital cost and low operation and maintenance cost (Liu *et al*., 2007). Because NF membranes have a very good separation of monovalent ions from multivalent ions and a very sharp molecular weight cut-off (MWCO), they have been used in many industrial applications in the dye, speciality chemicals and pharmaceutical industries and so on (Liu *et al*., 2007).

2.9.4 Reverse osmosis

RO employs the tightest membranes for liquid separation (Wang & Zhou, 2013). The reverse osmosis membranes do not contain pores and they operate mainly by a solutiondiffusion mechanisms (Coulson *et al*., 1991). Dissolved salts, inorganic solutes, and organic solutes with molecular weight greater than approximately 100daltons are rejected by RO membranes; water is able to pass through RO membranes (Wang & Zhou, 2013). Rejection of dissolved salts such as sodium chloride by RO membranes is typically 95-99.8% (Wang & Zhou, 2013). The operating pressures of RO processes are typically in the range of 100-1000 psi(Wang & Zhou, 2013). Examples of RO membrane applications include brackish water and seawater desalination, wastewater treatment, and the production of high-purity process water for industrial applications (Seader & Henley, 2006; H. Wang & Zhou, 2013).

RO has many advantages over other desalination techniques, including low energy requirements, low operating temperature, small footprint, modular design, and low water production costs (Kim et al., 2012). However, a stringent pretreatment is required to ensure high performance of RO membranes (Kim *et al*., 2012). RO can also effectively remove bacteria and viruses. RO is particularly effective when used in series with multiple units (Coulson *et al*., 1991).

2.10 Partial pressure membrane processes

Partial pressure membrane processes include pervaporation, gas separation and vapour permeation. The transport of materials in these processes are due to their partial pressure difference.

2.10.1 Pervaporation

Pervaporation among membrane processes is still considered to be a developing membrane technology (Wee *et al.*, 2008). In pervaporation a liquid feed is passed over the membrane surface and one component is able to pass through the membrane preferentially (Chapman *et al*., 2008a). The feed to the membrane is usually at a temperature close to that of its saturation temperature and this combined with the underside of the membrane being held under vacuum causes the liquid passing across the membrane to vaporize (Chapman *et al*., 2008b). The application of pervaporation includes solvent dehydration, separation of azeotropic mixtures, mixture of closed boiling point component and heat-sensitive products (Chapman *et al*., 2008; Coulson *et al*., 1991).

Overall permeabilities of species depend upon their solubilities in and diffusion rates through the membrane (Seader & Henley, 2006). Separation by pervaporation is almost independent of the vapor-liquid equilibrium, because the transport resistance depends on the sorption equilibrium and mobility of the permeate components in the membrane(Wee *et al*., 2008). Both porous and non porous media is used for pervaporation separation.

Polymer membranes such as polydimethylsiloxane, polyvinyl alcohol and polyimide are exploited in this membrane technology. Ceramic membranes such as reported. Zeolite A, titania and ziconia have also been reported (Wikipedia 2014).

2.10.2 Gas separation processes

The gas mixture is directed at the membrane medium where permeants are collected at the other side of the membrane. Here, unlike pervaporation, the same phase exits on both sides of the medium. Gas transport through membranes is based on Knudsen flow, sorption, molecular sieving and solution-diffusion. Dense or nanoprous medium is largely used for GS processes. Membranes made of polymers and copolymers in the forms of flat film or hollow fibers have been used for gas separation (Raavanchi *et al*., 2009). Common polymer membranes applied in GS are polysulfone, and polyether sulfone, carbon membranes from polyvinylidene chloride, polyimides, polyfurfuryl alcohol and phenolic resins are also exploited. GS for various applications has utilized inorganic media. Examples of commercial porous inorganic membranes are ceramic membranes, such as alumina, silica, titanium, and glass and porous metals, such as stainless steel and silver. Dense inorganic medium based on Pd metal and oxide have also been used. The most important use of gas permeation is in the separation of hydrogen from carbon monoxide, methane or nitrogen (Coulson *et al*., 1991c). Membrane permeation may also be used to separate carbon dioxide, hydrogen sulfide and water from natural gas (Coulson *et al*., 1991d). Substantial potential uses are the production of oxygen-enriched air for medical and furnace applications, and of nitrogen

–enriched air for the blanketing of fuels and stored foods (Coulson et al., 1991) .

2.11 Dialysis

Dialysis is a purely concentration driven membrane process. In a dialysis membraneseparation process, the feed is a liquid, at pressure, containing solvent, solutes of type **A**, and solutes of type B and/or insoluble, but dispersed colloidal matter. A sweep liquid or wash of the same solvent is fed at pressure to the other side of the membrane. The membrane is thin with micropores of a size such that solutes of type **A** can pass through by a concentration driving force. Solutes of type **B** are larger in molecular size than those of type **A** and pass through the membrane only with difficulty or not at all. Dialysis is attractive when the concentration differences for the main diffusing solutes are large and the permeability differences between those solutes and the other solute(s)and/or colloids is large (Seader & Henley, 2006). Diffusion dialysis has advantages, particularly from the point of energy consumption during its application (Akgemci *et al*., 2005). In the process, an external force is not required to promote separation, energy is only necessary to pump the feed and receiver solutions into the compartments (Akgemci *et al*., 2005). Its application includes removal of wastes in blood, treatment of waste water and purification of pharmaceutical products. Homogenous membranes have been largely exploited in this process.

2.12 Electrodialysis

Electrodialysis(ED) refers to an electrolytic process for separating an aqueous, electrolyte feed solution into a concentrate or brine and a dilute or desalted water (diluate) by means of an electric field and ion-selective membranes (Seader & Henley, 2006). This process has been widely applied to treat brackish water for potable use or to desalt and concentrate effluents for reuse (Arar *et al*., 2013). ED is also considered to be efficient treatment technology used for treatment of acidic waste effluents (Akgemci *et al*., 2005; Sirkar, 1997). In a typical ED cell, a series of anion and cation exchange membranes are arranged in an alternating pattern between an anode and a cathode to form individual cells or compartments. The process feed is pumped through the solution compartments (Choi *et al*., 2013; Coulson *et al*., 1991). When a direct current potential is applied between two electrodes, positively charged cations move toward the cathode (Choi *et al*., 2013; Coulson *et a*l., 1991; Seader & Henley, 2006), pass through the negatively charged cation-exchanged membrane and are retained by the positively charged anion-exchanged membrane(Choi *et al*., 2013). On the other hand, negatively charged anions move toward the anode pass through the positively charged anionexchange membrane and are retained by the negatively charged cation-exchange membrane (Choi *et al*., 2013). The net result is ion depletion and ion concentration in alternate compartments (Coulson *et al*., 1991).

2.13 Membrane distillation

Membrane Contactor technology offers a powerful tool for inter phase mass transfer (Curcio & Drioli, 2005) based on the principles of phase equilibria (Curcio & Drioli, 2005; Gryta, 2006). In membrane distillation(MD) there is a thermally driven vapor transport through non wetted porous hydrophobic membranes, where the driving force is the partial vapor pressure difference across the two sides of the membrane pores (Francis *et al*., 2013). The microporous hydrophobic membrane comes in contact with an aqueous heated solution on one side (feed or retentate (Chunrui *et a*l., 2010; Curcio & Drioli, 2005). The hydrophobic nature of the membrane prevents mass transfer in liquid phase and creates a vapour-liquid interface at the pore entrance (Curcio & Drioli, 2005). Here, volatile compounds evaporate (Curcio & Drioli, 2005; Gryta, 2006), diffuse and/or convect across the membrane pores, and are condensed and/or removed on the opposite side (permeate or distillate) of the system (Curcio & Drioli, 2005). The other side (the permeate side) may be brought into contact with four different phases. They are aqueous solution, sweeping gas, stagnant air gap plus a cold plate and a vacuum volume (Chunrui *et al*., 2010).

The important applications of MD process can be found in the water treatment technology, seawater desalination, and the concentration of aqueous solutions (Gryta, 2006) and azeotropic separations (Curcio & Drioli, 2005). MD membranes are made of hydrophobic synthetic material (e.g. PTFE, PVDF or PP)

2.14 Microfiltration process for water purification

Membrane technology is widely accepted as a means of producing various qualities of water from surface water, well water, brackish water seawater, (Bodzek *et al*. 2011) municipal and industrial wastewater treatment, and groundwater (Al-Shammari *et al*. 2012). Microfiltration (MF) membranes have been widely applied in drinking water treatment for the removal of particles, turbidity, and microorganisms from surface water and groundwater (Hakami, *et al.*, 2013; Saed, *et al* 2004). MF have turned out to be the most suitable methods, for pretreatment before desalination, removing suspended substances, some organic compounds and microbiological pollution (Bodzek *et al*., 2011). MF has proved to be attractive methods for the pretreatment of RO and NF water feed. Compared to conventional pretreatments, membrane-based pretreatment exhibited a higher NF flux(Lee *et al*., 2006). Their widespread use might be due to several factors including an increase in number and stringency of water quality regulations that cannot effectively be met by conventional treatment (Bottinoa *et al*., 2001). Microfiltration could provide a number of advantages including superior water quality, easier control of operation, lower maintenance, and reduced sludge production (Hakami *et al*., 2013).

Both pressurized and gravity-fed systems are considered (Jang *et al*. 2010). Some applications, such as groundwater and pretreatment to reverse osmosis (RO) systems are typically better suited for pressurized configurations (Al-Shammari *et al*., 2012). Submerged membranes had successfully replaced the settling clarifie r(Al-Shammari *et al*., 2012).

Microfiltration methods such as UF are not effective for the removal of anion micro pollutants (nitrates, fluoride, boron, chlorides, etc.). However, the method becomes more effective when combined with coagulations, that is, complexing of the ions in the mixture using polymers. nitrates and boron in water have been effectively removed by MF and UF with complexing polymer (Bodzek *et al*., 2011). The retention coefficient for nitrate using the latter method was more than79% (Bodzek *et al*., 2011).

MF can be used to remove heavy metals such as lead, mercury, selenium,iron, nickel, manganese, copper, cobalt, cadmium, zinc, chromium and others usually present in drinking water. MF membranes are used to remove only part of arsenic forms from water, mainly by means of integrated systems with coagulation and flocculation. The removal of As from water with membranes of pore size 0.22μm and 1.22μm using ferric coagulants and polymeric cationic flocculants has been reported. As removal was found to be more effective for hybrid systems than for single MF, according to the adsorption of As on coagulation flocks and separation of those flock by MF membrane. Iron and manganese can be removed in a modern way from underground waters by combining oxidation with air and microfiltration, in particular when the concentrations of these metals are high and changing. The advantage of the system is the production of water with high quality regardless of raw water quality and compact nature of the equipment . This MF technique is able to reduce Fe and Mn from 10mg/L and 5mg/L to less than 0.1mg/L and 0.05mg/L respectively. Its turbidity removal is from 10-500NTU to 0.01NTU(Bodzek *et al*., 2011). Oxidation processes at pH 8 followed by microfiltration produced permeate containing iron at concentrations below 0.3 mg/L (Setyadhi & Liu, 2013). The removal of Cu(II), Ni(II),Zn(II) and Pb(II) in water and wastewater has also been effective by combining MF with coagulations or membrane ion exchange.

Membrane processes, such as microfiltration (MF) and ultrafiltration (UF), are not effective in removing dissolved and synthetic organic compounds. Thus, addition of powdered activated carbon is suggested to enhance the removal of organic matter in seawater (Eusebio *et al*., 2011). The combination of MF with the carbon materials does not only improve the water quality, but also facilities hydrodynamic performance of the entire process. Studies showed that the coupling of microfiltration with flocculation using aluminium polychloride increased the rate of filtration rate by more than 200%(Saed *et al*., 2004). Other studies have shown that coupling of microfiltration with adsorption process using activated carbon caused the increasing of permeate flux and reducing fouling of the membrane. (Saed *et al*., 2004).

The turbidity of water is caused by the presence of suspended mineral and organic molecules of different sizes (colloids, coarse and fine suspensions). Usually, microfiltration or ultrafiltration are applied to decrease water turbidity to the level below 1 NTU (Bodzek *et al*., 2011). Water which contains microorganisms i.e., viruses, bacteria, protozoa and others (fungi, algae, snails,worms and crustacea) may cause many negative health effects. MF and UF are effective in removal of bacteria and protozoans in water and waste water. Standards set by World Health Organisation for E.coli, coliform and total coliform concentrations in drinking water are shown in Table 2.10. Also in the same table 2.10, allowable concentrations of heavy metals and other water quality parameters such as alkanity, nitrates, fluorides, total dissolved solids, hardness, total suspended solids, conductivity, etc. are found.

Table 2.10: Drinking Water Standards

Parameter	Drinking water satandards	Source
pH	6.5-8.5	GSA/WHO
TDS(mg/L)	<1000	GSA/WHO
TSS(mg/L)	50	GSA

Conductivity(μS/cm)	5-500	GSA
Turbidity(NTU)	5/<1	GSA/WHO
Alkanity	150	GSA
Lead(mg/L)	0.01/0.05	GSA/WHO/EPA
Iron(mg/L)	0.3/2	EPA/WHO
Copper(mg/L)	1.3/2	EPA/WHO
Cadmium(mg/L)	0.003	EPA/WHO
Zinc(mg/L)	5/3	EPA/WHO
Manganese(mg/L)	0.1/0.4	EPA/WHO
Sulfate(mg/L)	250 /400	GSA/WHO
Chloride(mg/L)	250	GSA/WHO
Phosphate(mg/L)	400	WHO
Ammonia(mg/L)	1.5	GSA/WHO
Total hardness(mg/L)	500	GSA/WHO
Coliform(faecal colifrom)(CFU/100mL)	0	WHO/GSA
E.coli(CFU/100mL)	0	WHO/GSA
Total coliform(CFU/100mL)	0	WHO/GSA

(Achisa, 2013; Akorli, 2012)

CHAPTER THREE

METHODDOLOGY

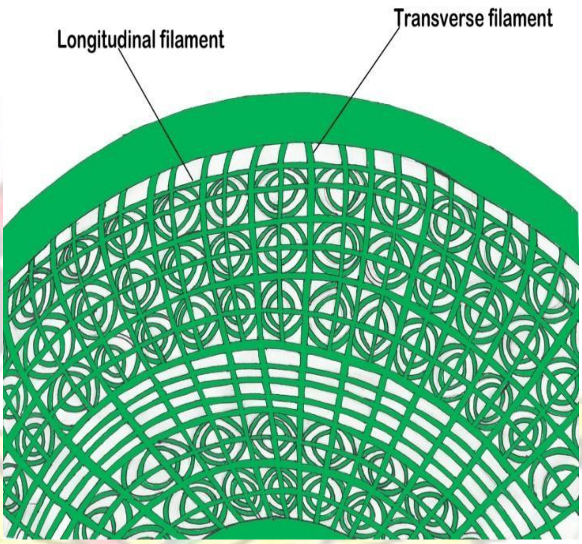
3.1 Membrane material (fabric) selection

Five (5) woven synthetic fabrics were selected for microfiltration for river source water treatment. Their selection was based on the physical examination of the porous nature of the fabrics, their strength, and microbial and chemical resistance. Three of the five fabrics were known to be made of polyester and the other two were tagged as X and Y fabrics. However, two of the three polyester fabrics were weaved locally and dubbed local twill weave polyester (LTW POL) and local plain weave polyester (LPW POL)

3.2 Spacer selection

The commonly used spacer for membrane modules is flatsheet mesh. Different shapes of mesh spacers are available; the common ones are ladder, triangular and spherical polymeric mesh. A basket lid from polymeric material was selected. It has circular longitudinal filaments, and vertical transverse filaments from the edge to the center. The basket lid has a diameter of 50 cm. The side view of the spacer and structure are shown in the Figure 3.1. The selection of the basket lid was because of its strength, availability and ease of use in construction.

(a)



(b)

Figure 3.1: (a) Side View of Single Basket Lid as Spacer, (b) Structure of the Basket Lid

3.3 Sealant Selection

The important properties of the sealants are resistance to temperature, water and other chemicals. The sealant must also be non-toxic. RTV silicone and polyurethane were selected.

3.4 Module and tank fittings selection

The following fittings were selected for the construction of the module and tank. The fittings as shown in Figure 3.2 are valve (size diameter 1.27 cm), flexible tube, which has a diameter of 1.27 cm and length of 45cm, and tank connectors of size 1.27 cm .

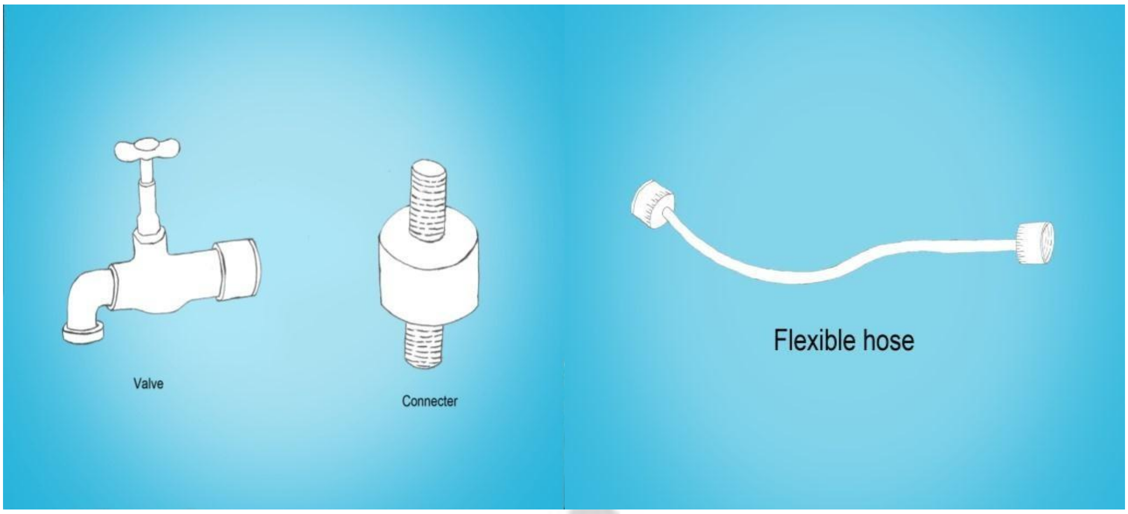


Figure 3.2: Module and Tank Fittings

3.5 Fabrics identification

Technical tests such as burn, microscopic appearance and acid/basic effects tests were carried out on the known (polyester) and unknown (X and Y) fabrics. The purpose of these tests was to identify X and Y fabric thus establishing their fiber chemistry and internal structure.

3.5.1 Burn test:

Procedure For each fiber sample, five or more strings were held with tweezers and a lit candle was used to burn the strings. The characteristic odour and ash for each fiber type were noted in addition to the peculiar behaviour when nearing the flame, in the flame and out of the flame.

3.5.2 Acid and Alkali Test:

Procedure

Acid effect test

Three pieces (samples) of equal size (2.5‖x2.5‖) were cut, weighed and placed in a 250ml beaker. 5ml of 70% sulfuric acid (reagent) was added and the mixture was left to stand for ten (10) minutes. Each beaker was then shaken to observe the solubility of the fabrics in the reagent.

Alkali effect test

For alkali effect test, the reagent for dissolution was 70% sodium hydroxide instead of sulfuric acid. Similarly fabrics samples were cut weighed and placed in a 250ml beaker. 5ml of 70% sodium hydroxide solution was added and the mixture was left to stand for 10 minutes. Each beaker was then shaken to observe the solubility of the fabrics in the sodium hydroxide solution.

3.5.3 Microscopic Appearance of fibers:

Procedure

A sample of each fabric (2-3 strings) was placed on the cleaned specimen slide. The microscope was set at a magnification of 100 microns (x10) and the image was viewed on the PC screen. The procedure was repeated for bulk strings of fabric.

3.6 Pore diameter measurement of fabrics

Following the identification of X and Y fabrics through the three (3) technical tests, the pore size (diameter) of polyester (POL), nylon (Nyl), nylon 2 (Nyl2), local plain weave polyester (LPW POL) and local twill weave polyester (LTW POL) was measured as:

A sample of each fabric was placed on the cleaned specimen slide. The microscope was set at a magnification of 100 microns (x10) and the image was viewed on the PC screen. The pores of the fabrics were determined using Image J software. Details of the use of Image J software is shown in appendix B.

3.7 Module construction

Modules were constructed from polyester (POL) and nylon (Nyl) fabric. 5 modules were constructed as follows:

3.7.1 Spacer construction

The two basket lids were joined together by applying the RTV silicone sealant. Figure 3.3 shows the spacer configuration.

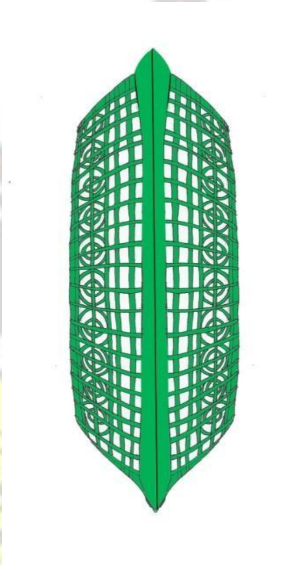


Figure 3.3: Side View of Two-Basket Lid Glued Together As Spacer

3.7.2 Circular Sheet Woven Fabric Filter (CSWFF)

Two (2) circular sheet filters were constructed from each fabric material. Two circular leaves of (diameter) 53 cm were cut from the membrane material. RTV silicone was applied to the edges of the leaves. The two leaves were sealed to half of the circumference. It was then allowed to dry for three days. The 50 cm diameter spacer was inserted into the fabric bag and sealed to 95% of the entire circumference. Following this, a half inch hole was cut at one side of the fabric bag. A tank connector was then fitted, with appropriate gaskets on each side of the connector to prevent leakage. The filter was finally sealed and dried with open air. 45 cm length flexible hose made of polyeutharane was connected to be used as permeate exit hose. Figure 3.4 shows the module configuration

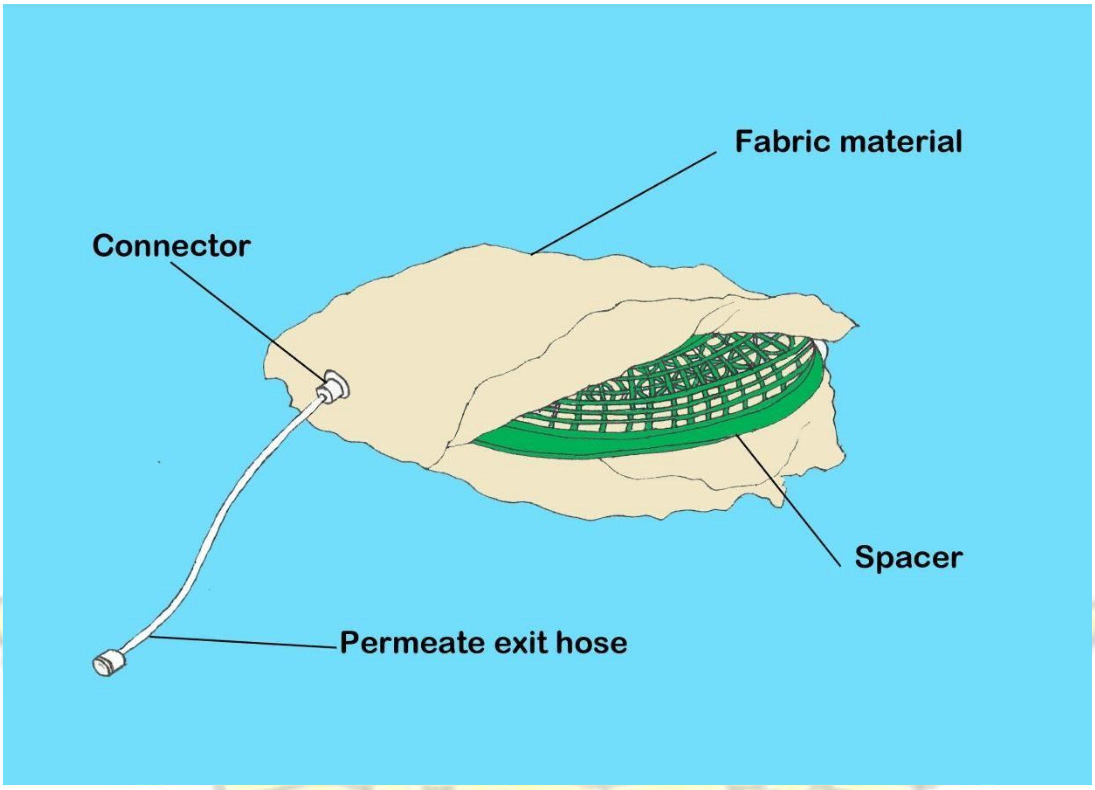


Figure 3.5: Circular Sheet Woven Fabric Filter (CSWFF)

3.7.3 Woven fabric activated carbon filter (WFACF)

It was constructed from the polyester (POL) fabric. The construction was similar to the CSWFF as described in Figure 3.5, however, the module gross diameter was 32cm, and 29cm diameter spacer was constructed by packing 447.4g activated carbon of 8mm size produced from bamboo. The WFACF module is shown in figure 3.6.

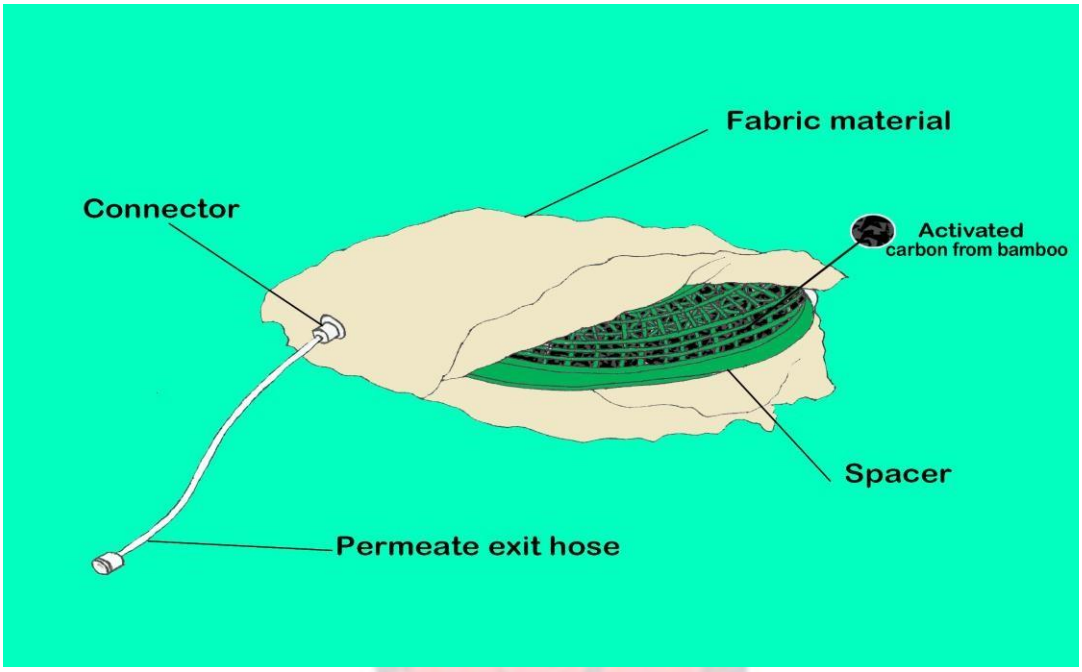


Figure 3.6: Woven Fabric Activated Carbon Filter (WFACF)

3.7.4 Symmetric fabric frame filter (SFFF)

This was constructed from the nylon (Nyl) fabric. A frame made of PVC was used as a substrate. Two rectangular leaves of the same size as the frame were cut from the NyL fabric. RTV silicone was applied to the surface of one side of the frame. One leaf was placed on this side and sealed. It was then allowed to dry for about 6 hours at average temperature of 30^{o}C. Similarly silicone was applied to the other side for sealing. However, a small area was left for the fitting connection. A half inch hole was cut at one side of the leave. The connector was then fixed and the small area was sealed. The Figure 3.7 shows SFFF module.

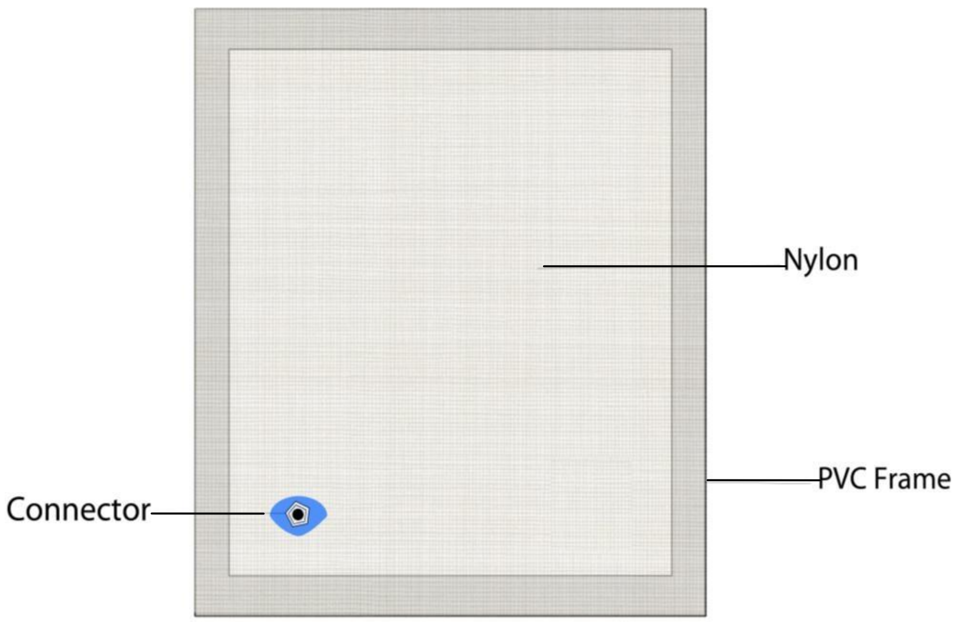


Figure 3.7: Symmetric Fabric Frame Filter (SFFF)

3.7.5 Composite fabric frame filter (CFFF)

This was constructed from both the NyL and POL fabrics. The construction was the same as asymmetric fabric frame filter. The only difference was the use of the fabrics, nylon and polyester. Nylon was placed on polyester and sealed with Polyurethane. The CFFF is shown in Figure 3.8

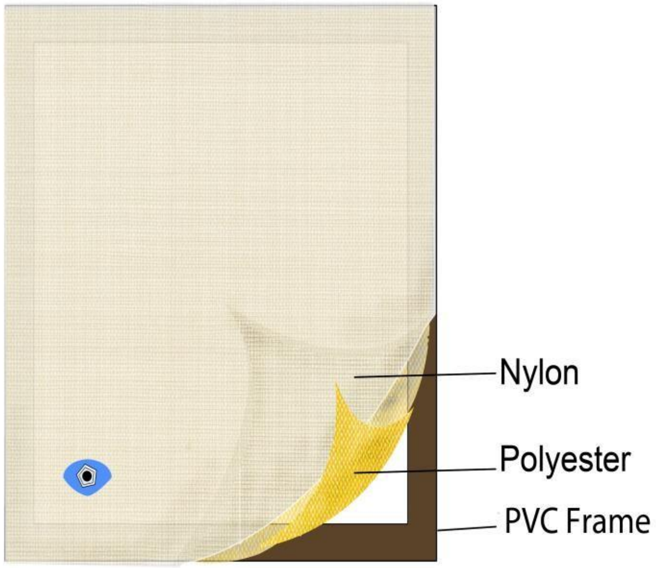


Figure 3.8: Composite Fabric Frame Filter (CFFF)

3.8 Water treatment system construction

Two holes opposite to each other were drilled at the lower part of a 100 L capacity cylindrical tank made from PVC, shown in Figure 3.9, one for the permeate exit valve and the other for the feed drainage valve. The two valves were fitted into the tank through the tank connectors; with appropriate RTV silicone sealant gaskets to prevent leakages.

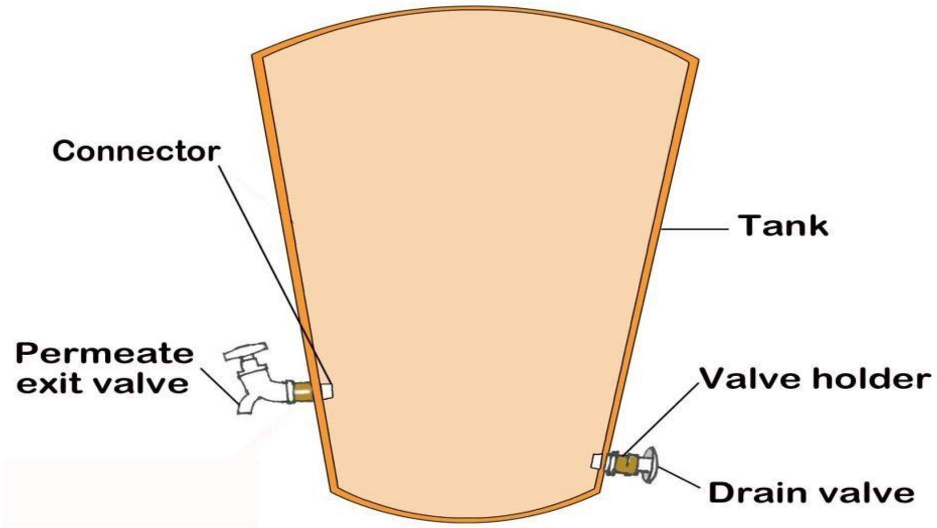
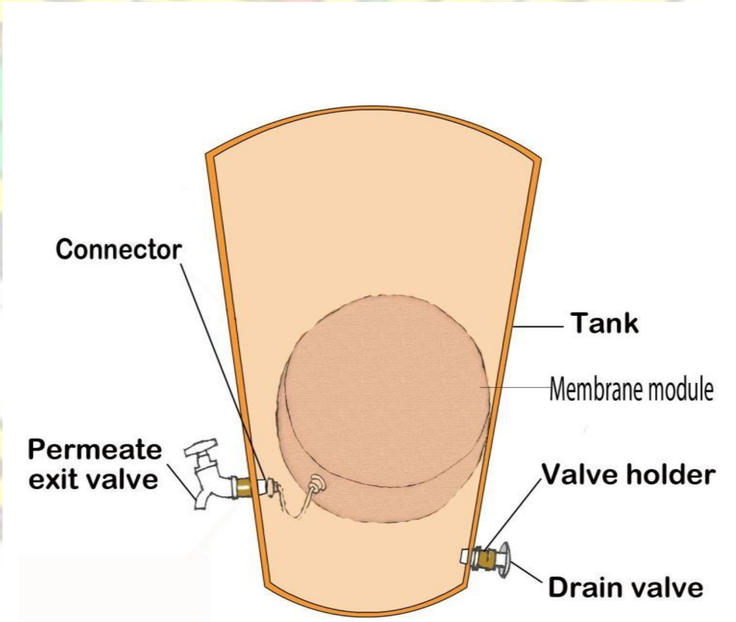
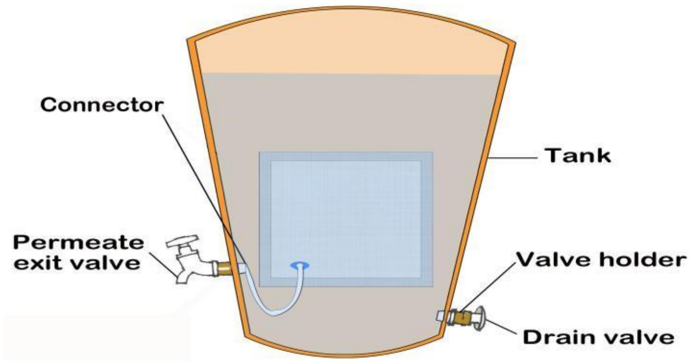


Figure 3.9: A 100L Cylindrical PVC Tank And Fittings

The module was placed in the tank, and the permeate exit hose was connected to the tank exit as shown in Figure 3.10.



(a)



(b)

Figure 3.10: Water Treatment Systems:(a) with CSWFF, (b) with CFFF

3.8.1 Modules and tank leak test

Module leakage: The five membrane modules were tested for leakage. The module (filter) was immersed in a pool of water. The module was filled with air through the permeate exit hose. The exit was closed and the module was immersed in water again.
Following this, observation was made to record any leakage.

Other leakages: the 100*L* (polyvinyl chloride)PVC tank was filled with piped water. Observation was made to record any leakage from the valves.

3.9 Collecting the raw water

Barrels for collecting water samples were washed thoroughly with detergent and rinsed several times with tap water. They were then rinsed with 10% HCl and finally rinsed with distilled water. The raw water was sampled at two locations; Ghana Water

Company Limited (GWCL) Mampong dam and river Offin near Domieabra all in Ashanti region. Raw water from river Offin was collected at various points using similar techniques on how rural residents fetch water from streams. Usually they fetch at locations where water appears to contain least suspended matter. And also facing upstream of the river. At the Mampong dam, the raw water was fetched from the top part (surface) of the dam because of safety reasons.

3.10 Raw water treatment

3.10.1 Raw water treatment with CSWFF-POL, CSWFF-Nyl , WFACF-POL, SFFF-Nyl and CFFF-POL/Nyl filter media

The water tank was washed thoroughly with liquid soap and rinsed several times with tap water. The raw water to be treated was used to rinse the tank two times. The filter to be used was also cleaned and tested for leakage. The leakage-free filter was attached to the inner side of the tank connector and the tank was filled with 70 L of raw feed water. Samples of the feed were taken into sterilized bottles for microbiological, physical and chemical, and heavy metals analyses. The permeate exit valve was then opened to allow permeate (filtrate) to flow. Samples of the permeate were taken after 5-10 minutes for analyses. For each treatment 1-2 sample were taken for analyses. CSWFF and WFACF media were used in 1st and 2nd batch water treatment (WT) whilst SFFF and CFFF media for only 2nd batch WT.

3.10.2 Gravity filtration (GF)

The POL sample was placed inside the plastic funnel which was then placed in the neck of the plastic bottle. The raw water was poured slowly and carefully (at constant flowrate) into the funnel taking care not to fill the funnel above the edge of the POL filter. The receiving bottle was labeled for microbiological, physical and chemical and heavy metals analyses. The procedure was repeated for NyL fabric. However, in the 2nd batch WT, it was extended to POL/Nyl medium

3.10.3 Aquatab water treatment.

Aquatab water treatment is one of the household water treatment systems (HWTS) in developing coutries such as Ghana, Tanzanai, Cambodia,etc. Aquatab chemical primary serves as disinfectant:it kills bacteria and protzoans in water. The purpose for this treatment was to test the performance of the constructed filter media when they are combined with aquatab chemicals.

Water treatment with aquatab

20 liters of raw water was mixed with 2 tablets of aquatab in 25L capacity barrel. The mixture was thoroughly shaken. After 30 minutes, samples were fetched and labeled for analyses. The procedure was repeated for 2nd batch water treatment. Similarly, 20 liters of treated water (product) from CSWFF-POLwas mixed with one tablet of aquatab in the barrel. It was then thoroughly shaken. After 30 minutes samples were fetched and labeled for analyses. The procedure was repeated for 2nd batch water treatment. However in this treatment it was extended to CFFF-POL/Nyl medium.

3.11 Chemical, physical, microbiological and heavy metal analyses

3.11.1 Determination of heavy metals:

100ml of the sample was measured into a cleaned and sterilized 250 ml beaker. 5ml and 2ml of HCl(hydrochloric acid) and HNO_3 (nitric acid) respectively were added to the sample. The beaker was placed on a hotplate and heated to between 90°C and 95°C until only 20ml of the sample was left. It was allowed to cool and diluted with deionised water to 100ml capacity. It was then transferred to reagent bottle and labeled for AAS analysis. All samples for AAS analysis followed the above procedure.

Preparation of standards for calibration curves

Lower concentrations were prepared from 1000ppm stock solutions of the metals (Fe,Cu,Zn, Pb,Mn, Cd,). The lower concentrations were prepared based on the linear range which is dependent on the wavelength for each metal. Table A5 of appendix A indicates the linear range of the metals.

Absorbance measurement

Standard samples and digested samples were anlysed by Atomic Absorption Spectrophotometer (AAS). For each sample, the flame analysis method was used to measure the absorbance of Fe, Zn, Cu, Cd, Mn and Pb . Three absorbance values were recorded for each measurement.

3.11.2 Determination of pH

In the laboratory, pH meter (HANNA model 209) was used to determine the pH of water samples. About 50ml of water sample was poured into a clean glass beaker and the electrode inserted into it. The button selector of the pH meter was turned and the pH was read and recorded. This was repeated three times for all other water samples.

3.11.3 Determination of alkalinity pH meter (HANNA model 209) and titration method were used to determine alkalinity of water samples. 50.0 mL of water sample was measured and transferred into a beaker. The probes of the pH meter were placed into the water sample. The sample was titrated with (0.02N) sulfuric acid solution while watching the resulting changes in pH. The titration continued until the pH reaches the endpoint of pH 4.5. The total alkalinity was calculated as shown below:

Alkalinity = Volume of acid used X 20

3.11.4 Determination of Total Dissolved Solids

A multifunctional HANNA meter (model HI 9032) was used to determine the total dissolved solids of water samples in the laboratory after calibration.

About 50ml of water sample was poured into a clean glass beaker. The electrode was then immersed into the sample and stirred to ensure uniform mixture. After the reading stabilised the value was read and recorded in mg/L.

3.11.5 Determination of Conductivity

Conductivity meter (HANNA model HI 9032) was used to determine the conductivity of water samples in the laboratory. It was calibrated by using standard sodium chloride solution of 12880 µS/cm. The conductivity meter was then returned to the operation mode for measurement.

About 50ml of water sample was poured into a clean glass beaker and the conductivity meter electrode was then inserted into the water. The value was read and recorded after five (5) minutes in µS/cm. The same procedure was repeated three times for all other water samples.

3.11.6 Determination of Turbidity

Turbidity of water samples was determined with HACH turbidimeter (model CO 150).

The turbidity meter was first calibrated with Formazin standard solutions of 0.2 Nephelometric turbidity units (NTU), 10 NTU, 100 NTU and 1000 NTU by filling consecutively a clean dry cuvette with the well mixed standard solutions. It was then returned to the measurement mode and used.

A clean dry cuvette was rinsed three times with the water sample to be tested. The cuvette was filled with the water sample to be analysed and then covered with light shield cap. The outer surface of the cuvette was wiped dry with a clean tissue paper. It was then pushed firmly into the optical well and the lid closed.

3.11.7 Measurement of total suspended solids:

A clean dried filter paper was weighed and inserted into a filter funnel. 50ml of sample was filtered through the filter paper and the filter medium was rinsed three times with distilled water (100ml in each case). The filter paper was removed, dried at room temperature for approximately 4 hours and weighed.

Total suspended solids (TSS) in mg/L was calculated as detailed below:

$$\text{mg Suspended Solids / L} = \frac{(A - B) \times 1000}{mL(sample)}$$

where:

A = weight of filter + dried residue, mg

B = weight of filter, mg

3.11.8 Determination of Total coliforms, e. coliforms and coliforms(faecal coliforms)

Membrane Filtration Method m-ColiBlue24® Broth

100 mL volume of sample was filtered through a 47-mm membrane filter using standard techniques. The filter was transferred to a 50-mm petri plate containing an absorbent pad saturated with m-ColiBlue24 broth. The filter was incubated at 35°C ± 0.5 °C for 24 hr. m-ColiBlue24 Broth is a nutritive,lactoseased medium, containing inhibitors to selectively

eliminate growth of non coliforms . Total coliform colonies growing on the medium are highlighted by a non-selective dye, 2,3,5-Triphenoltetrazolium Chloride (TTC) which produces red colored colonies.Among the total coliform colonies which grow up on the medium, any *E. coli* colonies are distinguishable by a selective blue color, resulting from the action of b-glucuronidase enzyme on 5-Bromo-4-Chloro-3Indolyl-Beta-D-glucuronide (BCIG). For fecal coliform test the filter was incubated at

44.5° (+/-0.2°) C.

Before testing the water samples, all the Petri dishes, pipette tips, and measuring cylinders were sterilized by boiling in water for 10 to 15 minutes and left to cool at ambient temperature before use. Isopropylene was used to clean all working surfaces. The forceps were flame sterilized (by candle flame) before every use. The portable filtration unit was sterilized by soaking the wick attached to its lower plate with methanol, igniting the methanol and immediately capping the filtration unit. The methanol ignition produces formaldehyde, which sterilizes the unit. The unit was left closed for 15 minutes for effective sterilization to take place.

Interpretation of results

The presence of red and blue colonies indicated the sample had total coliforms, while blue colonies indicated *E.coli*. The absence of red or blue colonies indicated that the sample contained no total coliforms or *E.coli*. The fecal coliform colonies appeared blue in color, while non-fecal coliform colonies appered gray.

The coliform density was directly given by the number of coliforms counted based on the formula below:

$$CFU\ /100ml = \frac{\square\square 100}{V}$$

Where:

N = the number of colonies counted;

V = the sample volume in ml.

In cases where no colonies were observed, the coliform colonies were reported as 0 CFU/100ml.

Table 3.1: Materials for tests and filters construction

Description	**Materials**	**Source**
Burn test	Fiber samples: polyester (Known), X (Unknown), and Y (Unknown), matches, a pair tongs	(Kadolph, 2013)
Acid and Alkali test	Fabric samples: polyester, X(Unknown), and Y(Unknown,70% sufuric acid, 70% sodium hydroxide,100ml beakers, 250ml volumetric flask,1 wash bottle, scissors, Analytical weighing balance, distilled water	(Kadolph, 2013)
Microscopic Appearance of fibers	Microscope (LEICA DFC290/PC), Fiber samples: polyester, X (Unknown), and Y (Unknown)	(Kadolph, 2013)
Pore size measurement of fabrics structure	LEICA DFC290/PC, Fabric samples: POL, Nyl, Nyl2, LPW POL and LTW POL	
Module construction	POL and NyL fabrics, RTV silicone, Polyurethane sealant ,Knife, scissors, Tape measure, 2 set polymeric spacer(29cm in diameter), 1 set polymeric spacer(50cm in diameter), 2 PVC frames(33cmX31cm) hand gloves, gun,	

Determination of heavy metals	standards (1000ppm of Fe, Cu, Cd, Pb, Zn, , Mn), AAS, labeled samples(filtrate and feed), conc HCl, conc HNO_3, KMnO4, reagents bottles(100ml, 200ml,300ml, 5L), plastic bowls, beakers(250ml, 500ml, 600ml), volumetric flaks(100ml), measuring cylinders(100ml, 500 ml), corks, watch glass, thermometer, hotplate	

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1.1 Fabrics identification

To establish the fiber chemistry of the unknown fabrics (X and Y), it was necessary to carry out standardized tests to identify their fibers and differentiate them from others. Tables 4.1, 4.2 and 4.3 indicate the results of fabric burn test, acid and alkali (solubility) test and microscopic appearance of fibers test respectively. The results of polyester (known fabric) in tables 4.1, 4.2, 4.3 is strongly mapped to tables 2.3, 2.4, 2,5 in chapter two. X and Y are indentified clearly as synthetic fabrics. The properties and characteristics of fibers of X and Y agree with other synthetic fabrics such as acrylic, nylon, olefin and polyester depicted in table 2.3 , compiled by Kadohph(2013). In table 4.2, fibers of X and Y are soluble in 70% sulfuric acid (strong mineral acid) and insoluble in 70% sodium hydroxide (strong alkali). From table 2.5, acrylic fibre is destroyed by strong alkalies and olefin is insoluble in strong mineral acids. However, nylon is decomposed by strong mineral acids and does not dissolve in alkalies. Therefore, characteristics of X and Y closely match that of nylon. It can be observed that fibers of X, Y and polyester have similar longitudinal characteristic appearances under the microscope. The appearances of X and Y are mapped to nylon, olefin and aramid in table 2.4. It can be deduced that X and Y are identified as nylon as shown in table 4.4

Table 4.1: Fabric Burn Test(Summary)

Sample	*When nearing flame*	*When in flame*	*Out of flame*	*Ash*	*Odour*
Known Polyester	pulls away	burns and melt	burn and self extinguish	hard black bead	sweet odour
Unknown X	pulls away	burns and melt	burn and self extinguish	hard gray-yellowish bead	odour, animal hairlike smell
Unknown Y	pulls away	burns and melt	burn and self extinguish	hard gray-yellowish bead	odour,animal hairlike smell

Table 4.2: Acid And Alkali Test On Fabrics(Summary)

	Acid	
Sample	*Sample weight (grams)*	*Observations*
Known Polyester	0.19000	Insoluble in 70% Sulfuric acid
Unknown X	0.22290	Soluble in 70% Sulfiric acid
Unknown Y	0.05400	Soluble in 70% Sulfiric acid
	Alkali	
Known Polyester	0.19000	Insoluble in 70% Sodium hydroxide
Unknown X	0.22290	Insoluble in 70% Sodium hydroxide
Unknown Y	0.05400	Insoluble in 70% Sodium hydroxide

Table 4.3:Microscopic Appearance Of Fabrics

Sample	*Appearance(single fiber) longitudinal view*	*Appearance (bulk) longitudinal view*
Known Polyester	smooth dark appearance	dark apperance
Unknown X	silver like colour, rod shape	silver-like colour
Unknown Y	dark apperance and rod-like shape	dark apperance

Table 4.4:Fabric Identification

Unknown fabric	Fabric	Weave style
X	Nylon(Nyl)	Twill
Y	Nylon(Nyl2)	Plain

4.1.2 Fabrics pore size

Following the identification of X and Y as nylon, average pores of fabrics was determined and shown in Figure 4.1. The detailed data are shown in Table B1-1 to Table B1-4 in appendix B.

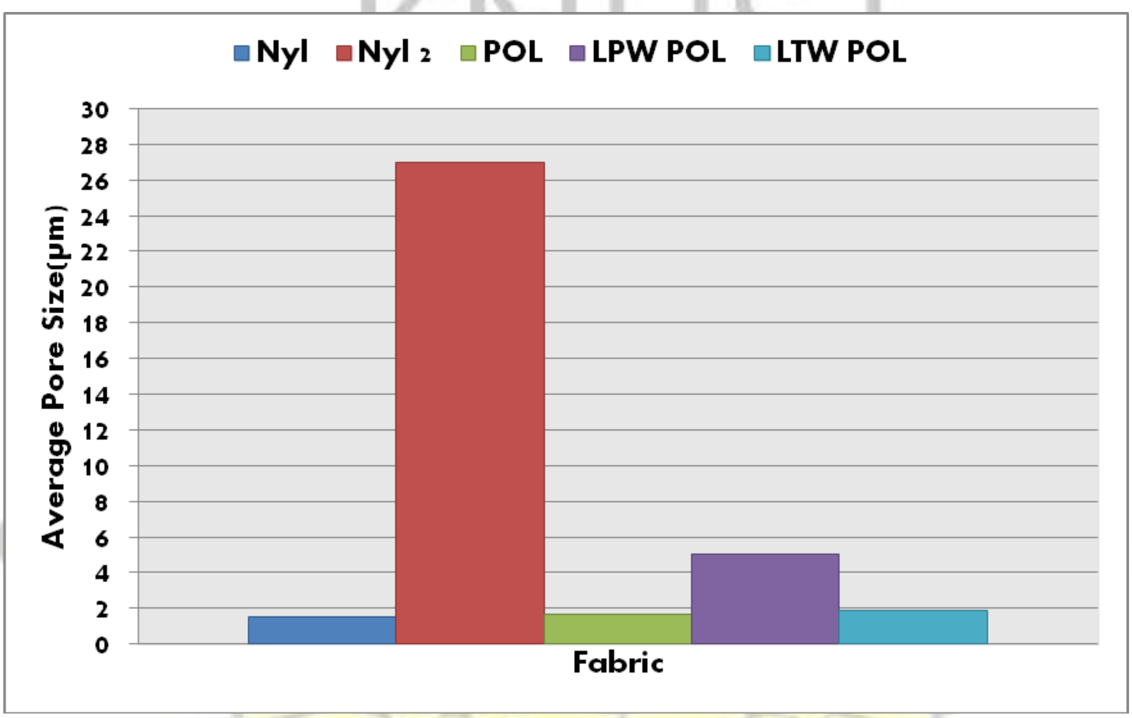


Figure 4.1: Average Pores of Fabrics for Microfiltration

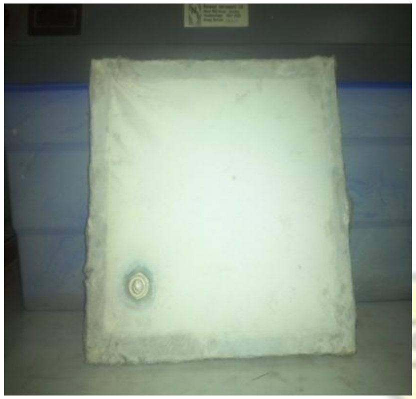
From Figure 4.1, averagely, nylon (Nyl), nylon (Nyl2) and polyester (POL) pores are1.5 µm, 27 µm and 1.7 µm respectively. The pores of local plain weave (LPW POL) and twill weave polyester (LTW POL) are 5µm and 1.9µm respectively. Comparatively all fabrics with the exception of nylon (Nyl2) meet standard pore size range for MF filter media: that is 0.1-10µm (Seader & Henley, 2006; Sirkar, 1997; Wang & Zhou, 2013). Among the four (4) potential MF media, Average pore size of nylon (Nyl) is the finest, followed by the polyester (POL) and twill weave polyester (LTW POL). Therefore, Nylon (Nyl) and polyester (POL) were ultimately selected and used for construction of MF filter media.

4.1.3 Filter media and tank system

Figure 4.12 and 4.13 show the 5 constructed filters and water treatment systems. The detailed engineering design and drawings are shown in appendix B.



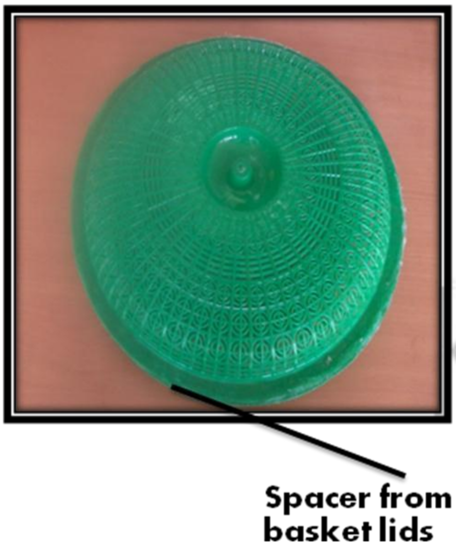
(a) **(b)** **(c)**



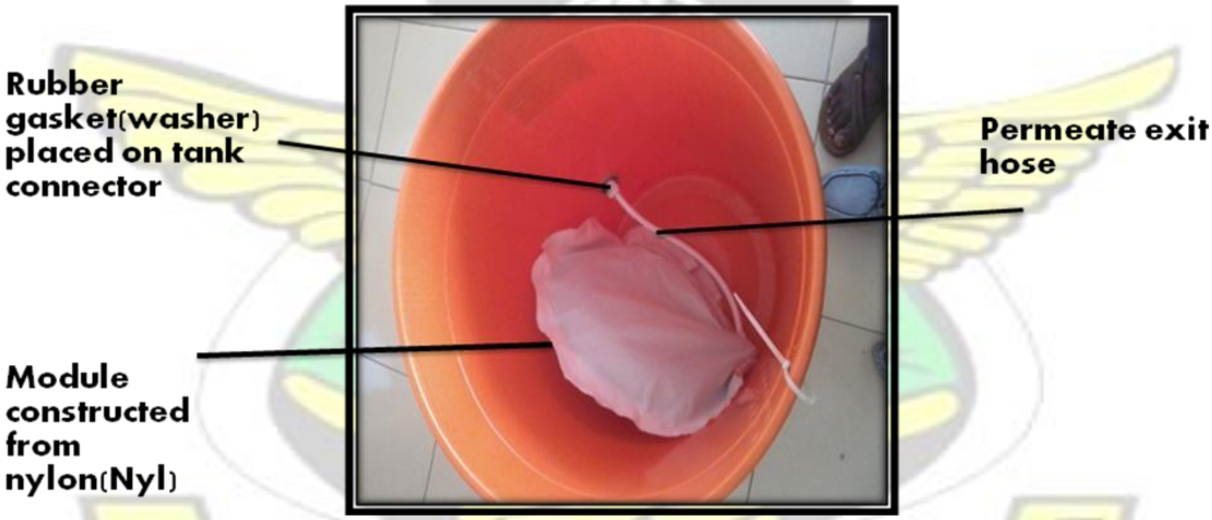

(d) **(e)**

Figure 4.2:(a)Circular Sheet Woven Fabric Filter(CSWFF-Nyl);(b)CSWFF-POL ; (c) Woven Fabric Activated Carbon

Filter(WFACF-POL);(d) Symmetric Fabric Frame Filter(SFFF-Nyl); (e) Composite Fabric Frame Filter (CFFF-POL/Nyl)



(g) (h)



(i)

Figure 4.3 :(g) Spacer; (h) Side View Of Tank System; (i) CSWFF-Nyl Fitted In The Tank System

4.2 Results of water treatment phase

Two batches of raw water from GWCL, Mampong Dam and River Offin were treated. For each filter (module) treatment, feed (raw water) and products (treated water) were sampled for water quality measurement. The parameters determined were turbidity, TDS, TSS,pH, alkalinity, conductivity, presence of heavy metals (Fe, Pb, Mn, Zn,Cd and Cu) and microbiological indicators(coli, ecoli and total coliform). The test for heavy metals in the samples was carried out in Chemical Analyses Lab of Kumasi Polytechnic. TDS, TSS, pH, alkalinity, turbidity and conductivity measurements on samples were conducted in the Water Quality Lab of Coca Cola Bottling Company, Kumasi and Langary Chemicals, Nsawam. Microbiological tests on samples were also perfomed at the Water Quality Lab of Coca Cola Bottling Company, Kumasi.

4.2.1 Comparism of treated water quality with drinking water standards

Tables 4.5, 4.6 represent pH of raw water (feed) and treated water (product) analysed in Coca Cola (CC) Lab and Langary(LAN) Lab. The pH of the treated water (product) varies between 6.0 and 7.4. According to GSA/WHO acceptable pH for drinking water is between 6.5 and 8.5(Akorli, 2012, Achisa, 2013). All treated water (products) with exception of treated water(products) from WFACF-POL and GF-Nyl filter medium, analyzed in CC lab meet the drinking water quality set by Ghana Standards Authority (1998) and WHO(1984). The pH values for products of WFACF-POL were 6.2 and 6.0(Table 4.5 and 4.6). The pH value 6.2 was also determined from the product of GFNyl(Table 4.5), and this is attributed to substantial removal of dissolved solids by the filter(Table 4.9). Similarly, the lower pH values from WFACF-POL medium are due to substantial removal of total dissolved solids (Table 4.9 and 4.10). the pH value 6.2 from the product of the carbon filter could also be linked to leaching of nitric acid which had been used to treat bamboo carbon the first time the filter was used, comparatively the pH value of the raw water(6.6) was closed(Table 4.5). By considering Tables 4.5 , 4.6, in the first batch water treatment, the pH values measured at LAN LAB for the same feed increased significantly. Explicitly, samples for CC LAB were analyzed after a few days they were picked, however, samples for LAN were kept over three weeks. Since these were not stored in refrigerator, the activities of microorganisms increased thus more CO_2 released to form more carbonates.

Tables 4.7, 4.8 show alkalinity values of treated water (product). The alkanity value ranges from 6 to 50mg/L indicating that all products meet drinking water standard on alkalinity which is 150mg/L.

From Tables 4.9, 4.10 the total dissolved solids (TDS) of the treated water (products) range from 40mg/L to 140mg/L. Averagely TDS recorded in CC Lab is higher than those from LAN Lab. TDS is a measure of the amount of material dissolved in water. This material can include carbonate, bicarbonate, chloride, sulfate, phosphate, nitrate, calcium, magnesium, sodium, organic ions, and other ions. Water containing TDS concentrations below 1000 mg/L is usually acceptable to consumers, although acceptability may vary according to circumstances (Bruvold and Ongerth, 1996 cited in Akorli 2012). However, the presence of high levels of TDS in water may be
objectionable to consumers owing to the resulting taste and to excessive scaling in water pipes, heaters, boilers, and household appliances(Akorli, 2012). Water with extremely low concentrations of TDS may also be unacceptable to consumers because of its flat, insipid taste (Bruvold and Ongerth, 1996 cited in Akorli, 2012).

	1st batch water treatment						2nd batch water treatment				
	CC LAB			LAN LAB			CC LAB			LAN LAB	
FILTER	**pH(Feed)**	**pH(Product)**	**pH(#Product)**	**pH(Feed)**	**pH(Product)**	**pH(#Product)**	**pH(Feed)**	**pH(Product)**	**pH(#Product)**	**pH(Feed)**	**pH(Product)**
GF-Nyl							6.80	6.60		7.00	6.64
GF-POL							6.80	6.70		7.00	6.61
CSWFF-Nyl							6.90	6.60		7.00	6.75
CSWFF-POL	7.50	7.10	6.60	7.18	7.15	7.10	6.90	7.00		7.00	6.58
WFACF-POL							6.90	6.40	6.00	7.00	6.66
AQUATT	6.80	7.00		7.24	7.40						
CFFF-POL/Nyl/AQUAT											
CSWFF-POL/AQUAT	6.80	7.30									
GF-POL/Nyl							6.90	6.70		7.00	6.50
SFFF-Nyl							6.90	7.00	6.80	7.00	6.55
CFFF-POL/Ny							6.90	6.50		7.00	6.51

Table 4.5:pH values of raw water(feed) and treated water(product) from Mampong Dam

	1st batch water treatment						2nd batch water treatment				
	CC LAB			LAN LAB			CC LAB			LAN LAB	
FILTER	**pH(Feed)**	**pH(Product)**	**pH(#Product)**	**pH(Feed)**	**pH(Product)**	**pH(#Product)**	**pH(Feed)**	**pH(Product)**	**pH(#Product)**	**pH(Feed)**	**pH(Product)**
GF-Nyl	7.00	6.20		7.26	7.24		7.10	6.70			

GF-POL	7.00	6.80		7.26	7.21		7.10	6.80		6.90	6.83
CSWFF-Nyl	6.90	6.50		7.56	7.33		6.90	6.70	6.70	6.90	6.73
CSWFF-POL	7.10	7.10					6.90	6.80		6.90	6.78
WFACF-POL	6.60	6.20	6.20	7.31	7.00	7.10				6.82	6.60
AQUATT							6.80	6.90		6.82	6.95
CFFF-POL/Nyl/AQUAT							6.80	6.60		6.82	6.70
CSWFF-POL/AQUAT							6.80	7.10		6.82	6.96
GF-POL/Nyl										6.90	6.63
SFFF-Nyl										6.90	6.55
CFFF-POL/Ny							6.90	6.60		6.90	6.72

Table 4.6:pH values of raw water(feed) and treated water(product) from River Offin

					mg/L						
GF-Nyl							17	16		50	45
GF-POL							17	17		50	50
CSWFF-Nyl							17	11		50	45
CSWFF-POL	33	29		45	40		17	16		50	40
WFACF-POL							15	9	6	50	40

AQUATT	33	34		40	45						
CFFF-POL/Nyl/AQUAT											
CSWFF-POL/AQUAT	33	33									
GF-POL/Nyl							15	16		50	45
SFFF-Nyl							15	15	16	50	45
CFFF-							17	15		50	45

Table 4.7:Alkalinity(Alk) values of raw water(feed) and treated water(product) from Mampong Dam

	1st batch water treatement						2nd batch water treatement				
	CC LAB			LAN LAB			CC LAB			LAN LAB	
FILTER	**Alk(Feed)**	**Alk(Product)**	**Alk(#Product)**	**Alk(Feed)**	**Alk(Product)**	**Alk(#Product)**	**Alk(Feed)**	**Alk(Product)**	**Alk(#Product)**	**Alk(Feed)**	**Alk(Product)**
					mg/L						
GF-Nyl	26	18		50	45		11	11			
GF-POL	26	23		50	45		11	11		40	35
CSWFF-Nyl	34	27		40	45		11	11	11	40	35
CSWFF-POL	31	30					11	11		40	30
WFACF-POL	34	27	24	45	40	40				35	35
AQUATT							12	13		35	40
CFFF-POL/Nyl/AQUAT							12	13		35	40
CSWFF-POL/AQUAT							12	13		35	40
GF-POL/Nyl										40	35

SFFF-Nyl			40	35
CFFF-POL/Ny	11	11	40	30

Table 4.8:Alkalinity(Alk) values of raw water(feed) and treated water(product) from River Offin

	1st batch water treatement						2nd batch water treatement				
	CC LAB			LAN LAB			CC LAB			LAN LAB	
FILTER	**Alk(Feed)**	**Alk(Product)**	**Alk(#Product)**	**Alk(Feed)**	**Alk(Product)**	**Alk(#Product)**	**Alk(Feed)**	**Alk(Product)**	**Alk(#Product)**	**Alk(Feed)**	**Alk(Product)**
POL/Ny											
GF-Nyl							90	80		80	65
GF-POL							90	80		80	70
CSWFF-Nyl							90	80		80	70
CSWFF-POL	130	110	80	70	60	60	90	80		80	70
WFACF-POL							80	70	60	80	80
AQUATT	80	90		60	70						
CFFF-POL/Nyl/AQUAT											
CSWFF-											

POL/AQUAT	80	90					
GF-POL/Nyl			80	80		80	80
SFFF-Nyl CFFF-			80	80	80	80	70
POL/Ny			90	90		80	70

Table 4.9:TDSvalues of raw water(feed) and treated water(product) from Mampong Dam

	1st batch water treatement						**2nd batch water treatement**				
	CC LAB			**LAN LAB**			**CC LAB**			**LAN LAB**	
FILTER	**TDS (Feed)**	**TDS (Product)**	**TDS (#Product)**	**TDS (Feed)**	**TDS (Product) mg/L**	**TDS (#Product)**	**TDS (Feed)**	**TDS (Product)**	**TDS (#Product)**	**TDS (Feed)**	**TDS (Product)**
GF-Nyl	150	90		95	60		70	60			
GF-POL	150	140		80	80		70	60		50	50
CSWFF-Nyl	90	90		70	70		70	60	60	50	50
CSWFF-POL	90	80					70	70		50	50
WFACF-POL	110	100	80	70	60	65				60	50
AQUATT							60	80		60	70
CFFF-POL/Nyl/AQUAT							60	70		60	60
CSWFF-POL/AQUAT							60	110		60	75
GF-POL/Nyl										50	40
SFFF-Nyl										50	50

CFFF-POL/Ny							70	70		50	50

Table 4.10:TDSvalues of raw water(feed) and treated water(product) from River Offin

	1st batch water treatement						2nd batch water treatement				
	CC LAB			LAN LAB			CC LAB			LAN LAB	
FILTER	TDS(Feed)	TDS(Product)	TDS(#Product)	TDS(Feed)	TDS(Product)	TDS(#Product)	TDS(Feed)	TDS(Product)	TDS(#Product)	TDS(Feed)	TDS(Product)
					mg/L						

Tables 4.11, 4.12 present the electrical conductivity of the treated water (products). The range is between 90μS/cm and 320μS/cm. The electrical conductivity of water measures the capacity of water to conduct electrical current and it is directly related to the concentration of salts dissolved in water, and therefore to the total dissolved solids (TDS)(Akorli, 2012). As indicated in table 2.10, the recommended conductivity for drinking water is5-500μS/cm. Comparing the conductivity range to the 5-500μS/cm, all treated water (products) meet the acceptable drinking water standards.

The total suspended solids of treated water (TSS) is presented in Tables 4.13, 4.14. The lowest TSS was 0.008mg/L and highest was 22mg/L. TSS can include a wide variety of material, such as silt, decaying plant and animal matter, industrial wastes, and sewage. High concentrations of suspended solids can cause many problems for stream health. TSS can combine with toxic compounds and heavy metals, and lead to an increase in water temperature. As indicated in table 2.10, all TSS values of the treated water meet drinking water standards.

From Tables 4.15, 4.16, the turbidity of the treated water is from 0.3NTU to 12NTU. The accepted drinking water standard is 5NTU, set by Ghana Standard Authority (GSA)(Achisa, 2013; Akorli, 2003)**.** There are few treated water from GF-Nyl, GF-POL, CSWFF-Nyl, CSWFF-POL and SFFF-Nyl medium which do not meet the turbidity standard 5NTU (Table 4.15 and 4.16). These results are due to the short run time. Between 5 and 10 minutes there have not been much particulate (including colloids and bacteria) deposition to trap more fine particles in the raw feed, thus leading to high turbidity. Similar studies from Achisa (2013) and Pikwa et al (2010) , where they treated raw water using polyester woven fabric and studied turbidity (NTU) with change in time. Both researchers have reported higher turbidities (5-10 NTU) in 0-20 minutes. However lower turbidities (<1NTU) were recorded for water samples taken after 30 or more minutes. Again all media in which aquatab chemical was introduced to enhance micro bacterial removal in the raw water, their permeate (treated water) indicated higher turbidities, even more than the feed water samples (Table 4.15 and 4.16). The increase in turbidity (NTU) in the treated water could be as a result of the dissolved chemicals from the aquatab. The aquatab makes the treated water cloudy thus increases the turbidity

Table 4.11:Conductivity (CDT)values of raw water(feed) and treated water(product) from Mampong Dam

	1st batch water treatement						2nd batch water treatement				
	CC LAB			LAN LAB			CC LAB			LAN LAB	
FILTER	CDT (Feed)	CDT (Product)	CDT (#Product)	CDT (Feed)	CDT (Product)	CDT (#Product)	CDT (Feed)	CDT (Product)	CDT (#Product)	CDT (Feed)	CDT (Product)
					µS/cm						
GF-Nyl	270	200		160	140		140	130			
GF-POL	270	320		160	160		140	120		110	100
CSWFF-Nyl	190	170		140	130		140	130	130	110	110
CSWFF-POL	190	170					140	140		110	100
WFACF-POL	220	210	200	140	125	130				110	90
AQUATT							130	160		110	120
CFFF-POL/Nyl/AQUAT							130	140		110	120
CSWFF-POL/AQUAT							130	220		110	120
GF-POL/Nyl										110	100
SFFF-Nyl										110	110
CFFF-POL/Ny							140	140		110	100

Table 4.12:Conductivity(CDT) values of raw water(feed) and treated water(product) from River Offin

	1st batch water treatement						2nd batch water treatement				
	CC LAB			LAN LAB			CC LAB			LAN LAB	
FILTER	CDT (Feed)	CDT (Product)	CDT (#Product)	CDT (Feed)	CDT (Product)	CDT (#Product)	CDT (Feed)	CDT (Product)	CDT (#Product)	CDT (Feed)	CDT (Product)
					µS/cm						
GF-Nyl							180	170	160	140	
GF-POL							180	170	160	150	
CSWFF-Nyl							190	160		160	150
CSWFF-POL	260	220	160	150	120	130	190	170		160	140
WFACF-POL							170	150	140	160	150
AQUATT	180	200		120	140						
CFFF-POL/Nyl/AQUAT											
CSWFF-POL/AQUAT	180	180									
GF-POL/Nyl							170	170	170	160	160
SFFF-Nyl							160	165		160	150
CFFF-POL/Ny							190	180		160	150

Table 4.13:TSS values of raw water(feed) and treated water(product) from Mampong Dam

	1st batch water treatement						2nd batch water treatement				
	CC LAB			LAN LAB			CC LAB			LAN LAB	
FILTER	TSS(Feed)	TSS (Product)	TSS (#Product)	TSS (Feed)	TSS (Product)	TSS (#Product)	TSS (Feed)	TSS (Product)	TSS (#Product)	TSS (Feed)	TSS (Product)
					mg/L						
GF-Nyl	28.600	14.000		0.204	0.144		22.000	15.000			
GF-POL	28.600	18.000		0.204	0.145		22.000	14.000		0.110	0.008
CSWFF-Nyl	31.200	21.800		1.090	0.090		28.000	11.000	14.000	0.110	0.036
CSWFF-POL	24.500	20.400					28.000	13.000		0.110	0.079
WFACF-POL	26.100	12.000	8.000	0.123	0.107	0.019				0.112	0.103
AQUATT							18.000	9.000		0.112	0.034
CFFF-POL/Nyl/AQUAT							18.000	6.000		0.112	0.024
CSWFF-POL/AQUAT							18.000	10.000		0.112	0.146
GF-POL/Nyl										0.110	0.047

SFFF-Nyl										0.110	0.082
CFFF-POL/Ny							28.000	10.000		0.110	0.068

Table 4.14:TSS values of raw water(feed) and treated water(product) from River Offin

	1st batch water treatement						**2nd batch water treatement**				
	CC LAB			**LAN LAB**			**CC LAB**			**LAN LAB**	
FILTER	**TSS (Feed)**	**TSS (Product)**	**TSS (#Product)**	**TSS (Feed)**	**TSS (Product)**	**TSS (#Product)**	**TSS (Feed)**	**TSS (Product)**	**TSS (#Product)**	**TSS (Feed)**	**TSS (Product)**
					mg/L						
GF-Nyl							38.000	17.000		0.397	0.378
GF-POL							38.000	20.000		0.397	0.211
CSWFF-Nyl							14.000	13.000		0.397	0.123
CSWFF-POL	27.800	20.000	19.000	0.202	0.062	0.098	14.000	11.000		0.397	0.397
WFACF-POL							28.000	11.000	6.000	0.397	0.093

AQUATT	31.200	19.500		0.062	0.098						
CFFF-POL/Nyl/AQUAT											
CSWFF-POL/AQUAT	31.200	22.400									
GF-POL/Nyl							28.000	9.000		0.397	0.274
SFFF-Nyl							28.000	10.000	7.000	0.397	0.283
CFFF-POL/Ny							14.000	14.000		0.397	0.292

Table 4.15:Turbidity(TBD)values of raw water(feed) and treated water(product) from Mampong Dam

	1st batch water treatment						**2nd batch water treatment**				
	CC LAB			**LAN LAB**			**CC LAB**			**LAN LAB**	
FILTER	**TBD (Feed)**	**TBD (Product)**	**TBD (#Product)**	**TBD (Feed)**	**TBD (Product)**	**TBD (#Product)**	**TBD (Feed)**	**TBD (Product)**	**TBD (#Product)**	**TBD (Feed)**	**TBD (Product)**
					NTU						
GF-Nyl	0.94	0.68		2.70	1.06		10.55	9.64			

GF-POL	0.94	0.59		2.70	1.50		10.55	9.76		3.00	2.00
CSWFF-Nyl	1.59	0.38		2.67	1.30		8.24	5.87	5.13	3.00	3.00
CSWFF-POL	1.12	0.61					8.24	6.67		3.00	2.00
WFACF-POL	0.88	2.36	2.02	5.00	5.00	3.00				3.00	1.50
AQUATT							7.72	12.32		3.00	5.00
CFFF-POL/Nyl/AQUAT							7.72	9.16		3.00	5.00
CSWFF-POL/AQUAT							7.72	8.28		3.00	4.00
GF-POL/Nyl										3.00	2.00
SFFF-Nyl										3.00	3.00
CFFF-POL/Ny							8.24	4.05		3.00	1.20

Table 4.16:Turbidity(TBD) values of raw water(feed) and treated water(product) from River Offin

1st batch water treatment	2nd batch water treatment

	CC LAB			LAN LAB			CC LAB			LAN LAB	
FILTER	**TBD(Feed)**	**TBD (Product)**	**TBD (#Product)**	**TBD (Feed)**	**TBD (Product)**	**TBD (#Product)**	**TBD (Feed)**	**TBD (Product)**	**TBD (#Product)**	**TBD(Feed)**	**TBD (Product)**
					NTU						
GF-Nyl							5.71	4.51		5.00	4.00
GF-POL							5.71	5.45		5.00	4.00
CSWFF-Nyl							6.32	8.67		5.00	5.00
CSWFF-POL	1.18	1.10	0.30	5.00	3.00	3.00	6.32	4.31		5.00	3.00
WFACF-POL							6.06	2.10	2.60	5.00	2.00
AQUATT	1.20	1.50		3.00	4.00						
CFFF-POL/Nyl/AQUAT											
CSWFF-POL/AQUAT	1.20	2.59									
GF-POL/Nyl							6.06	2.64		5.00	4.00
SFFF-Nyl CFFF-							6.06	5.68	4.67	5.00	3.00
POL/Ny							6.32	4.69		5.00	1.50

Tables 4.17 to 4.20 indicate the levels of some heavy metals of the raw water and treated water. The range for manganese (Mn), copper (Cu) and zinc (Zn) are 0.0000-0.0182 mg/L,0.000-0.0042 mg/L and 0.0054-0.0350 mg/L respectively. Cadmium has recorded the highest range of concentration (0.0522-1.2870 mg/L). The amount of lead and iron ranges from 0.0000 to 0.3676 mg/L and 0.0470 to 1.0972 mg/L respectively. With reference to drinking water standards in table 2.10, the concentrations of manganese, copper and zinc in the treated water are within the acceptable limits set by EPA. Manganese in water is a common, naturally occurring problem. It causes a bitter taste in water, and at concentrations above 0.05 mg/L, it causes dark scale in pipes and water heaters. High levels of manganese cause black staining of plumbing fixtures and laundry. A small amount of copper is essential for plants and animals. Concentrations exceeding 0.1 mg/L are also useful for controlling algae and plankton growth. Copper levels in drinking water over 1.0 mg/L result in a metallic taste and also cause blue-green staining on fixtures. Copper levels above 1.3 mg/L can cause health related problems. Zinc is essential to human metabolism and has been found to be necessary for proper body growth. Although essential in our diet, high zinc concentrations in water can irritate the human digestive system. Levels above 5 mg/L cause a bitter metallic taste and opalescence in alkaline drinking water.

The recommended cadmium concentration for drinking water is 0.003mg/L(Table 2.10) among the heavy metals cadmium is considered one of the most harmful to health because of its high toxicity, even at relatively low doses(*Meneghel et al* , 2013). It was observed that even single treated water does not meet cadmium standard for drinking water. This is could be linked to high concentrations of cadmium in the raw water fetched from Mampong Dam and River Offin for treatment. Cadmium can be added to soil through phosphate fertilizer(*Meneghel et al* , 2013) and indeed the raw water locations are agricultural produce lands. Another reason is due to availability of cadmium ions in the raw water. Higher pH values (8-9) result the precipitation of heavy metals present in solvent(*Salmani et al*, 2013). By considering the pH range (7.5-6.6) (Table 4.5 and 4.6) of raw water, the likely cadmium ions present would be Cd^{2+}, this implies that more cadmium ion present are dissolved. Therefore, the filtration technique would not be efficient to remove a large amount of cadmium metal in the feed. Comparatively, one of 4-5 treated water from GF-POL/Nyl and WFACF-POL medium do not meet the drinking water standard of iron. The iron concentrations from their treated water were reported as 1.0188mg/L and 1.0972mg/L(Table 4.20) respectively. Iron levels over 0.3 mg/L cause several problems. It leaves reddish brown stains on laundry, porcelain fixtures, sinks and tubs. It also results in a metallic taste in the water. Higher levels of iron may also discolor the water or result in sediment.

The GSA and EPA recommended limit of lead in drinking water are 0.01mg/L and 0.05mg/L(Table 2.10) respectively. Among the filters, only treated water from CSWFFPOL and CSWFF-Nyl medium met the drinking water standard for lead. Lead like cadmium form complexes such Pb^{2+}, Pb (OH^{+}), etc. at higher alkaline environment (*Malamis et al*, 2011). However, most of the pH of the raw water was between 6.6 and 7.2(Table 4.5 and 4.6). This indicates that more lead ions are soluble in the feed, thus does not make microfiltration more effective in remediation of lead metal. *Malamis et al* (2011) studies on the effect of pH on metal removal using Microfiltration medium (polyvnylidene fluoride) with norminal pore size 0.04µm have shown that at pH(3-6), the lead(II) removal was 13-44% but higher pH(7-9), there was significant increase in removal efficiency which was 96-100%.

Coliform(feacal coliform), *Escherichia coli (e.coli)* and total coliform bacteria tests were carried out to determine the presence of pathogens (protozoans and bacteria) in water. From tables 4.17 to 4.20, no treated water shows the presence of *e.coli* and coliform (fecal coliform) bacteria. Most of the raw water were free from e,coli and coliform(faecal colifrom) with the exception of feed for 1 of 2 treatments from WFACF-POL medium, and a feed for CFF-POL/Nyl/AQUAT medium. Although e.coli and feacal coliform counts were very low (1-2CFU/100mL)(Table 4.17 and 4.19). Fecal coliforms are the group of the total coliforms that are considered to be present specifically in the gut and feces of warm-blooded animals. Escherichia coli (*e.coli*) is the major species in the fecal coliform group. The presence of both coliform(fecal coliform) and *e.coli* in water is an indication of recent sewage or animal waste contamination. The absence of the two indicators in the treated water shows that WHO and GSA standards (Table 2.10) in respect of sanitary condition of the treated water is met.

All treated water as shown in the tables contain total coliform bacteria. The range is from 6CFU/100ml to 45CFU/100ml. All treated water from GF-POL and GF-Nyl medium were found to contain high TC counts (28CFU/100mL-45CFU/100mL). Total coliforms (TC) include bacteria that are found in the soil, in water that has been influenced by surface water, and in human or animal waste. Testing for total coliform bacteria is a reliable indicator for testing water quality because they travel with disease producing organisms. Per WHO and GSA guidelines (Table 2.10), potable water for human consumption must be total coliform(TC) free. However, the treated water do not meet the set standards in respect to total coliform bacteria indicator. The high concentrations of TC in the gravity filtrations (GFs) are because of the exposure of the filtration process to atmosphere (environment) thus results in continual growth of pathogens in the treated water.

Table 4.17: Concentration of heavy metals and bacteria in raw water and treated water (1st batch water treatment)

Filter	CSWFF-Nyl		GF-Nyl		GF-POL		WFACF-POL			CSWFF-POL	
Parameter	Feed	Product	Feed	Product	Feed	Product	Feed	Product	Product#	Feed	Product
Lead(mg/L)	0.7353	0.0735	0.0735	0.0000	0.0735	0.0735	0.2941	0.1471	0.0735	0.5147	0.2206
Iron(mg/L)	0.1411	0.1254	0.1567	0.0940	0.1567	0.1097	0.2821	0.1254	0.0940	0.1254	0.1097
Copper(mg/L)	0.0006	0.0000	0.0006	0.0006	0.0006	0.0006	0.0012	0.0000	0.0006	0.0012	0.0006
Cadmium(mg/L)	1.5304	0.5391	1.7217	0.8696	1.7217	1.2870	1.6522	0.8870	0.0522	0.7826	0.4348
Zinc(mg/L)	0.0135	0.0054	0.0323	0.0054	0.0323	0.0242	0.0188	0.0081	0.0054	0.0188	0.0081
Manganese(mg/L)	0.0061	0.0000	0.0122	0.0000	0.0122	0.0122	0.0122	0.0061	0.0000	0.0304	0.0061
Coliform(CFU/100mL)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	2.0000	0.0000	0.0000	0.0000	0.0000
E.coli(CFU/100mL)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	2.0000	0.0000	0.0000	0.0000	0.0000
Total coliform(CFU/100mL)	28.000	17.000	32.000	29.000	32.000	39.000	35.000	15.000	17.000	29.000	16.000

Water source: Mampong Dam

Table 4.18: Concentration of heavy metals and bacteria in raw water and treated water (1st batch water treatment)

Filter	CSWFF-POL			AQUATT		CSWFF-POL/AQUAT	
Feed	Feed	Product	#Product	Feed	Product	Feed	Product
Lead(mg/L)	0.1471	0.1471	0.0000				
Iron(mg/L)	0.8464	0.1567	0.0068				
Copper(mg/L)	0.0012	0.0006	0.0000				

Cadmium(mg/L)	0.4000	0.1739	0.0568				
Zinc(mg/L)	0.0430	0.0350	0.0350				
Manganese(mg/L)	0.0365	0.0365	0.0006				
Coliform(CFU/100mL)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
E.coli(CFU/100mL)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total coliform(CFU/100mL)	32.000	18.000	15.0000	26.000	12.000	26.000	8.000

Water source:River Offin

Table 4.19: Concentration of heavy metals and bacteria in raw water and treated water (2nd batch water treatment)

Filter	**GF-Nyl**		**GF-POL**		**CSWFF-Nyl**		**CSWFF-POL**	
Parameter	**Feed**	**Product**	**Feed**	**Product**	**Feed**	**Product**	**Product**	**Feed**	**Product**
Lead(mg/L)	0.2206	0.1471	0.1471	0.0735	0.6618	0.3676	0.3676	0.2206	0.2206
Iron(mg/L)	0.1411	0.0784	0.0940	0.0627	0.1097	0.0627	0.0470	0.1254	0.1097
Copper(mg/L)	0.0006	0.0006	0.0000	0.0000	0.0006	0.0006	0.0006	0.0000	0.0000
Cadmium(mg/L)	1.7217	0.8696	0.8696	0.5913	0.6087	0.5391	0.4000	0.7826	0.6783
Zinc(mg/L)	0.0323	0.0161	0.0188	0.0081	0.0188	0.0135	0.0108	0.0054	0.0054
Manganese(mg/L)	0.0061	0.0061	0.0061	0.0061	0.0061	0.0061	0.0000	0.0000	0.0000
Coliform(CFU/100mL)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
E.coli(CFU/100mL)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total coliform(CFU/100mL)	38.000	36.000	38.000	37.000	26.000	13.000	14.000	26.000	14.000

Filter	**CFFF-POL/Ny**		**AQUATT**		**CFFF-POL/Nyl/AQUAT**		**CSWFF-POL/AQUAT**	
Parameter	**Feed**	**Product**	**Feed**	**Product**	**Feed**	**Product**	**Feed**	**Product**

Coliform(CFU/100mL)	0.0000	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000	0.0000
E.coli(CFU/100mL)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total coliform(CFU/100mL)	26.000	10.000	22.000	6.0000	22.000	9.0000	22.000	8.0000

Water source: Mampong Dam

Table 4.20: Concentration of heavy metals and bacteria in raw water and treated water (2nd batch water treatment)

Filter	GF-POL/Nyl		SFFF-Nyl			WFACF-POL			CFFF-POL/Nyl	
Parameter	**Feed**	**Product**	**Feed**	**Product**	**Product#**	**Feed**	**Product**	**Product**	**Feed**	**Product**
Lead(mg/L)	0.0735	0.0735	0.2941	0.2206	0.2206	0.3676	0.2206	0.0735	0.2206	0.0735
Iron(mg/L)	1.0345	1.0188	0.1411	0.1254	0.1254	1.4107	1.0972	0.7053	0.1567	0.0784
Copper(mg/L)	0.0024	0.0018	0.0042	0.0036	0.0036	0.0042	0.0024	0.0006	0.0048	0.0042
Cadmium(mg/L)	0.1565	0.1391	0.0870	0.0696	0.0522	0.1913	0.1391	0.0870	0.1304	0.0522
Zinc(mg/L)	0.0242	0.0242	0.0161	0.0108	0.0108	0.0161	0.0081	0.0054	0.0323	0.0135
Manganese(mg/L)	0.0182	0.0061	0.0182	0.0182	0.0182	0.0122	0.0000	0.0000	0.0182	0.0061
Coliform(CFU/100mL)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
E.coli(CFU/100mL)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total coliform(CFU/100mL)	17.000	11.000	17.000	10.000	12.000	17.000	12.000	10.000	23.000	10.000

Filter	GF-Nyl		GF-POL		CSWFF-Nyl		CSWFF-POL	
Parameter	**Feed**	**Product**	**Feed**	**Product**	**Feed**	**Product**	**Feed**	**Product**

Coliform(CFU/100mL)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
E.coli(CFU/100mL)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total coliform(CFU/100mL)	20.000	28.000	20.000	45.000	23.000	9.0000	23.000	6.0000

Water source: River Offin

4.2.2 Performance of filter media in terms of TDS, TSS, turbidity and conductivity removal

The filter media for filtration was categorized into nylon, polyester, composite, and aquatab. Following phyiso-chemical and biological analyses of the treated and untreated water, the removal efficiency of the filters were determined as;

$$\square\square \frac{INIValue \square FINValue}{INIValue} x100$$

$\square$=Removal efficiency, %

INIValue =initial concentration

FINValue =final concentration

Figure 4.4a to figure 4.4e shows the efficiency of filters on TDS, TSS, turbidity and conductivity removals. More detail data are found in table A3-1 and A3-2 of appendix A.

4.2.2.1 Filters made of nylon

From figure 4.4a and 4.4c, the average removal efficiency for CSWFF-Nyl on TDS, TSS, turbidity and conductivity are 12.70, 62.46, 52.06 and 10.15 respectively. GF-Nyl is basically a gravity filtration and its main purpose was to establish a quick idea of the performance of nylon (Nyl) material. From figure 4.4a and 4.4d, the filter's average percent removal on TDS, TSS, turbidity and conductivity are 24.20, 41.89, 29.51 and 12.72 respectively. SFFF-Nyl average percent removal of TDS, TSS, turbidity and conductivity are 4.17, 56.00, 31.47 and 5.02 respectively as shown in figure 4.4c.

4.2.2.2 Filters made of polyester

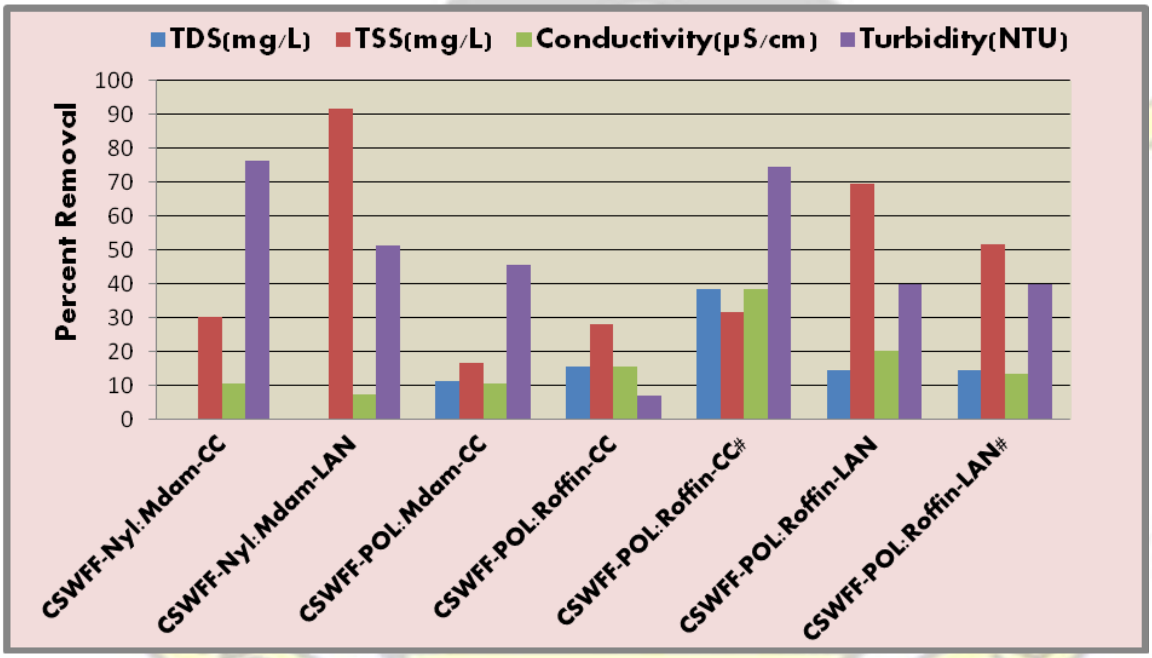
From figure 4.4a and 4.4c, CSWFF-POL average percent performance in terms of TDS, TSS, turbidity and conductivity removals are 16.73, 37.55, 40.54 and 16.23 respectively. GF-POL serves the same purpose as GF-Nyl filter medium. Its average percent performance on removal of TDS, TSS, turbidity and conductivity are 11.14, 48.22, 33.76 and 8.80 respectively as shown in figure 4.4a and 4.4d. WFACF-POL filter medium which is combination of activated carbon from bamboo and polyester (POL) material. From figure 4.4b and 4.4e, WFACF-POL average percent performance in terms of TDS, TSS, turbidity and conductivity removals are 15.99, 51.48, 54.49 and 10.67 respectively.

4.2.2.3 Composite filter made of polyester and nylon

CFFF-POL/Nyl average percent performance in terms of TDS, TSS, turbidity and conductivity removals are 3.13, 42.97, 60.28 and 6.87 respectively as shown in figure 4.4c. GF-POL/Nyl medium records 6.67, 52.04, 26.67 and 9.09 in the same order as shown in figure 4.4d.

4.2.2.4 Aquatab treatment

From figure 4.4b and 4.4e Aquatab treatment(AQUATT) average percent performance on TDS ,TSS, turbidity and conductivity removals are -19.79, 52.38, -46.15 and -14.99 respectively. CSWFF-POL/AQUAT is basically aquatab treatment of the product of CSWFF-POL filter. CSWFF-POL/AQUAT average percent performance in terms of TDS, TSS, turbidity and conductivity removals are -40.28, 36.33,-52.13 and -26.10 respectively as shown in figures 4.4b, 4.4e. CFFF-POL/Nyl/AQUAT also records -8.34, 72.62, -42.66 and -8.39 in the same order as shown in figure 4.4e. Comparatively the three filter media follow the same trend. The filter media improve TSS reduction in the treated water (product), however, the concentration of TDS, turbidity and conductivity increased. The aquatab is a chemical disinfectant which is manufactured by Medentech for water treatment(PATH, 2009). Its primary purpose is to kill pathogens present in water, however, the usage of aquatabs as disfectant of products of the filter media and also for raw water treatment resulted in significant increase in TDS, turbidity and conductivity. The increase is attributed to solubility of the constituents of aquatab in the water. There is also possibility of formation of disinfection byproducts (DBPs) thus all contribute to the increase in TDS and conductivity. Dissolved inorganic and organic constituents are present naturally in the water supply source, present in treated drinking water and also added by the water users(*Graczyk et al*, 2009). A coagulant property of the aquatab is the primary factor for the reduction in TSS. Coagulation process can substantially reduce the concentration of biodegradable organic matter.



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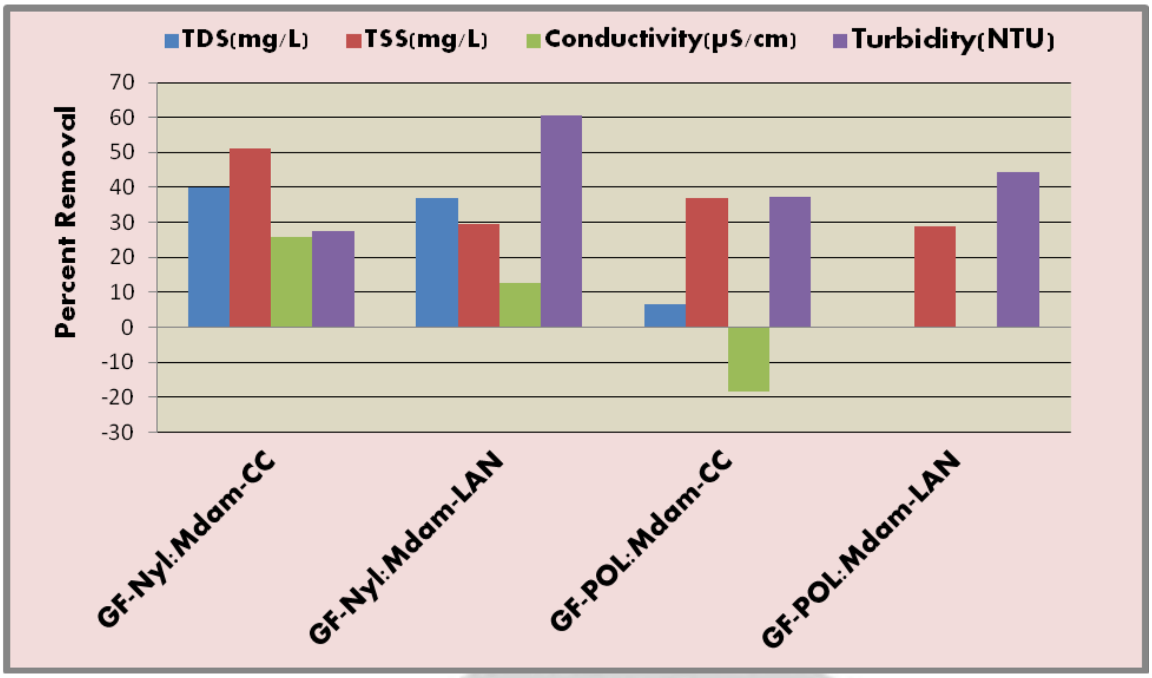
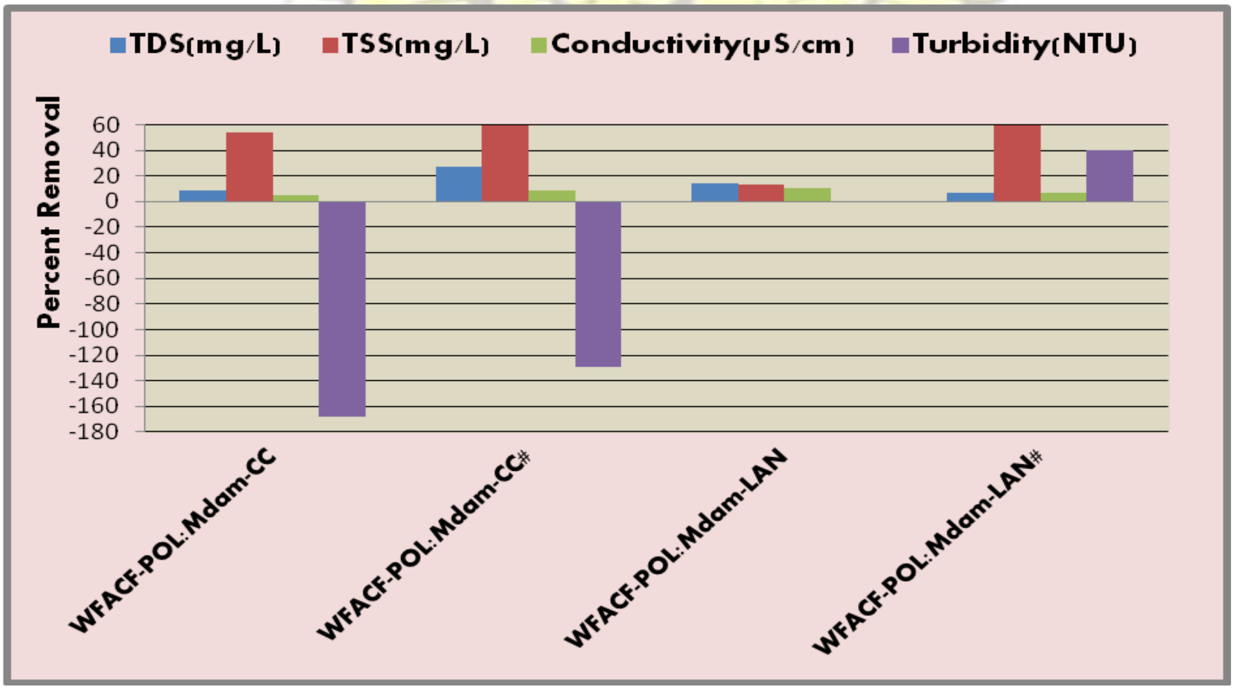


a2 Figure 4.4a: Performance of Filters on TDS, TSS, Turbidity and Conductivity Removals in 1st Batch Water Treatment (WT)



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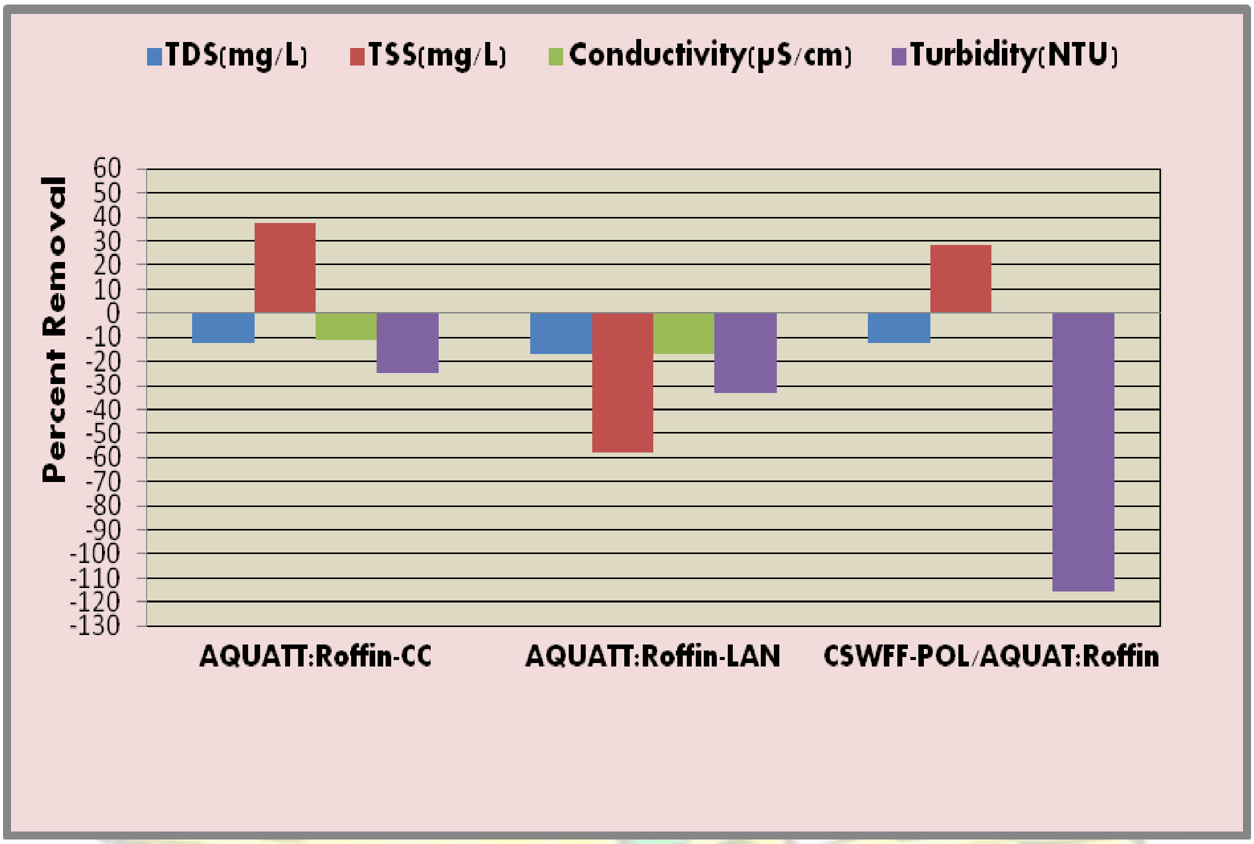

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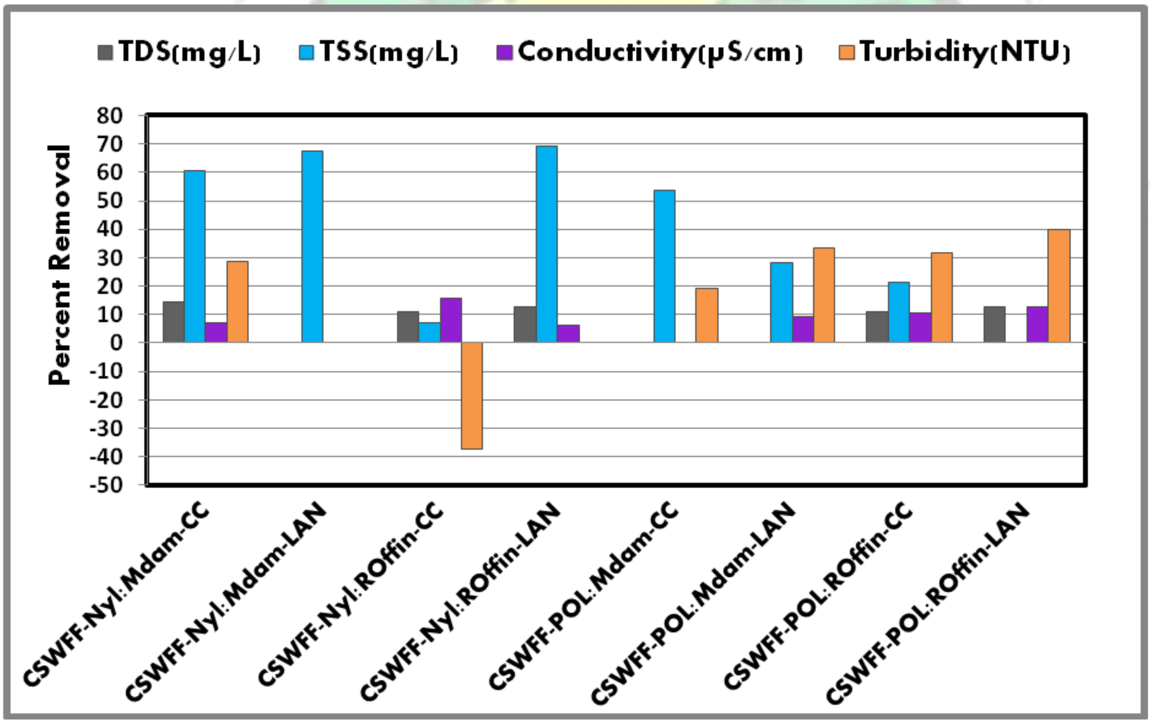
Figure 4.4b: Performance of Filters on TDS, TSS, Turbidity and Conductivity Removals in 1st Batch Water Treatment (WT)



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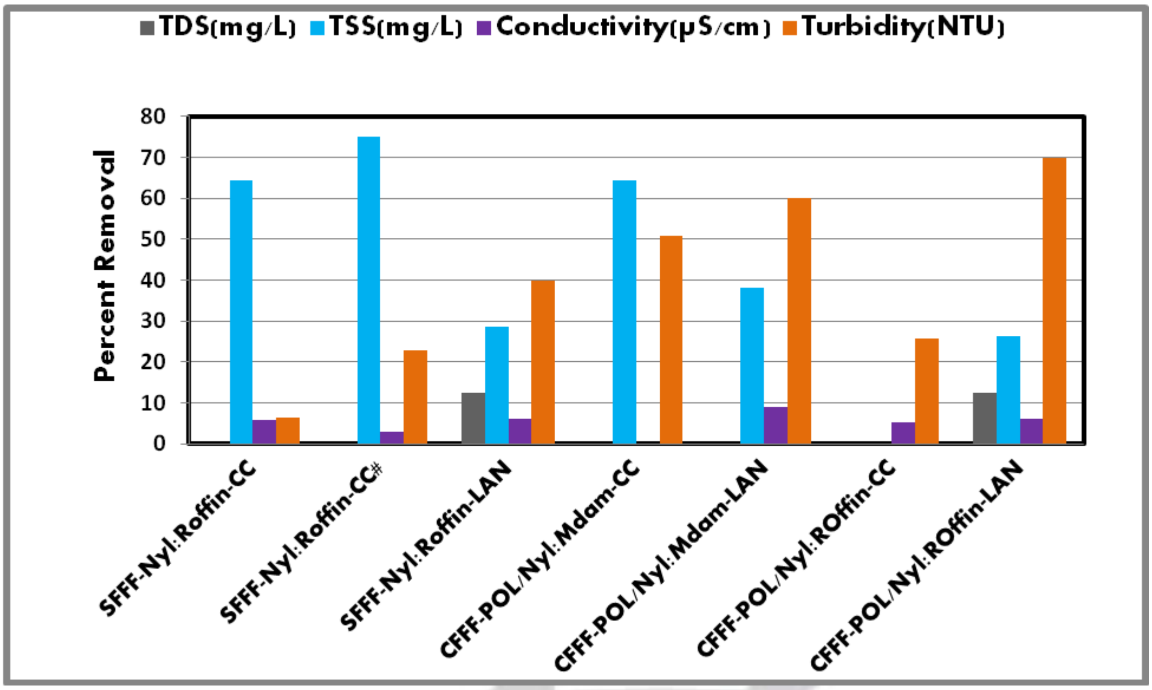

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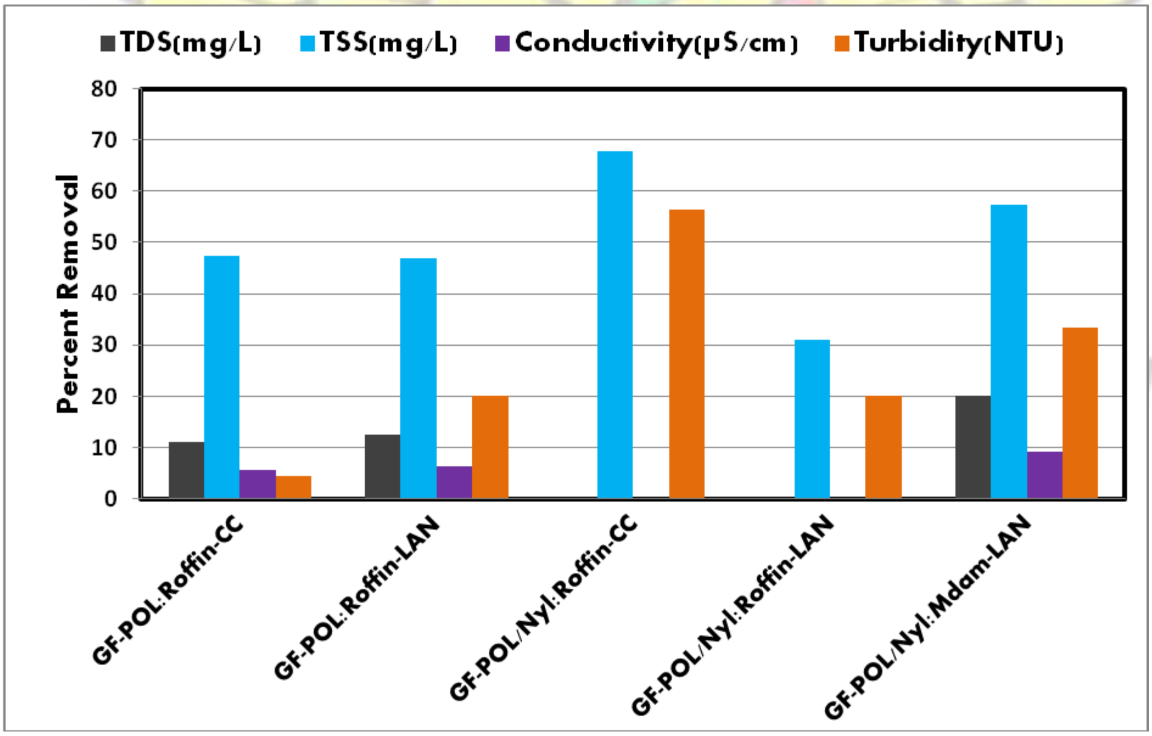
Figure 4.4c: Performance of Filters on TDS, TSS, Turbidity and Conductivity Removals in 2nd Batch Water Treatment (WT)



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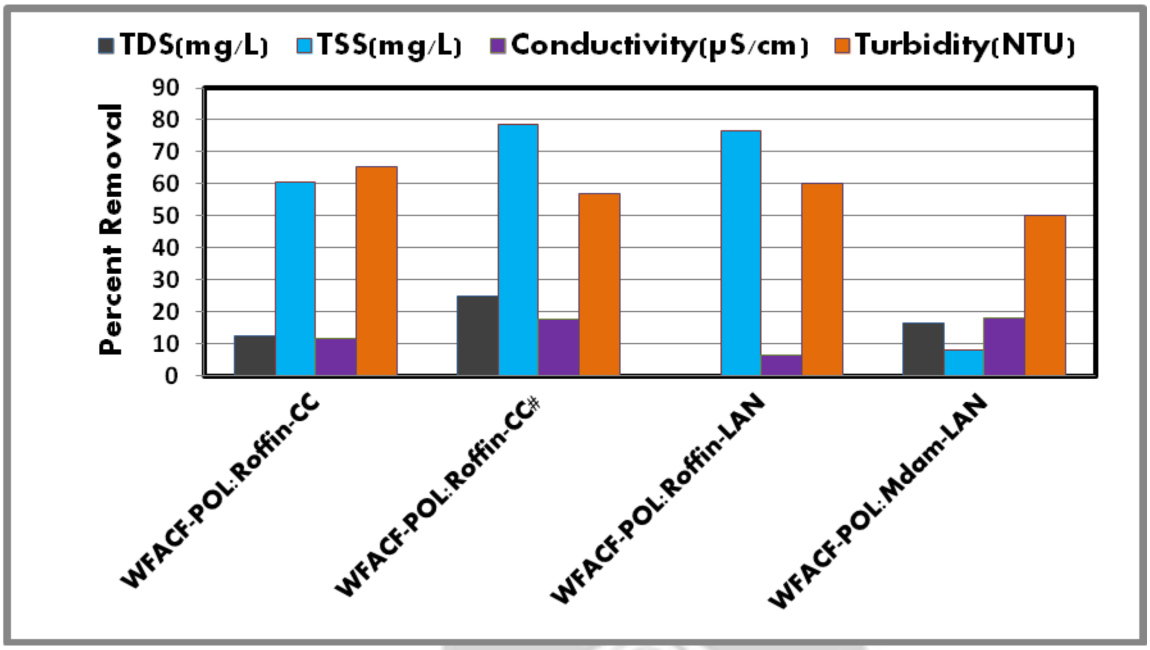

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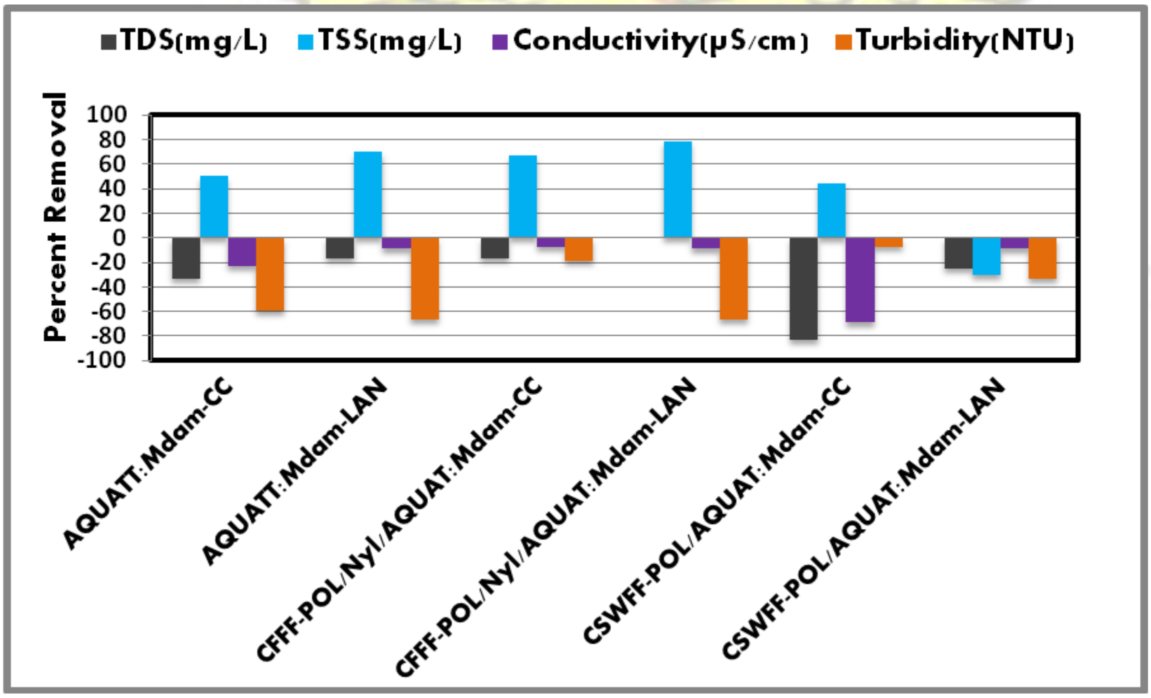
Figure 4.4d: Performance of Filters On TDS, TSS, Turbidity and Conductivity Removals in 2nd Batch Water Treatment(WT)



e1 Figure 4.4e: Performance of Filters on TDS, TSS, Turbidity and Conductivity Removals in 2nd Batch Water Treatment (WT)

4.2.3 Performance of filter media in terms faecal coliform, *e.coli*, total coliform removals

4.2.3.1 Filters made of nylon

From figure 4.5a and 4.5b, CSWFF-Nyl medium removes 100% faecal coliform and *e.coli* bacteria present in the treated water whilst its average performance on total coliform removal is 50.05%. GF-Nyl average percent removal on total coliform is -9.33 as depicted in figure 4.5a to4.5c. The negative performance of GF-Nyl is the reflection of potential for microbial growth since the gravity filtration (GF) was being exposed to the environment for a longer time. From figure 4.5b, on averagely, SFFF-Nyl also removes
35.30% total coliform bacteria present in the treated water

4.2.3.2 Filters made of polyester

The average percent removal of total coliform bacteria by CSWFF-POL filter medium is 52. 35 whilst GF-POL performance in terms of total coliform removal is -48.08 %. As shown in figure 4.13a-4.13c. Again, the negative performance of the GF-POL can be explained similarly to the GF-Nyl. From figure 4.5a and 4.5c, on averagely, WFACFPOL removes 44.79% total coliform bacteria in the treated water. From the same figures, WFACF-POL removes any trace of *e.coli* and fecal coliform bacteria found in the raw water.

4.2.3.3 Composite filters made of polyester and nylon

CFFF-POL/Nyl medium performance in terms of total coliform removal is 59.03% whilst GF-POL/Nyl removes 35.29% of the same bacteria as shown in figure 4.5b-4.5c.

4.2.3.4 Aquatab treatment

From figure 4.5a and 4.5c, Average percent removal of total coliform with aquatab treatment of raw water (AQUATT) is 63.29. CSWFF-POL/AQUAT medium

performance in terms of total coliform removal is 63.64 %(Figure 4.13a and 4.13c).

CFFF-POL/Nyl/AQUAT medium removes 59.09% total coliform in the treated water (Figure 4.13c)

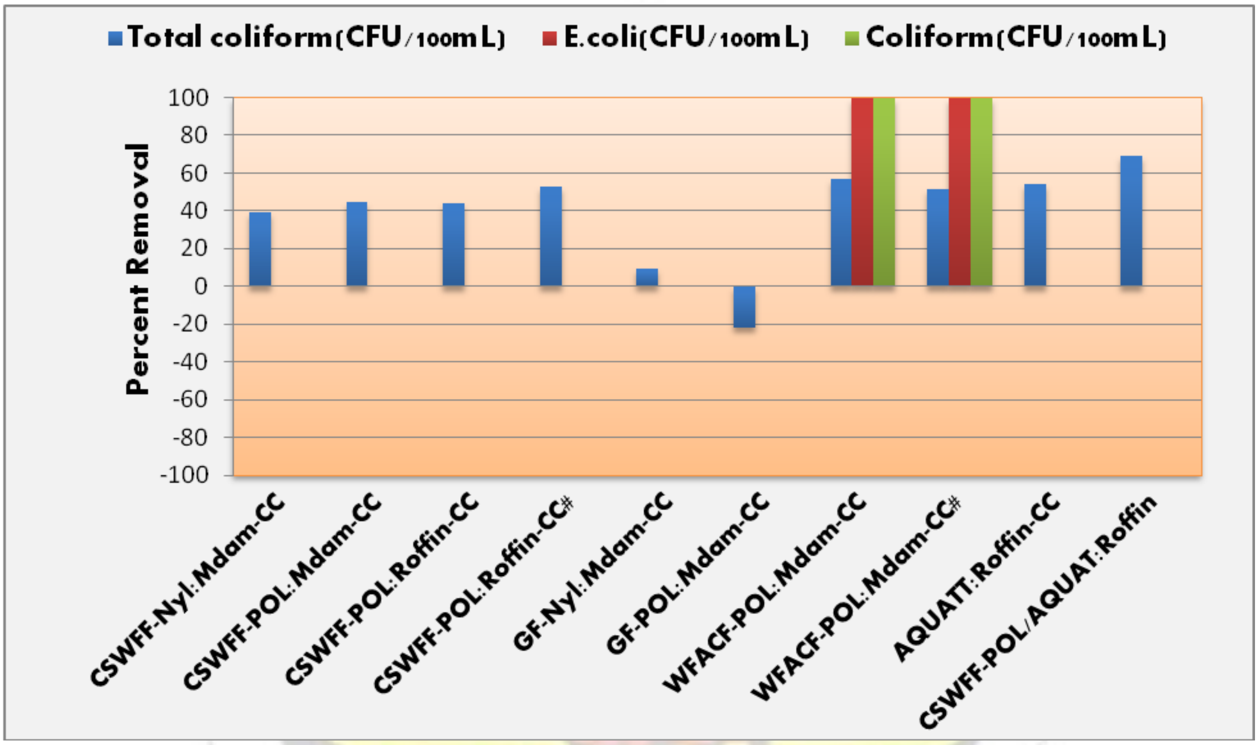


Figure 4.5a: Performance of Filters on Coliform, E.Coli and Total Coliform

Bacterial Removals In 1st Batch Water Treatment (WT)

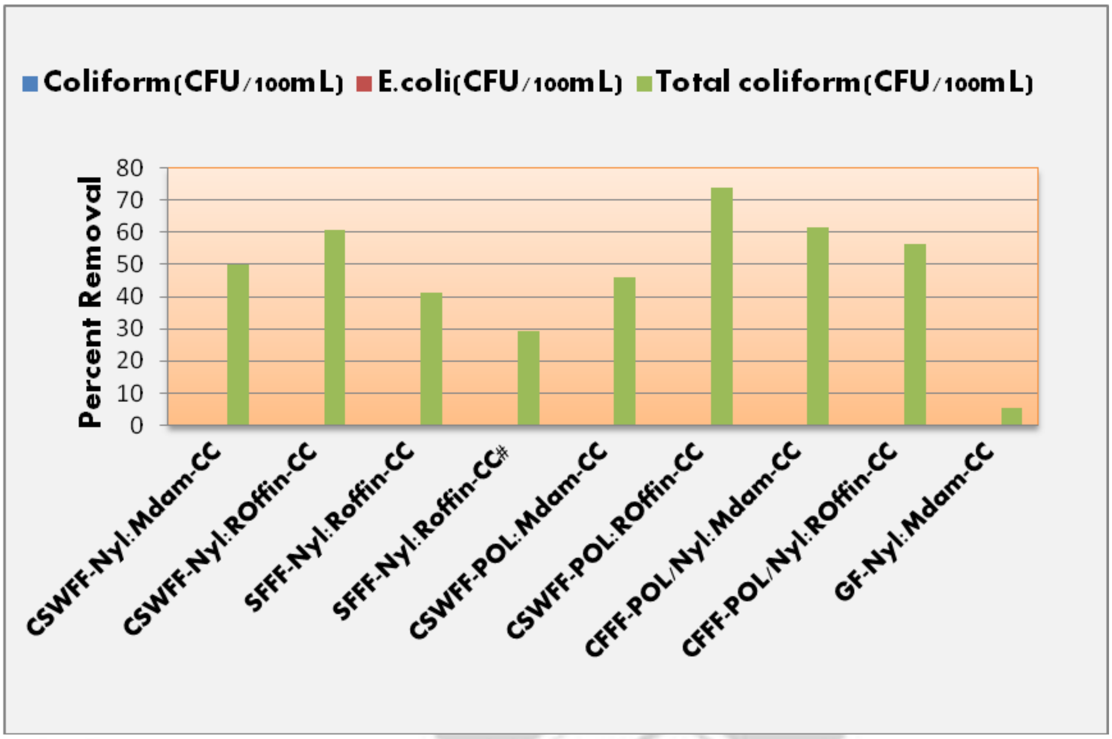


Figure 4.5b: Performance of Filters on Coliform, E.Coli and Total Coliform

Bacterial Removals in 2nd Batch Water Treatment (WT)

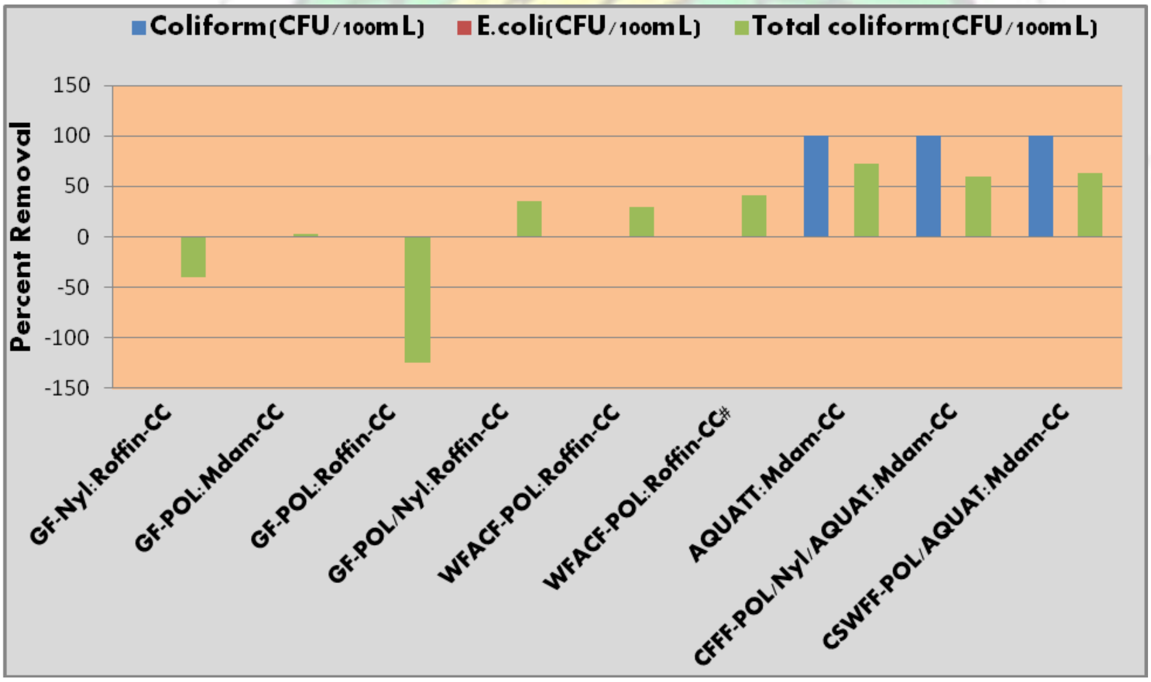


Figure 4.5c: Performance of Filters on Coliform, E.Coli and Total Coliform Bacterial Removals in 2nd Batch Water Treatment (WT)

4.2.4 Performance of filter media in terms of heavy metal removals

4.2.4.1 Filters made of nylon

CSWFF-Nyl average percent performance in terms of Pb, Fe, Cu, Cd, Zn and Mn removals are 67.00, 27.00, 50.00, 38.10, 44.29 and50 respectively as shown in figure 4.6a-4.6c. From the same figures, GF-Nyl performance on Pb, Fe, Cu, Cd, Zn and Mn removals are 66.67, 42.22, 0.00, 49.49, 66.65 and 50.00 respectively. SFFF-Nyl average percent performance on Pb, Fe, Cu, Cd, Zn and Mn are 25.00, 11.11, 14.29,30, 33.33 and 0.00 respectively as indicated in figure 4.6c.

4.2.4.2 Filters made of polyester

From figure 4.6a-4.6c, CSWFF-POL average percent performance in terms of Pb, Fe, Cu, Cd, Zn and Mn removals are 39.29, 51.42, 50.00,50.02, 23.66,and 44.61 respectively. GF-POL performance on removal Pb, Fe, Cu, Cd, Zn and Mn are 25.00, 31.67, 0.00, 28.63, 41.07 and 0.00 respectively. WFACF-POL medium performance in terms of Pb, Fe, Cu, Cd, Zn and Mn removals are 61.25, 48.61, 69.64, 56.25, 61.31 and87.5 respectively. WFACF-POL removes more Pb,Cu, Cd, Zn and Mn ions in the raw water than CSWFF-POL and GF-POL medium. Generally the performance of separation relies on the polyester medium pore(*Kan et al*, 2012). Since WFACF-POL is packed with granular carbon from bamboo, sorption effect is combined with size exclusion thus making filtration performance high in the hybrid filter.

4.2.4.3 Composite filters made of nylon and polyester

From figure 4.6c, CFFF-POL/Nyl average percent performance in terms of Pb, Fe, Cu, Cd, Zn and Mn removals are 66.67, 50.00, 12.50, 60.00, 58.33 and 66.67 respectively. GF-POL/Nyl average percent performance in terms of Pb, Fe, Cu, Cd, Zn and Mn removals are 0.00, 1.52, 25.00, 11.11, 0.00 and 66.67 respectively as shown in figure

4.6c. The composite CFFF-POL/Nyl obtained the highest removal efficiency of all metal ions except Mn. The filter's high performance may be attributed to the contact time and quick formation of cake during filtration. The latter promotes biosorption of the ions to the cake thus improving metal ion removal

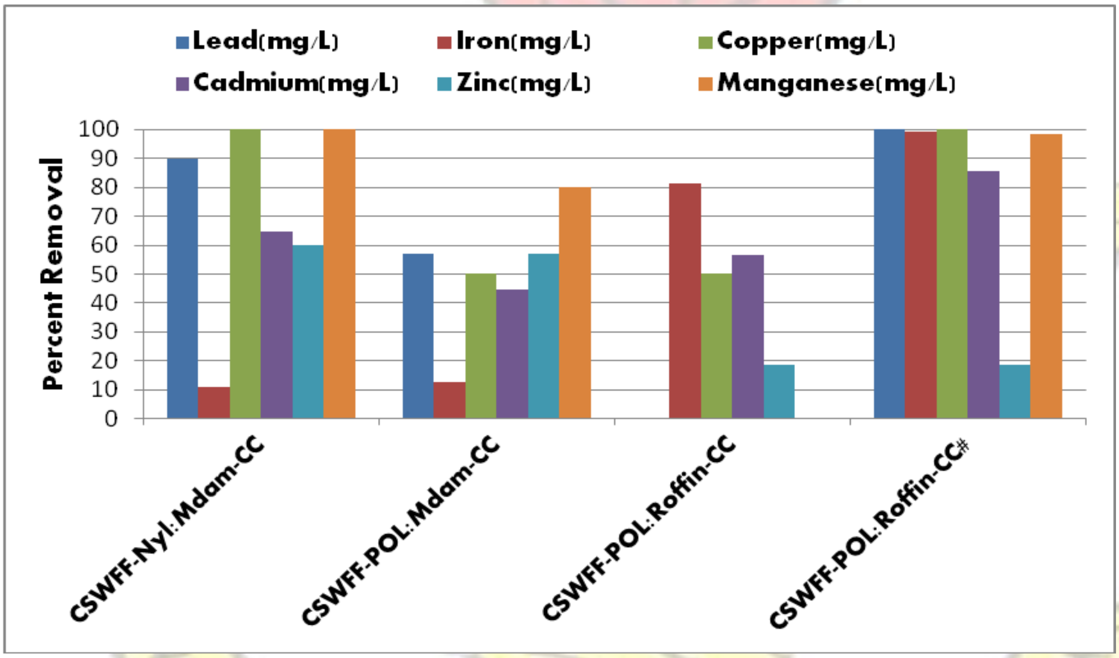


Figure 4.6a: Performance of filters in terms of heavy metals removals in 1st batch water treatment (WT)

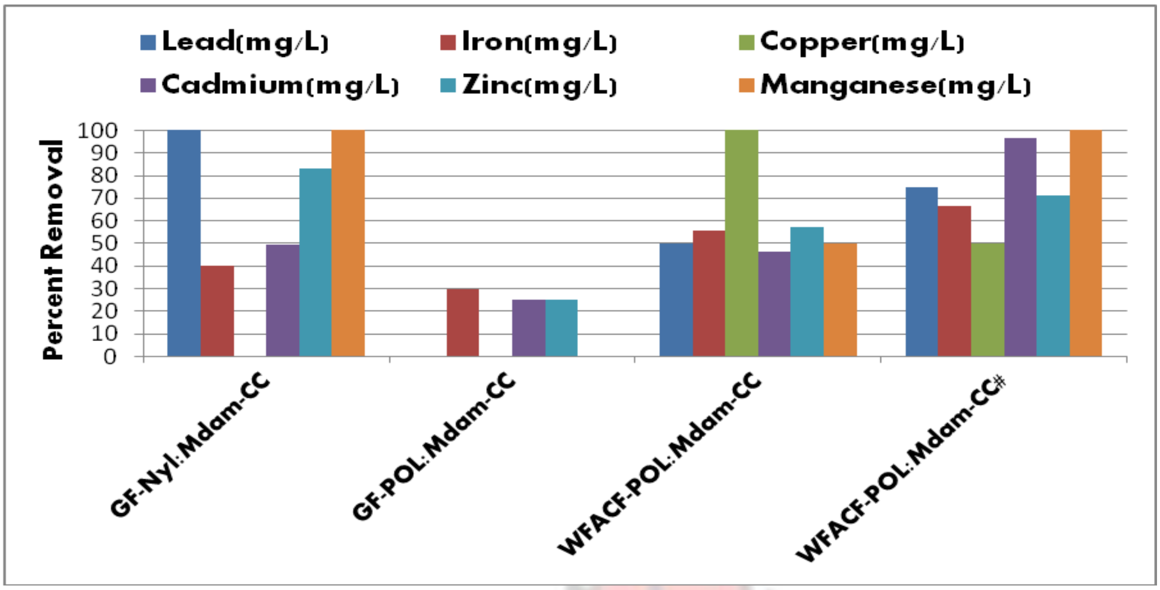
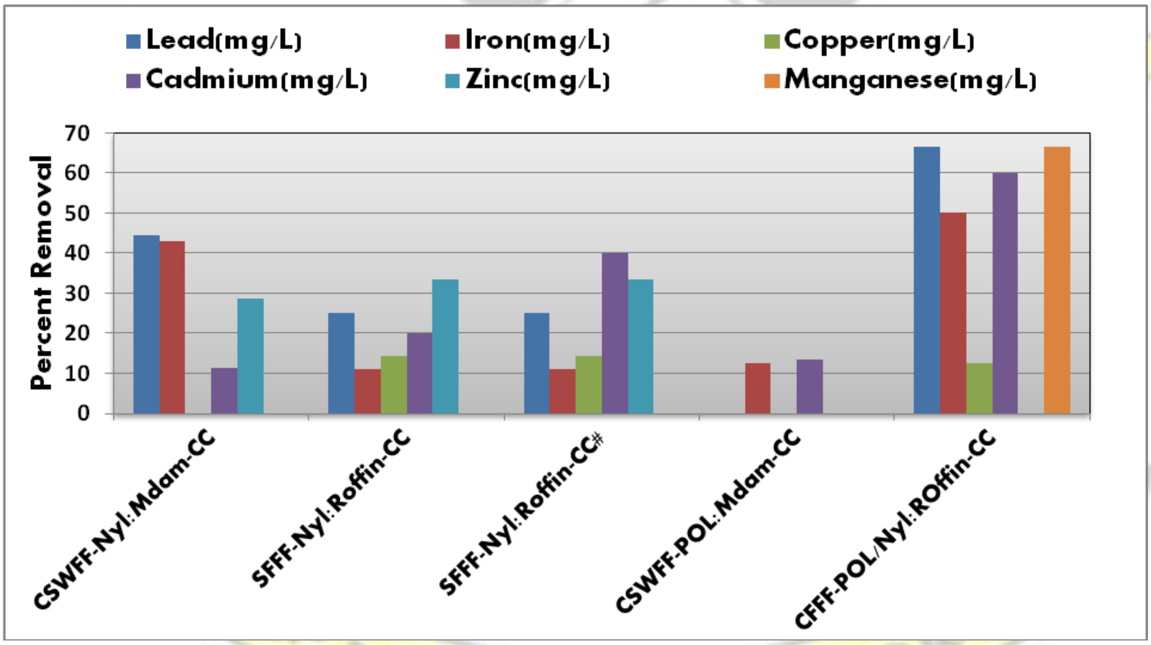


Figure 4.6b: Performance of Filters In Terms Of Heavy Metals Removals In 1st Batch Water Treatment (WT)



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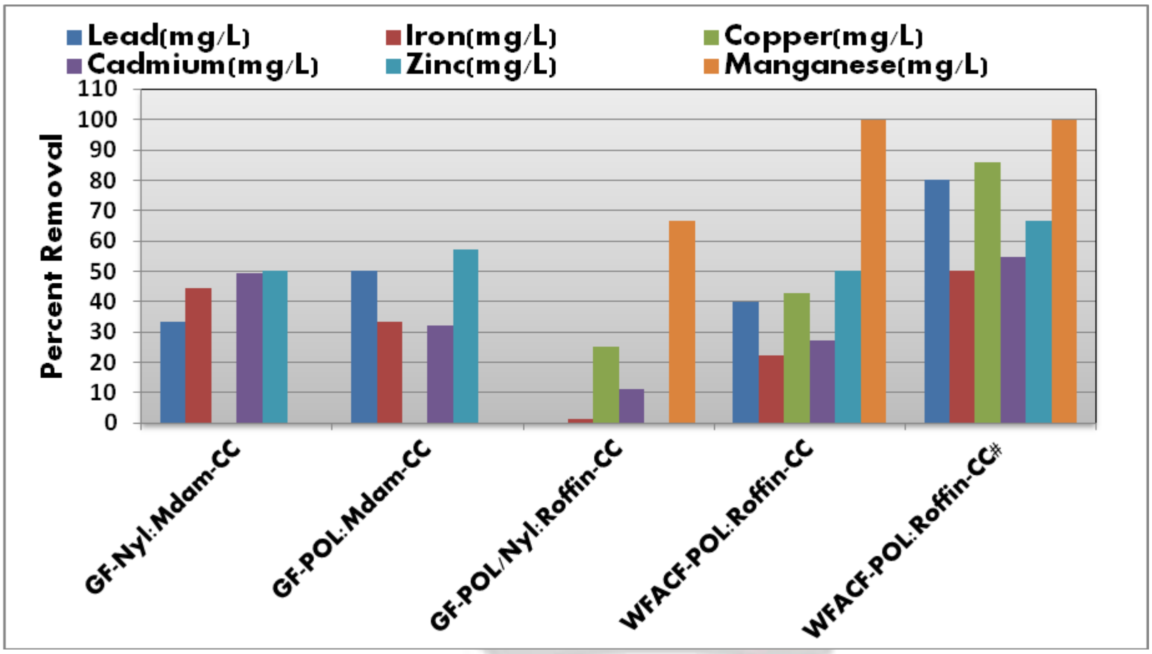

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Figure 4.6c: Performance of Filters In Terms Of Heavy Metals Removals In 2nd Batch Water Treatment (WT)

4.2.5 Comparison of filter media performance

Figure 4.7 summarizes the performance of filters in terms of TDS, TSS, turbidity and conductivity removals in the raw water. By comparing the four categories of the filter media, it is observed that GF-Nyl filter, made of nylon, achieved the highest performance (24.2%) in TDS removal in the raw water, followed by CSWFF-POL and WFACF-POL. The removal efficiencies of TDS for the filters were 16.73% and 15.99% respectively. The performance of the composite filter media is the lowest as shown in figure 4.7a. MF systems can only be effective in removing colloids, ionic and non ionic molecules which correspond to its molecular weight cut off(*Bodzek et al*., 2011). Smaller or low molecular weights dissolved compounds (both natural and synthetic) are effectively removed by RO, hybrid systems (coagulation, flocculation followed by MF/UF) and sorption.TDS determines the present of salts such as sulfate, carbonate, nitrate, etc., ions, natural organic matter(NOM) and organic carbons(OC) dissolved in water. GF-Nyl's removal efficiency of TDS is comparable to a similar work conducted by Tuan (2008).A ceramic microfiltration system (CMS) was used to treat raw water for 9days. However, the TDS removal was very low, less than 10%.

The highest performance of TDS removal for GF-Nyl medium is due to the finest pore diameter of the nylon as indicated in figure 4.1, availability of amide functional group in nylon structure and free amine groups at the ends of its polymeric chains(Baig, 2010), and low pressure for the filtration. Microfiltration separates large molecules by sieving mechanism, therefore, GF-Nyl filter with pore size slightly lower than polyester concentrates more particulates and colloids in the raw water than filters made of polyester. The removal efficiency of TDS is improved as large molecules and ions are attached to sediments at the surface of the membrane. The amide group also makes nylon more electron rich than polyester, thus attracts positively charged ions and non ions in the raw water(Baig, 2010). GF-Nyl filtration was carried out at low pressure compared to CSWFFs, WFACF, CFFF-POL/Nyl and SFFF-Nyl medium. As result of this there was no material swollen to increase membrane pores to resulting in reduction of the filter efficiency.

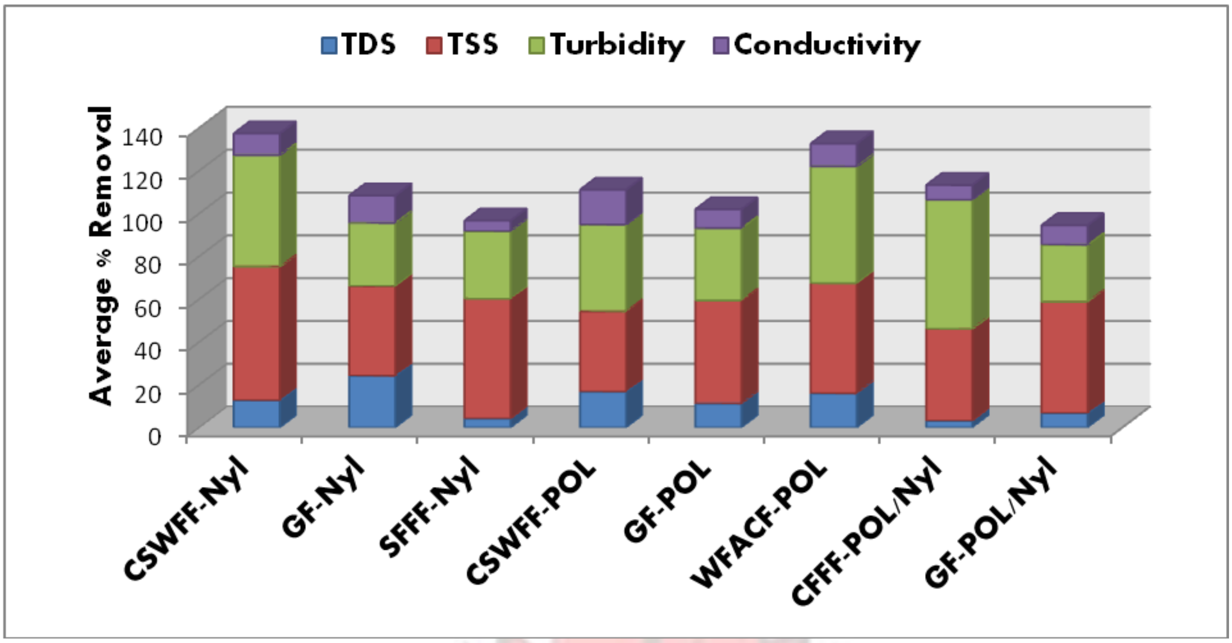

Figure 4.7a: Average Percent Filter Media Performance On TDS, TSS, Turbidity And Conductivity Removals

From figure 4.7a, nylon filter, CSWFF-Nyl had good efficiency removal of TSS (62.46%) in the raw water. The filter performance is approximately 17, 23 and 18 percent greater than composite (GF-POL/Nyl), hybrid system (WFACF-POL) and polyester filter (GFPOL) respectively. The CSWFF-Nyl filter has a fine pore diameter (Figure 4.1). Unlike SFFF and CFFF configuration there was more air inside the filter. This obviously led to the decrease in permeate flow thus concentrating more solids at the membrane surface. This confirms that the decrease in air permeate through the membrane causes the decrease in filtration efficiency(Landage, 2013).

The composite filter, CFFF-POL/Nyl performed highest for removal efficiency of turbidity than any filter (Figure 4.7a). A nylon based filter, CSWFF-Nyl and the hybrid system compete with the composite filter. The percent removal of turbidity for the composite filter was 60.28. the CFFF-POL/Nyl outstanding performance was due to the position of the polyester layer and the hydrophobic nature of the two materials(Taher, 2012; Kadolf, 2013). Nylon absorbs water more than polyester(*Ghaharpour et al*, 2011; Kadolf, 2013). Because of its hydrophilic nature among modern synthetic fibers, sizeable particulates are found in the feed to the polyester layer. These particulates are hydrophobic thus found them easily binding to the surface of the polyester medium thus increasing filtration efficiency.

A polyester based filter, CSWFF-POL obtained the highest removal efficiency of conductivity (16.23%) followed by GF-Nyl, which was 12.72%. Hybrid filter and composite medium also record 10.67 and 9.09 percent respectively. Comparatively the effectiveness of the filter media on conductivity removal is closed. Conductivity is a measure of concentrations of ions found in the feed. It is an indirect measure of TDS(Akorli, 2012). Although the COO functional group in the structure of polyester and CO group at the ends of it chain make it electron rich, thus like nylon can effectively bind to positively charge ions in the raw water. However, at low pH, H^+ in the feed competes with the presence of cations, which leads to the decrease in filtration efficiency(Landdaburu-Aguirre, 2012). By comparing pH values for the filter media (Tables 4.5, 4.6), CSWFF-POL filtrations were carried out at pH slightly higher than other filters. Therefore more cations could be bound to the medium to improve removal efficiency of conductivity

The figure 4.7b also summarizes the percent removal of total coliform bacteria in the raw water. CSWFF-POL/AQUATT obtained the highest performance in terms of total coliform bacteria removal in the raw water. The removal efficiency for the filter was 63.64%, slightly higher than treatment of raw water with aquatab chemical (AQUATT).The percent removal of coliform bacteria for AQUATT was 63.29. Composite filter media performances follow AQUATT. CFFF-POL/Nyl and CFFF-

POL/Nyl/AQUAT remove 59.03 and 59.09 percent of total coliform bacteria in the raw water respectively. CSWFF-Nyl filter performance on removal of total coliform bacteria was closed to CSWFF-POL. Both filters remove 50.05 and 52.35 percent of total coliform bacteria respectively. The hybrid filter, WFACF-POL had the lowest removal efficiency of total coliform bacteria among the four categories of the filter media (Figure 4.7b). As mentioned earlier total coliform count is a useful indicator of water pollution. The presence of total coliforms in water may be used as an indicator of faecal pollution, since total coliforms are excreted from warm blooded animals (Grabow and Du Preez, 1979: cited in Foit, 2010). It is, however,not as specific as the isolation of faecal coliforms since many species are also found in soil and aquatic environments. It is, however, considered a gold standard when used as a sanitary parameter for evaluating the quality of drinking water(Foit, 2010). Again MF as low pressure membrane filtration removes bacteria and pathogens by size exclusion mechanism(Achisa, 2013). Bacteria (0.5–10 µm), cysts and oocytes(3–15 µm) are larger and thus they can be totally eliminated during MF(*Bodzek et al*., 2011). The filters removal of total coliform bacteria would be dependent on their pore diameters and the formation of cake (including biofilm) at the surface of the media. The latter would facilitate the removal of bacteria during filtration. This is because the microorganisms find it convenient to be attached to sediments. However, the cake formation is also dependent on pores of the filter media and pressure for the filtrations. As shown in figure 4.7b, CSWFF-Nyl and CSWFF-POL are closed in terms of total coliform removal. This is owing to the closeness of their pores distribution (Table B1-1 and Table B1-3 in appendix B). The highest performance from CSWFF-POL/AQUATT is ascribed to the lower turbidity of the treated water from CSWFF-POL as compared to turbidity of raw for AQUATT, and a tablet of aquatab which was added to the treated water of CSWFF-POL. The presence of suspended solid matter in

water determines the turbidity of the water. High turbidity can reduce the efficiency of disinfection by increasing the disinfectant demand. It is recommended that the turbidity of water should be less than 1 NTU before disinfection(Achisa, 2013). At high turbidity, bacteria present in water would be attached to the colloids and solid particles thus preventing bacteria inactivation. Turbidity for products of CSWFF-POL and raw water for AQUATT were 0.30NTU -6.67NTU and 1.20NTU-7.72NTU (Tables 4.15, 4.16) respectively. The values show that aquatab would be more effective to remove total coliform bacteria in the treated from CSWFF-POL than raw water for AQUATT. Although, the dosage for AQUATT was twice of CSWFF-POL/AQUATT. The incomplete removal of total coliform by CSWFF-POL/AQUAT and CFFFPOL/Nyl/AQUATT was due to their considerable high turbidity values (Tables 4.15,
4.16). *Pikwa et al* (2010) added 3drops of chlorine to 2L of permeate from Remote Rural Water Treatment System (RRWTS). The turbidity of the permeate and *e.coli* count were <1NTU and 980-23count/100mL respectively. However, the result showed complete removal of *e coli* in the permeate. Comparatively, among the MF systems, the composite (CFFF-POL/Nyl) filter performance was the highest. This may be attributed to the combination of nylon and polyester, thus more pathogens are sieved.

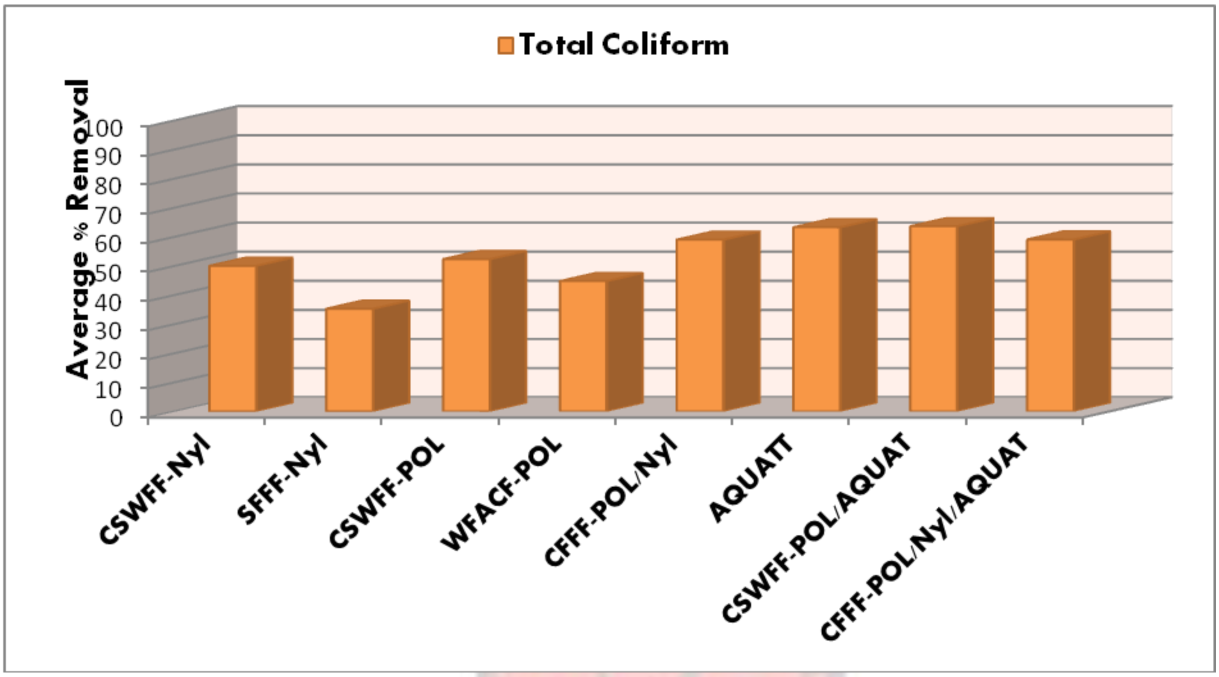

Figure 4.7b: Average Performance of Filter Media on Total Coliform Removal

The Figure 4.7c indicates the average performance of filter media on some heavy metals removals. The nylon filter, CSWFF-Nyl removed 67% Pb in the treated water whilst composite (CFFF-POL/Nyl) and hybrid filter (WFACF-POL) removed 66.67 and 61.25 percent respectively. Polyester filter media performance on lead (Pb) removal is low. Pecernt removal of Fe for CSWFF-POL, CFFF-POL/Nyl and WFACF-POL are 51.42, 50.00 and 48.61 respectively. The nylion filter media is the lowest among the four categories of the filter media. The hybrid filter, WFACF-POL is the highest removal of Cu in the treated water. Its percent removal of copper is 69.64% whilst CSWFF-Nyl and CSWFF- POL remove 50%. composite filter performance is the lowest among the four categories. The composite filter, CFFF-POL/Nyl performance on cadmium removal is the highest follwed by WFACF-POL. The performance of nylon and polyester filter on Cd removal is closed. Their percent removal are 49.49 and 50.02 respectively. Nylon filter,GF-Nyl is highest performance on removal of zinc. It removes 66.65 percent Zn whilist WFACF-POL and CFFF-POL/Nyl remove 61.31 and 58.33 percent. WFACFPOL records the highest performace of Mn removal, followed by composite, CFFFPOL/Nyl and CSWFF-POL. The lowest performance on Mn removal is polyester.

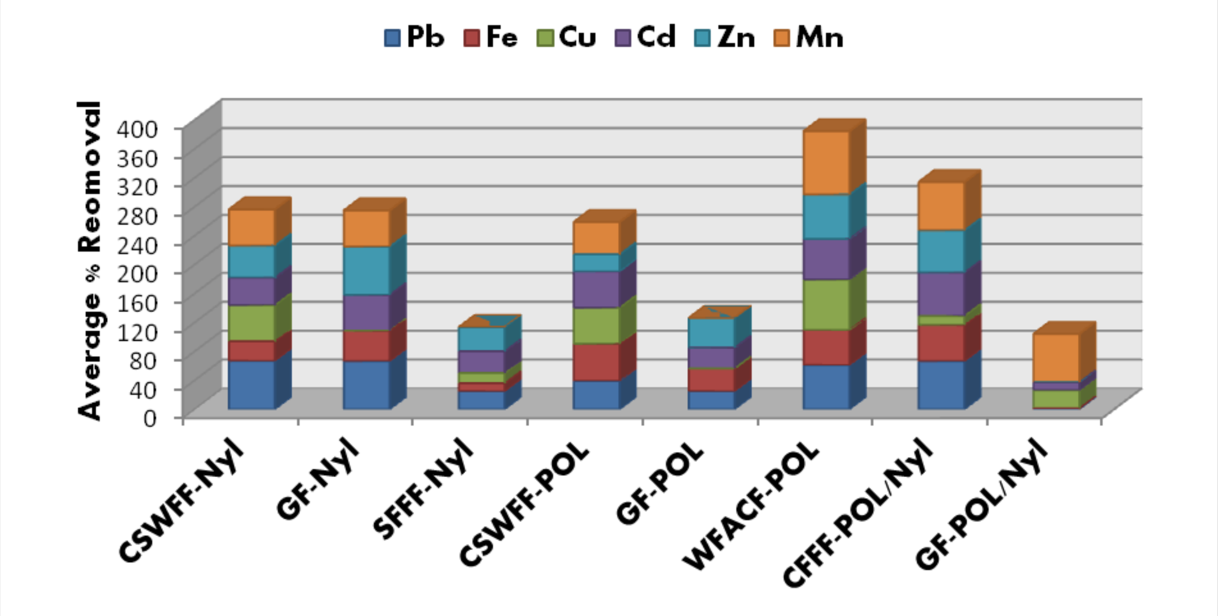

Figure 4.7c: Average Performance of Filter Media on Pb, Fe, Cu, Cd, Zn and Mn Removals

The heavy metals removal by MF is primarly dependent on size exclusion. In this mechanism insoluble metals are trapped based on filter media pores (*Kan et al*, 2012). Sorption mechanism can also contribute greatly in removal of heavy metals in water durimg microfiltration process. Usually sorption becomes more effective in MF when cake or sludge is formed at the surface of membranes, where metal ions are adsorbed to the cake. Biosorption technique in MF for heavy metals remdiation in water is also dependent on pH. At low pH biosorption is dominant in removal of metals in water but at high pH precipitation is dominat in removal of heay metal ions.(Setyadhi & Liu, 2013, *Malamis et al*, 2010). The highest performance of CSWFF-Nyl filter for Pb removal was due to the pH values for CSWFF-Nyl filtrations and finest pore of the medium(Figure

4.1). The pH range of raw water for CSWFF-Nyl filtrations was 7.5--6.9 , higher than CFFF-POL/Nyl(composite) and WFACF-POL(hybrid) medium(Tables 4.5, 4.6). at this pH , a large number of Pb ions is precipitated or insoluble in the raw water for CSWFFNyl filtrations than composite and hybrid medium. Therefore, large particles would be available to be sieved by the nylon filter. Morever, amide and amines funtional group in nylon structure also contribute to the filter's highest removal effiiciency of Pb. At short run time(5-10minutes) and pH range 7.5-6.9, sorption effect would also be contributed by CONH funtional group in nylon thus making it negatively charge to attract more ions than filters made of polyester(Landdaburu-Aguirre, 2012).

Although for Fe ions removal in the raw water, CSWFF-POL had the highest percentage removal but performance was closed to composite (CFFF-POL/Nyl) and hybrid (WFACF-POL). Again pH was a leading factor. The pH values of raw water for CSWFF-POL filtrations were higher than raw water for CFFF-POL/Nyl and WFACF medium filtrations(Tables 4.5,4.6). At high pH of water for CSWFF-POL filtrations ,more Fe (II) are oxidized to Fe(III) thus leading to more oxides(including hydorxides and oxyhydroxes) precipitated in the raw feed(Setyadhi & Liu, 2013). Another reason is that Fe oxides are hydrophillic(Setyadhi & Liu, 2013) thus finding them easier rejected by the polyester which is more hydrophobic than nylon(Kadolph, 2013).

Copper like other heavy metals can be removed in water by size exclusion principle as well as sorption when MF is applied. Formation of copper oxides in water is similar to heavy metals such nickel, cadmium, lead, iron, etc. WFACF-POL medium has recorded the highest removal efficiency of copper in the raw water. the combination of carbon sorbent with ployester medium might be the factor. pH values of raw water for WFACFPOL filtrations were quite lower than raw water for CSWFF-Nyl and CSWFF-POL medium filtrations (Tables 4.5, 4.6). at low pH 2-6 sorption contibutes more in removal of metal ions. Therefore, at pH 7 or slightly less, active sites are increased (there is no competion between H^+ and Cu^{2+} in the water) carbon granules thus improving the filtration efficiency of the filter(*Blázquez et al,* 2005).

Composite filter(CFFF-POL/Nyl) removes cadmium ions in the raw water than the remaing filters. The results show that combintion of nylon and polyester was the reason for highest percentage of cadmium removal by the composite filter. Cadimium ions would still be insoluble at pH7. Therefore large cadmium particles are filtered by the POL-Nyl medium. cadmium oxides precipitates are hydrophibic in nature, they tend to bind to the two membrane fabrics which are hyrophobic thus facilittaes in the removal of cadmium ions than other filters.

The results indictaed in figure 4.7c show that nylon filter, GF-Nyl performed better in removing zinc ions in the raw water. This could be linked to low pressure GF –Nyl filtrations, quick formation of cake and finest pore of the nylon. Large precipitates available in the raw water were removed by the nylon finest pores. Moreover, oxides of zinc are hydrophobic thus tends to bind to the nylon thus removing more zinc ions.

Mn(II) like Fe(II) under goes oxidation to form Mn(IV) oxides, which are insoluble water. the hybrid(WFACF-POL) filter obtanied the highest percentage in removal Mn in the raw water. This may be due to the increased in ative sites of carbon materials at pH 7 or less of raw water for the hybrid filter filtrations.

In general, the hybrid filter performance on heavy metlas removals is the highest followed by the composite and nylon filter. The hybrid system combines sieving with adsorption mechanism for the separation thus facilitates the removal of ions more than other filter media. The presence of amide and amines funtional groups in nylon makes its surface negatively charge than polyester. Therefore, combining sieving principle with sorption places it ahead of poyester in terms of ions removal.

4.3 Effect of run time on water quality parameters(TDS, TSS, Turbidity, Conductivity, total coliform and heavy metals(Pb(II), Fe(II) ,Cu(II) Cd(II), Zn(II) and Mn (II)

The table 4.21 shows the effect of run times on water quality parameters. The cycle time for all fitration was 5-10 minutes, however, samples were taken after 10-15 mintues for some filtrations to deterimine either there would be improved removal of pollutants in the raw water. In general there was significant decerase in TDS, TSS, turbidity and conductivity for samples taken after 10-15 minutes(Table 4.21). turbidity andd TDS for samples from CSWFF-Nyl and #WFACF-POL respectively ,were not improved at 10-15 minutes. MF performace is actually dependent on pores of the filter and the accumulation of cake at the surface of the filter after some time. A studytu conducted by Achisa (2013) on the use woven fabirc polyester(uncoated) for RRWTS for clay suspension water treatment showed increase in turbidity of the water with time. At 30 minutes the turbidity of the water dropped from 40NTU to 3NTU and remained constant.however, similar studies conducted by *Pikwa et al*(2010) removed turbidity significantly with time, and at 60 minutes , turbidities of permeate samples were below 1NTU. *Eusebio et al* (2011), studies on removal of humic acid (NOM) in sea water by combining activated carbon with microfiltration process also showed effect of run time on removal of dissolved organic carbons (DOC) in the water. TSS is also improved with time in ceramic microfiltration (CMF) application in surface water treatment. On the first day of operations, TSS concentration was 0.5mg/L, however after three days CMF removes 100% TSS in the water(Tuan, 2008).

From table 4.21, 2 out 4 samples taken after 10-15 minutes showed significant removal of total coliform bacteria in the raw water. This could be due to significant increase in cake at the surface of the filters with time thus trapping more bacteria. Achisa(2013) and Pikwa et al(2010) found significant reduction in *e.coli* with time in their studies on the use of RRWTS for clay suspension water and river water respectively. Again from table 4.21, all water samples (treated water) taken after 10-15 minutes have shown an increase in removal efficiency of Fe(II), Cd(II) and Mn(II) for all filters. In the case of Pb(II), Cu(II) and Zn(II), there was significant increase in removal efficiency with the exception of a sample from CSWFF-POL and two samples from CSWFF-Nyl.CSWFFNyl could not improve Pb(II) and Cu(II) removal whilst CSWFF-POL too could not improve zn(II). The improved removal efficiency of divalent cations in the raw water is because of the accumulation of cake or sludge after some time. The run time effects on removal efficiency of the metals agree with studies conducted by *Pikwa et al* (2010) and Tuan. (2008). They applied RRWTS and CMF respectively for water treatment and monitored concentration of Fe and Mn with time. Results from *Pikwa et al* (2010) show that at 30 minutes, Fe and Mn have been reduced from 0.88mg/L to 0.06mg/L and from 0.08mg/L to 0.04mg/L respectively. A research conducted by Bernard and Jimoh (2013) on on the use activated carbon from orange peel proves that there is contact time effect on removal of heavy metals in water. They concluded that there is significant increase in removal efficiency of Pb(II), Fe(II) Cu(II) and Zn. Pb (II), Cu (II) and Zn (II) all attained equilibrium within 60 min and 40 min for Fe (II).

Table 4.21: Effect of run time on water quality parameters

	WFACF-POL			CSWFF-POL			CSWFF-Nyl			#WFACF-POL		
Parameter	Feed	Product	Product#	Feed	Product	Product#	Feed	Product	Product#	Feed	Product	Product#
pH	6.6000	6.2000	6.2000	7.5000	7.1000	6.6000	6.9000	6.7000	6.7000	6.9000	6.4000	6.0000
TDS(mg/L)	110.00	100.00	80.000	130.00	110.00	80.000	70.000	60.000	60.000	80.000	70.000	60.000
TSS(mg/L)	26.100	12.000	8.000	27.800	20.000	19.000	28.000	11.000	14.000	28.000	11.000	6.000
Conductivity(μS/cm)	220.00	210.00	200.00	260.00	220.00	160.00	140.00	130.00	130.00	170.00	150.00	140.00
Turbidity(NTU)	0.8800	2.3600	2.0200	1.1800	1.1000	0.3000	8.2400	5.8700	5.1300	6.0600	2.1000	2.6000
Alkanity(mg/L)	34.000	27.000	24.000	33.000	30.000	29.000	11.000	11.000	11.000	15.000	9.0000	6.0000
Lead(mg/L)	0.2941	0.1471	0.0735	0.1471	0.1471	0.0000	0.6618	0.3676	0.3676	0.3676	0.2206	0.0735
Iron(mg/L)	0.2821	0.1254	0.0940	0.8464	0.1567	0.0068	0.1097	0.0627	0.0470	1.4107	1.0972	0.7053
Copper(mg/L)	0.0012	0.0000	0.0006	0.0012	0.0006	0.0000	0.0006	0.0006	0.0006	0.0042	0.0024	0.0006
Cadmium(mg/L)	1.6522	0.8870	0.0522	0.4000	0.1739	0.0568	0.6087	0.5391	0.4000	0.1913	0.1391	0.0870
Zinc(mg/L)	0.0188	0.0081	0.0054	0.0430	0.0350	0.0350	0.0188	0.0135	0.0108	0.0161	0.0081	0.0054
Manganese(mg/L)	0.0122	0.0061	0.0000	0.0365	0.0365	0.0006	0.0061	0.0061	0.0000	0.0122	0.0000	0.0000
Fecal coliform(CFU/100mL)	2.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
E.coli(CFU/100mL)	2.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total coliform(CFU/100mL)	35.000	15.000	17.000	32.000	18.000	15.0000	26.000	13.000	14.000	17.000	12.000	10.000

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusions

1. In the first stage of this study, the microscopic images of the five (5) fabrics were captured using LEICA DFC290. With the aid of Image J software, pore distribution of the fabrics was measured. It was found that the pore size of Nylon (Nyl), Nylon2 (Nyl2) and polyester were 1.5 µm, 27 µm and 1.7 µm respectively. Similarly the pore size of the local plain weave (LPW POL) and weave polyester (LTW POL) are 5 µm and 1.9 µm, respectively. Using the standard pore size range of MF filter media of 0.1 µm to 10 µm (Seader and Henley, 2006; Sikar, 1997; Wang and Zhou, 2013), polyester (POL), nylon (Nyl) and local twill waeve polyester (LTW POL) and local plain weave polyester (LPW POL) are eligible candidate for selection. Polyester (POL) and nylon (Nyl) of having average pore size of 1.5 µm and 1.7 µm were selected because of its availability in the local market.

2. Following this, the filter media were constructed from the two (2) selected fabrics and were categorized as: nylon, polyester, hybrid (activated carbon and polyester) and composite (polyester and nylon). The active membrane surface area for CSWFF, SFFF/CFFF and WFACF were 295 cm^2, 1785 cm^2 and 163 cm^2 respectively.

3. The filter media were used to treat raw water from GWCL, Mampong Dam and River Offin. The treatment cycle was 5-10 minutes. Products (treated water) were analyzed to measure concentrations of TDS, TSS, turbidity, conductivity, total coliform, faecal coliform, *e.coli* bacteria, Pb, Fe, Cu, Cd, Zn and Mn.

4. In spite polyester leads nylon in terms of conductivity, Fe, and cadmium removals. Comparatively, performance of nylon filter media in terms of pollutants removals is slightly ahead filters solely made of polyester. The percent removals of TDS, TSS, turbidity, conductivity, and total coliform bacteria for nylon media are 24.20, 62.46, 52.06, 12.72, and 50.02 respectively. Nylon percent performance in terms of Pb,Fe,Cu, Cd,Zn and Mn removals are 67, 42.22,50.00, 49.49,66.65 and 50.00 respectively. However, removal efficiency for composite and hybrid filter in terms of bacteria and heavy metals removal was encouraging. There was an also increased in performance of the filter media in terms of bacteria when aqautab chemical is combined. However, aquatab combination decreased conductivity, turbidity and TDS of the treated water. All filter media removed 100% faecal coliform and *e.coli* bacteria in treated water. The run time effect improved the percentage removal of the pollutants in the raw water.

5.2 Recommendations

The performances of the two selected fabrics are close, therefore both nylon and polyester must be utilized for microfiltration for surface water treatment. The study considered a short cycle time (5-10 minutes) for all filtration. Therefore, the filters must be operated for several days to determine the performance rate of the filter media in terms of pollutants removals. Clearly the studies had been focused on the measurement of the performance of the filter in respect of water quality, therefore, permeate flux and optimum trasmembrane pressure must also be investigated.

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APPENDIX A

Table A1-1: Quality of raw and treated water from GWCL, Mampong Dam -1ST BATCH TREATMENT ,CC&K'POL LAB

FILTERS	***CSWFF-Nyl***		***GF-Nyl***		***GF-POL***		***WFACF-POL***			***CSWFF-POL***	
Parameter	**Feed**	**Product**	**Feed**	**Product**	**Feed**	**Product**	**Feed**	**Product**	**Product#**	**Feed**	**Product**
pH	6.9000	6.5000	7.0000	6.2000	7.0000	6.8000	6.6000	6.2000	6.2000	7.1000	7.1000

TDS(mg/L)	90.000	90.000	150.00	90.000	150.00	140.00	110.00	100.00	80.000	90.000	80.000
TSS(mg/L)	31.200	21.800	28.600	14.000	28.600	18.000	26.100	12.000	8.0000	24.500	20.400
Conductivity(µS/cm)	190.00	170.00	270.00	200.00	270.00	320.00	220.00	210.00	200.00	190.00	170.00
Turbidity(NTU)	1.5900	0.3800	0.9400	0.6800	0.9400	0.5900	0.8800	2.3600	2.0200	1.1200	0.6100
Alkanity(mg/L)	34.000	27.000	26.000	18.000	26.000	23.000	34.000	27.000	24.000	31.000	30.000
Lead(mg/L)	0.7353	0.0735	0.0735	0.0000	0.0735	0.0735	0.2941	0.1471	0.0735	0.5147	0.2206
Iron(mg/L)	0.1411	0.1254	0.1567	0.0940	0.1567	0.1097	0.2821	0.1254	0.0940	0.1254	0.1097
Copper(mg/L)	0.0006	0.0000	0.0006	0.0006	0.0006	0.0006	0.0012	0.0000	0.0006	0.0012	0.0006
Cadmium(mg/L)	1.5304	0.5391	1.7217	0.8696	1.7217	1.2870	1.6522	0.8870	0.0522	0.7826	0.4348
Zinc(mg/L)	0.0135	0.0054	0.0323	0.0054	0.0323	0.0242	0.0188	0.0081	0.0054	0.0188	0.0081
Manganese(mg/L)	0.0061	0.0000	0.0122	0.0000	0.0122	0.0122	0.0122	0.0061	0.0000	0.0304	0.0061
Fecal coliform(CFU/100mL)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	2.0000	0.0000	0.0000	0.0000	0.0000
E.coli(CFU/100mL)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	2.0000	0.0000	0.0000	0.0000	0.0000
Total coliform(CFU/100mL)	28.000	17.000	32.000	29.000	32.000	39.000	35.000	15.000	17.000	29.000	16.000

Table A1-2: Quality of raw and treated water from GWCL, Mampong Dam-1ST BATCH TREATMENT,LAN LAB

FILTERS	***GF-Nyl***		***GP-POL***		***CSWFF-Nyl***		***WFACF-POL***		
Parameter	**Feed**	**Product**	**Feed**	**product**	**Feed**	**product**	**Feed**	**Product**	**Product#**
pH	7.2600	7.2400	7.2600	7.2100	7.5600	7.3300	7.3100	7.0000	7.1000
TDS(mg/L)	95.000	60.000	80.000	80.000	70.000	70.000	70.000	60.000	65.000
TSS(mg/L)	0.2040	0.1440	0.2040	0.1450	1.0900	0.0900	0.1230	0.1070	0.0190

Conductivity(μS/cm)	160.00	140.00	160.00	160.00	140.00	130.00	140.00	125.00	130.00
Turbidity(NTU)	2.7000	1.0600	2.7020	1.5000	2.6700	1.3000	5.0000	5.0000	3.0000
Alkanity(mg/L)	50.000	45.000	50.000	45.000	40.000	45.000	45.000	40.000	40.000

Table A1-3:Quality of raw and treated water from River Offin-1ST BATCH TREATMENT,CC&K'POLY LAB

FILTERS	***CSWFF-POL***			***AQUATT***		***CSWFF-POL/AQUAT***	
Parameter	**Feed**	**Product**	**Product#**	**Feed**	**Product**	**Feed**	**Product**
pH	7.5000	7.1000	6.6000	6.8000	7.0000	6.8000	7.3000
TDS(mg/L)	130.00	110.00	80.000	80.000	90.000	80.000	90.000
TSS(mg/L)	27.800	20.000	19.000	31.200	19.500	31.200	22.400
Conductivity(µS/cm)	260.00	220.00	160.00	180.00	200.00	180.00	180.00
Turbidity(NTU)	1.1800	1.1000	0.3000	1.2000	1.5000	1.2000	2.5900
Alkanity(mg/L)	33.000	30.000	29.000	33.000	34.000	33.000	33.000
Lead(mg/L)	0.1471	0.1471	0.0000				
Iron(mg/L)	0.8464	0.1567	0.0068				
Copper(mg/L)	0.0012	0.0006	0.0000				
Cadmium(mg/L)	0.4000	0.1739	0.0568				
Zinc(mg/L)	0.0430	0.0350	0.0350				
Manganese(mg/L)	0.0365	0.0365	0.0006				
Fecal coliform(CFU/100mL)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

E.coli(CFU/100mL)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total coliform(CFU/100mL)	32.000	18.000	15.0000	26.000	12.000	26.000	8.000

Table A1-4:Quality of raw and treated water from River Offin-1ST BATCH TREATMENT, LAN LAB

FILTERS	***CSWFF-POL***		***AQUATT***		
Parameter	Feed	Product	Product#	Feed	Product
pH	7.1800	7.1500	7.1000	7.2400	7.4000
TDS(mg/L)	70.000	60.000	60.000	60.000	70.000
TSS(mg/L)	0.2020	0.0620	0.0980	0.0620	0.0980
Conductivity(µS/cm)	150.00	120.00	130.00	120.00	140.00
Turbidity(NTU)	5.0000	3.0000	3.0000	3.0000	4.0000
Alkanity(mg/L)	45.000	40.000	40.000	40.000	45.000

Table A2-1: Quality of raw and treated water from GWCL, Mampong Dam-2ND BATCH TREATMENT,CC&K'POLY LAB

FILTERS	***GF-Nyl***		***GF-POL***		***CSWFF-Nyl***			***CSWFF-POL***	
Parameter	**Feed**	**Product**	**Feed**	**Product**	**Feed**	**Product**	**Product#**	**Feed**	**Product**
pH	7.1000	6.7000	7.1000	6.8000	6.9000	6.7000	6.7000	6.9000	6.8000
TDS(mg/L)	70.000	60.000	70.000	60.000	70.000	60.000	60.000	70.000	70.000
TSS(mg/L)	22.000	15.000	22.000	14.000	28.000	11.000	14.000	28.000	13.000
Conductivity(µS/cm)	140.00	130.00	140.00	120.00	140.00	130.00	130.00	140.00	140.00
Turbidity(NTU)	10.550	9.6400	10.550	9.7600	8.2400	5.8700	5.1300	8.2400	6.6700
Alkanity(mg/L)	11.000	11.000	11.000	11.000	11.000	11.000	11.000	11.000	11.000
Lead(mg/L)	0.0735	0.1471	0.1471	0.0735	0.6618	0.3676	0.3676	0.2206	0.2206
Iron(mg/L)	0.1411	0.0784	0.0940	0.0627	0.1097	0.0627	0.0470	0.1254	0.1097
Copper(mg/L)	0.0006	0.0006	0.0000	0.0000	0.0006	0.0006	0.0006	0.0000	0.0000
Cadmium(mg/L)	1.7217	0.8696	0.8696	0.5913	0.6087	0.5391	0.4000	0.7826	0.6783
Zinc(mg/L)	0.0323	0.0161	0.0188	0.0081	0.0188	0.0135	0.0108	0.0054	0.0054
Manganese(mg/L)	0.0061	0.0061	0.0061	0.0061	0.0061	0.0061	0.0000	0.0000	0.0000
Fecal coliform(CFU/100mL)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
E.coli(CFU/100mL)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total coliform(CFU/100mL)	38.000	36.000	38.000	37.000	26.000	13.000	14.000	26.000	14.000

contd

FILTERS	***CFFF-POL/Nyl***	***AQUATT***	***CFFF-POL/Nyl/AQUAT***	***CSWFF-POL/AQUAT***

Parameter	Feed	Product	Feed	Product	Feed	Product	Feed	Product
pH	6.9000	6.6000	6.8000	6.9000	6.8000	6.6000	6.8000	7.1000
TDS(mg/L)	70.000	70.000	60.000	80.000	60.000	70.000	60.000	110.00
TSS(mg/L)	28.000	10.000	18.000	9.0000	18.000	6.0000	18.000	10.000
Conductivity(µS/cm)	140.00	140.00	130.00	160.00	130.00	140.00	130.00	220.00
Turbidity(NTU)	8.2400	4.0500	7.7200	12.320	7.7200	9.1600	7.7200	8.2800
Alkanity	11.000	11.000	12.000	13.000	12.000	13.000	12.000	13.000
Fecal coliform(CFU/100mL)	0.0000	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000	0.0000
E.coli(CFU/100mL)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total coliform(CFU/100mL)	26.000	10.000	22.000	6.0000	22.000	9.0000	22.000	8.0000

Table A2-2: Quality of raw and treated water from River Offin-2ND BATCH TREATMENT, CC&K'POLY LAB

FILTERS	***GF-POL/Nyl***		***SFFF-Nyl***			***WFACF-POL***			***CFFF-POL/Nyl***	
Parameter	**Feed**	**Product**	**Feed**	**Product**	**product#**	**Feed**	**Product**	**Product#**	**Feed**	**Product**
pH	6.9000	6.7000	6.9000	7.0000	6.8000	6.9000	6.4000	6.0000	6.9000	6.5000
TDS(mg/L)	80.000	80.000	80.000	80.000	80.000	80.000	70.000	60.000	90.000	90.000
TSS(mg/L)	28.000	9.000	28.000	10.000	7.000	28.000	11.000	6.000	14.000	14.000

Conductivity(µS/cm)	170.00	170.00	170.00	160.00	165.00	170.00	150.00	140.00	190.00	180.00
Turbidity(NTU)	6.0600	2.6400	6.0600	5.6800	4.6700	6.0600	2.1000	2.6000	6.3200	4.6900
Alkanity(mg/L)	15.000	16.000	15.000	15.000	16.000	15.000	9.0000	6.0000	17.000	15.000
Lead(mg/L)	0.0735	0.0735	0.2941	0.2206	0.2206	0.3676	0.2206	0.0735	0.2206	0.0735
Iron(mg/L)	1.0345	1.0188	0.1411	0.1254	0.1254	1.4107	1.0972	0.7053	0.1567	0.0784
Copper(mg/L)	0.0024	0.0018	0.0042	0.0036	0.0036	0.0042	0.0024	0.0006	0.0048	0.0042
Cadmium(mg/L)	0.1217	0.1391	0.0870	0.0696	0.0522	0.1913	0.1391	0.0870	0.1304	0.0522
Zinc(mg/L)	0.0242	0.0242	0.0161	0.0108	0.0108	0.0161	0.0081	0.0054	0.0323	0.0135
Manganese(mg/L)	0.0182	0.0061	0.0182	0.0182	0.0182	0.0122	0.0000	0.0000	0.0182	0.0061
Fecal coliform(CFU/100mL)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
E.coli(CFU/100mL)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total coliform(CFU/100mL)	17.000	11.000	17.000	10.000	12.000	17.000	12.000	10.000	23.000	10.000

FILTERS	***GF-Nyl***		***GF-POL***		***CSWFF-Nyl***		***CSWFF-POL***	
Parameter	**Feed**	**Product**	**Feed**	**Product**	**Feed**	**Product**	**Feed**	**Product**
pH	6.8000	6.6000	6.8000	6.7000	6.9000	6.6000	6.9000	7.0000
TDS(mg/L)	90.000	80.000	90.000	80.000	90.000	80.000	90.000	80.000
TSS(mg/L)	38.000	17.000	38.000	20.000	14.000	13.000	14.000	11.000
Conductivity(µS/cm)	180.00	170.00	180.00	170.00	190.00	160.00	190.00	170.00
Turbidity(NTU)	5.7100	4.5100	5.7100	5.4500	6.3200	8.6700	6.3200	4.3100

Alkanity(mg/L)	17.000	16.000	17.000	17.000	17.000	11.000	17.000	16.000
Fecal coliform(CFU/100mL)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
E.coli(CFU/100mL)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total coliform(CFU/100mL)	20.000	28.000	20.000	45.000	23.000	9.0000	23.000	6.0000

Tabel A2-3: Quality of raw and treated water from GWCL, Mampong Dam-2ND BATCH TREATMENT, LAN LAB

FILTERS	***GF-POL***		***GF-POL/Nyl***		***CSWFF-Nyl***		***CSWFF-POL***		***CFFF-POL/Nyl***	
Parameter	**Feed**	**Product**	**Feed**	**Product**	**Feed**	**Product**	**Feed**	**Product**	**Feed**	**Product**
pH	6.9000	6.8300	6.9000	6.6300	6.9000	6.7300	6.9000	6.7800	6.9000	6.7200
TDS(mg/L)	50.000	50.000	50.000	40.000	50.000	50.000	50.000	50.000	50.000	50.000
TSS(mg/L)	0.1100	0.0080	0.1100	0.0470	0.1100	0.0360	0.1100	0.0790	0.1100	0.0680
Conductivity(µS/cm)	110.00	100.00	110.00	100.00	110.00	110.00	110.00	100.00	110.00	100.00

Turbidity(NTU)	3.0000	2.0000	3.0000	2.0000	3.0000	3.0000	3.0000	2.0000	3.0000	1.2000
Alkanity(mg/L)	40.000	35.000	40.000	35.000	40.000	35.000	40.000	30.000	40.000	30.000

FILTERS	***SFFF-Nyl***		***WFACF-POL***		***AQUATT***		***CFFF-POL/Nyl/AQUAT***		***CSWFF-POL/AQUA***	
Parameter	**Feed**	**Product**	**Feed**	**Product**	**Feed**	**Product**	**Feed**	**Product**	**Feed**	**Product**
pH	6.9000	6.5500	6.8200	6.6000	6.8200	6.9500	6.8200	6.7000	6.8200	6.9600
TDS(mg/L)	50.000	50.000	60.000	50.000	60.000	70.000	60.000	60.000	60.000	75.000
TSS(mg/L)	0.1100	0.0820	0.1120	0.1030	0.1120	0.0340	0.1120	0.0240	0.1120	0.1460
Conductivity(µS/cm)	110.00	110.00	110.00	90.000	110.00	120.00	110.00	120.00	110.00	120.00
Turbidity(NTU)	3.0000	3.0000	3.0000	1.5000	3.0000	5.0000	3.0000	5.0000	3.0000	4.0000
Alkanity(mg/L)	40.000	35.000	35.000	35.000	35.000	40.000	35.000	40.000	35.000	40.000

Table A2-4:Quality of raw and treated water from River Offin-2ND BATCH TREATMENT, LAN LAB

FILTERS	***GF-Nyl***		***GF-POL/Nyl***		***GF-POL***		***SFFF-Nyl***		***CSWFF-Nyl***	
Parameter	**Feed**	**Product**	**Feed**	**Product**	**Feed**	**Product**	**Feed**	**Product**	**Feed**	**Product**
pH	7.0000	6.6400	7.0000	6.5000	7.0000	6.6100	7.0000	6.5500	7.0000	6.7500
TDS(mg/L)	80.000	65.000	80.000	80.000	80.000	70.000	80.000	70.000	80.000	70.000
TSS(mg/L)	0.3970	0.3780	0.3970	0.2740	0.3970	0.2110	0.3970	0.2830	0.3970	0.1230
Conductivity(µS/cm)	160.00	140.00	160.00	160.00	160.00	150.00	160.00	150.00	160.00	150.00
Turbidity(NTU)	5.0000	4.0000	5.0000	4.0000	5.0000	4.0000	5.0000	3.0000	5.0000	5.0000
Alkanity(mg/L)	50.000	45.000	50.000	45.000	50.000	50.000	50.000	45.000	50.000	45.000

FILTERS	***CSWFF-POL***		***CFFF-POL/Nyl***		***WFACF-POL***	
Parameter	**Feed**	**Product**	**Feed**	**Product**	**Feed**	**Product**
pH	7.0000	6.5800	7.0000	6.5100	7.0000	6.6600
TDS(mg/L)	80.000	70.000	80.000	70.000	80.000	80.000
TSS(mg/L)	0.3970	0.3970	0.3970	0.2920	0.3970	0.0930
Conductivity(µS/cm)	160.00	140.00	160.00	150.00	160.00	150.00
Turbidity(NTU)	5.0000	3.0000	5.0000	1.5000	5.0000	2.0000
Alkanity(mg/L)	50.000	40.000	50.000	45.000	50.000	40.000

Table A3-1: Filters performance on removal of pollutants in raw water from GWCL, Mampong Dam and River Offin-1ST BATCH TREATMENT

FILTER/WS/LAB	***CSWFF-Nyl:MdamCC***	***CSWFF-Nyl:MdamLAN***	***CSWFF-POL:MdamCC***	***CSWFF-POL:RoffinCC***	***CSWFF-POL:RoffinCC#***	***CSWFF-POL:RoffinLAN***	***CSWFF-POL:RoffinLAN#***	***AQUATT:RoffinCC***
Parameter				**% REMOVAL**				
TDS(mg/L)	0.000	0.000	11.11	15.38	38.46	14.29	14.29	-12.50
TSS(mg/L)	30.13	91.74	16.73	28.06	31.65	69.31	51.49	37.50
Conductivity(µS/cm)	10.53	7.143	10.53	15.38	38.46	20.00	13.33	-11.11
Turbidity(NTU)	76.10	51.31	45.54	6.78	74.58	40.00	40.00	-25.00
Lead(mg/L)	90.00		57.14	0.00	100.0			
Iron(mg/L)	11.11		12.50	81.48	99.20			
Copper(mg/L)	100.0		50.00	50.00	100.0			
Cadmium(mg/L)	64.77		44.44	56.52	85.80			

Zinc(mg/L)	60.00	57.14	18.75	18.75	
Manganese(mg/L)	100.0	80.00	0.00	98.44	
Fecal coliform(CFU/100mL)	0.000	0.000	0.000	0.000	0.000
E.coli(CFU/100mL)	100.0	0.000	0.000	0.000	0.000
Total coliform(CFU/100mL)	39.29	44.83	43.75	53.13	53.85

Contd

FILTER/WS/LAB	***AQUATT: Roffin-LAN***	***GF-Nyl:MdamCC***	***GF-Nyl:MdamLAN***	***GF-POL:MdamCC***	***GF-POL:MdamLAN***	***WFACF-POL:MdamCC***	***WFACF-POL:MdamCC#***	***WFACF-POL:Mdam-LAN***	***WFACF-POL:MdamLAN#***	***CSWFF-POL/AQUAT: Roffin-CC***
Parameter				**% REMOVAL**						
TDS(mg/L)	-16.67	40.00	36.84	6.667	0.000	9.091	27.27	14.29	7.143	-12.50
TSS(mg/L)	-58.06	51.05	29.41	37.06	28.92	54.02	69.35	13.01	84.55	28.21
Conductivity(µS/cm)	-16.67	25.93	12.50	-18.52	0.000	4.545	9.091	10.71	7.143	0.000
Turbidity(NTU)	-33.33	27.66	60.74	37.23	44.49	-168.2	-129.5	0.000	40.00	-115.8
Lead(mg/L)		100.0		0.00		50.00	75.00			
Iron(mg/L)		40.00		30.00		55.56	66.67			
Copper(mg/L)		0.000		0.000		100.0	50.00			
Cadmium(mg/L)		49.49		25.25		46.32	96.84			
Zinc(mg/L)		83.33		25.00		57.14	71.43			
Manganese(mg/L)		100.0		0.000		50.00	100.0			
Fecal coliform(CFU/100mL)		0.000		0.000		100.0	100.0			0.000

E.coli(CFU/100mL)	0.000	0.000	100.0	100.0	0.000
Total coliform(CFU/100mL)	9.375	-21.88	57.14	51.43	69.23

Table A3-2:Filters performance on removal of pollutants in raw water from GWCL, Mampong Dam and River Offin-2ND BATCH TREATMENT

FILTER/WS/LAB	***CSWFF-Nyl:Mdam -CC***	***CSWFF-Nyl:Mdam -LAN***	***CSWFF-Nyl:ROffin -CC***	***CSWFF-Nyl:ROffin -LAN***	***SFFF-Nyl:Roffin -CC***	***SFFF-Nyl:Roffin -CC#***	***SFFF-Nyl:Roffin -LAN***	***CSWFF-POL:Mdam -CC***	***CSWFF-POL:Mdam - LAN***	***CSWFF-POL:ROffin -CC***	***CSWFF-POL:ROffin -LAN***
			Parameter					**% REMOVAL**			
TDS(mg/L)	14.29	0.000	11.11	12.50	0.000	0.000	12.50	0.000	0.000	11.11	12.50
TSS(mg/L)	60.71	67.27	7.143	69.02	64.29	75.00	28.72	53.57	28.18	21.43	0.000
Conductivity(µS/cm)	7.143	0.000	15.79	6.250	5.882	2.941	6.250	0.000	9.091	10.53	12.50
Turbidity(NTU)	28.76	0.000	-37.18	0.000	6.271	22.94	40.00	19.05	33.33	31.80	40.00
Lead(mg/L)	44.44				25.00	25.00		0.000			
Iron(mg/L)	42.86				11.11	11.11		12.50			
Copper(mg/L)	0.000				14.29	14.29		0.000			
Cadmium(mg/L)	11.43				20.00	40.00		13.33			
Zinc(mg/L)	28.57				33.33	33.33		0.000			
Manganese(mg/L)	0.000				0.000	0.000		0.000			
Fecal coliform(CFU/100mL)	0.000		0.000		0.000	0.000		0.000		0.000	

E.coli(CFU/100mL)	0.000	0.000	0.000	0.000	0.000	0.000
Total coliform(CFU/100mL)	50.00	60.87	41.18	29.41	46.15	73.91

contd

FILTER/WS/LAB	*CFFF-POL/Nyl:Mdam-CC*	*CFFF-POL/Nyl:Mdffin-LAN*	*CFFF-POL/Nyl:ROm-CC*	*CFFF-POL/Nyl:ROin-CC*	*GF-Nyl:Mdain-LAN*	*GF-Nyl:Roffam-CC*	*GF-Nyl:Roffam-LAN*	*GF-POL:Mdam-LAN*	*GF-POL:Mdffin-CC*	*GF-POL:Roffin-CC*	*GF-POL:Roffin-LAN*	*GF-POL/Nyl:Roffin-CC*
Parameter								**% REMOVAL**				
TDS(mg/L)	0.000	0.000	0.000	12.50	14.29	11.11	18.75	14.29	0.000	11.11	12.50	0.000
TSS(mg/L)	64.29	38.18	0.000	26.45	31.82	55.26	4.786	36.36	92.73	47.37	46.85	67.86
Conductivity(µS/cm)	0.000	9.091	5.263	6.250	7.143	5.556	12.50	14.29	9.091	5.556	6.250	0.000
Turbidity(NTU)	50.85	60.00	25.79	70.00	8.626	21.02	20.00	7.488	33.33	4.553	20.00	56.44
Lead(mg/L)			66.67		33.33			50.00				0.000
Iron(mg/L)			50.00		44.44			33.33				1.515
Copper(mg/L)			12.50		0.000			0.000				25.00
Cadmium(mg/L)			60.00		49.49			32.00				11.11
Zinc(mg/L)			58.33		50.00			57.14				0.000
Manganese(mg/L)			66.67		0.000			0.000				66.67
Fecal coliform(CFU/100mL)	0.000		0.000		0.000	0.000		0.000		0.000		0.000

E.coli(CFU/100mL)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Total coliform(CFU/100mL)	61.54	56.52	5.263	-40.00	2.632	-125.0	35.29

FILTER/WS/LAB	*GF-POL/Nyl:Roffin-LAN*	*GF-POL/Nyl:Mdam-LAN*	*WFACF-POL:Roffin-CC*	*WFACF-POL:Roffin-CC#*	*WFACF-POL:Roffin-LAN*	*WFACFPOL:Mdam-LAN*	*AQUAT T: MdamCC*	*AQUAT T: Mdam-LAN*	*CFFF-POL/Nyl/AQUAT: Mdam-CC*	*CFFF-POL/Nyl/AQUAT: Mdam-LAN*	*CSWFF-POL/AQUAT :MdamCC*	*CSWFFPOL/AQUAT: Mdam-LAN*
Parameter								**% REMOVAL**				
TDS(mg/L)	0.000	20.00	12.50	25.00	0.000	16.67	-33.33	-16.67	-16.67	0.00	-83.33	-25.00
TSS(mg/L)	30.98	57.27	60.71	78.57	76.57	8.036	50.00	69.64	66.67	78.57	44.44	-30.36
Conductivity(µS/cm)	0.000	9.091	11.76	17.65	6.250	18.18	-23.08	-9.091	-7.69	-9.09	-69.23	-9.09
Turbidity(NTU)	20.00	33.33	65.35	57.10	60.00	50.00	-59.59	-66.67	-18.65	-66.67	-7.25	-33.33
Lead(mg/L)			40.00	80.00								
Iron(mg/L)			22.22	50.00								
Copper(mg/L)			42.86	85.71								
Cadmium(mg/L)			27.27	54.55								
Zinc(mg/L)			50.00	66.67								
Manganese(mg/L)			100.0	100.0								

Coliform(CFU/100mL)	0.000	0.000	100.0	100.0	100.0
E.coli(CFU/100mL)	0.000	0.000	0.000	0.000	0.000
Total coliform(CFU/100mL)	29.41	41.18	72.73	59.09	63.64

Table A4-1:Absorbance measurement in 1st batch water treatment

GWCL, MAMPONG DAM

FILTERS	***CSWFF-Nyl***		***GF-POL***		***GP-Nyl***		***WFACF-POL***		***CSWFF-POL***		
Parameter	**Feed**	**Product**	**Feed**	**Product**	**Feed**	**Product**	**Feed**	**Product**	**Product#**	**Feed**	**Product**
Lead(abs)	0.0100	0.0010	0.0010	0.0010	0.0010	0.0000	0.0040	0.0020	0.0010	0.0020	0.0020
Iron(abs)	0.0090	0.0080	0.0100	0.0070	0.0100	0.0060	0.0180	0.0080	0.0060	0.0540	0.0100
Copper(abs)	0.0010	0.0000	0.0010	0.0010	0.0010	0.0010	0.0020	0.0000	0.0010	0.0020	0.0010
Cadmium(abs)	0.0880	0.0310	0.0990	0.0740	0.0990	0.0500	0.0950	0.0510	0.0030	0.0230	0.0100
Zinc(abs)	0.0050	0.0020	0.0120	0.0090	0.0120	0.0020	0.0070	0.0030	0.0020	0.0160	0.0130
Manganese(abs)	0.0010	0.0000	0.0020	0.0020	0.0020	0.0000	0.0020	0.0010	0.0000	0.0060	0.0060

RIVER OFFIN

FILTERS	***CSWFF-POL***		
Parameter	Feed	Product	Product#
Lead(abs)	0.0070	0.0030	0.0030
Iron(abs)	0.0080	0.0060	0.0070
Copper(abs)	0.0020	0.0000	0.0010

Cadmium(abs)	0.0450	0.0310	0.0250
Zinc(abs)	0.0070	0.0020	0.0030
Manganese(abs)	0.0050	0.0020	0.0010

Table A4-2: Absorbance measurement in 2nd batch water treatment

GWCL, MAMPONG DAM

FILTERS	***CSWFF-Nyl***		***GF-POL***		***GF-Nyl***		***WFACF-POL***			***CSWFF-POL***	
Parameter	**Feed**	**Product**	**Feed**	**Product**	**Feed**	**Product**	**Feed**	**Product**	**Product#**	**Feed**	**Product**
Lead(abs)	0.009	0.005	0.002	0.001	0.003	0.002	0.005	0.003	0.001	0.003	0.003
Iron(abs)	0.007	0.003	0.006	0.004	0.009	0.005	0.09	0.07	0.045	0.008	0.007
Copper(abs)	0.001	0.001	0	0	0.001	0.001	0.007	0.004	0.001	0	0
Cadmium(abs)	0.035	0.023	0.05	0.034	0.099	0.05	0.011	0.008	0.005	0.045	0.039
Zinc(abs)	0.007	0.004	0.007	0.003	0.012	0.006	0.006	0.003	0.002	0.002	0.002
Manganese(abs)	0.001	0	0.001	0.001	0.001	0.001	0.002	0	0	0	0

RIVER OFFIN

FILTERS	***CSWFF-POL***		***CFFF-POL/Nyl***		***GF-POL/Nyl***		***SFFF-Nyl***		
Parameter	**Feed**	**Product**	**Feed**	**Product**	**Feed**	**Product**	**Feed**	**Product**	**Product#**
Lead(abs)	0.002	0.002	0.003	0.001	0.001	0.001	0.004	0.003	0.003
Iron(abs)	0.054	0.01	0.01	0.005	0.066	0.065	0.009	0.008	0.008
Copper(abs)	0.002	0.001	0.008	0.007	0.004	0.003	0.007	0.006	0.006

Cadmium(abs)	0.023	0.01	0.0075	0.003	0.009	0.008	0.005	0.004	0.003
Zinc(abs)	0.016	0.013	0.012	0.005	0.009	0.009	0.006	0.004	0.004
Manganese(abs)	0.006	0.006	0.003	0.001	0.003	0.001	0.003	0.003	0.003

Table A5: Linear range of elements

Element	Symbol	Wavelength	Linear Range
Cadmium	Cd	228nm	2.0ppm
Copper	Cu	324.8nm	5.0ppm
		327.4nm	5.0ppm
		216.5nm	20.0ppm
		222.6nm	50.0ppm
Iron	Fe	248.3nm	6.0ppm
		252.3nm	10.0ppm
		302.1nm	10.0ppm
		296.7nm	20.0ppm
Manganese	Mn	279.5nm	2.0 ppm
		279.8nm	5.0ppm
		280.1nm	5.0ppm
Lead	Pb	283.3ppm	20.0ppm
		217.0nm	20.0ppm
Zinc	Zn	213.9nm	1.0ppm

Source:(Perlkin-Elmer Corporation, 1996)

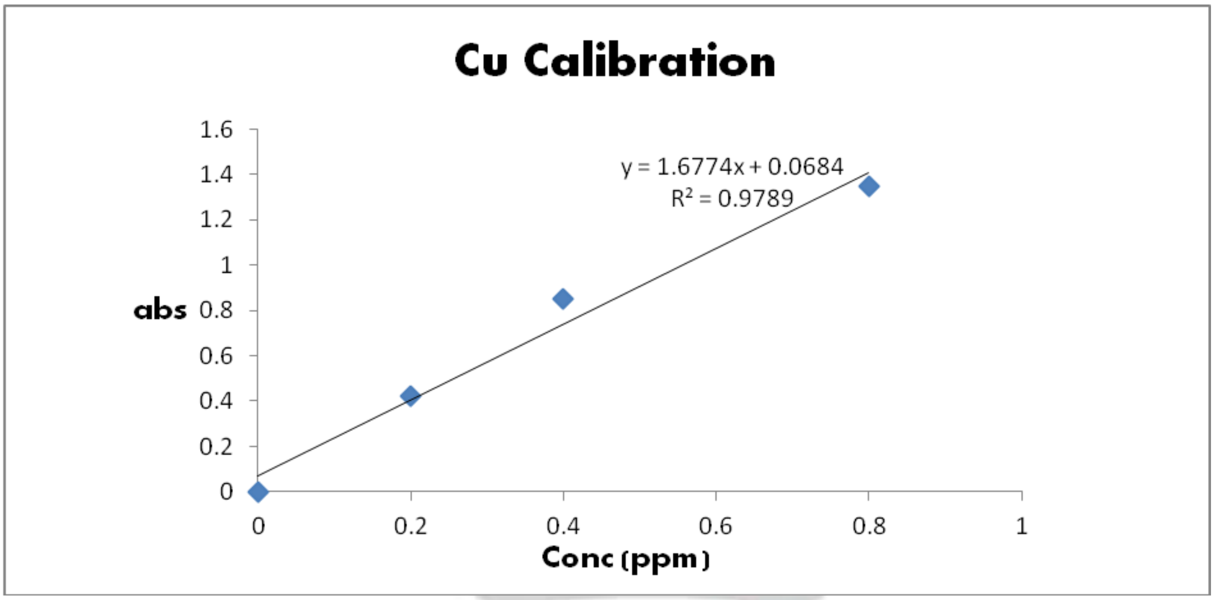


Figure A1-1: Copper Calibration Graph

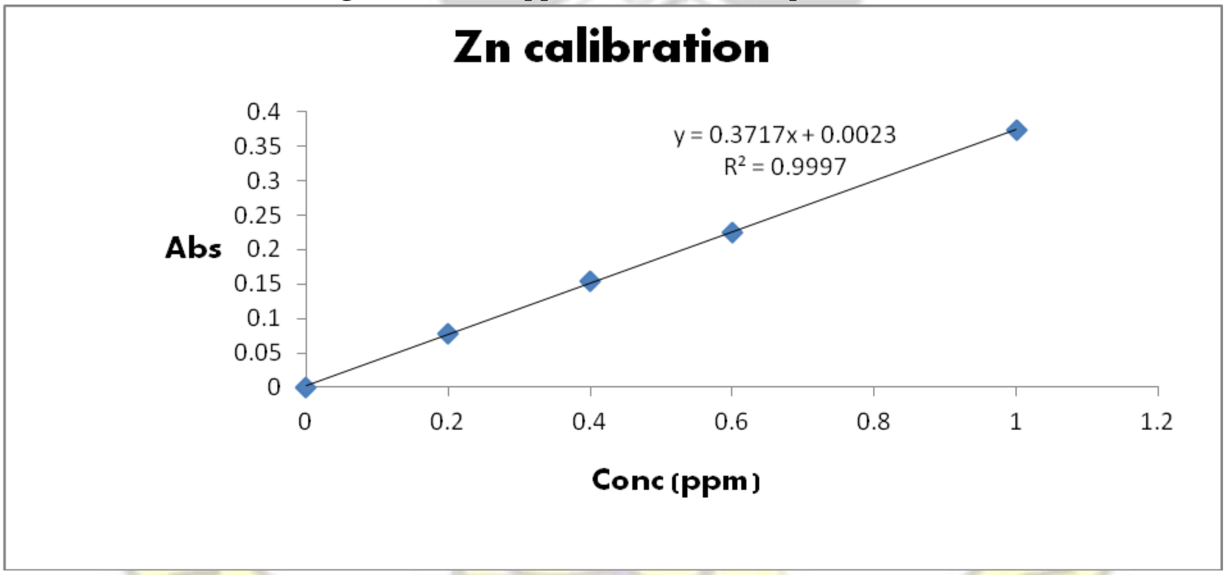


Figure A1-2: Zinc Calibration Graph

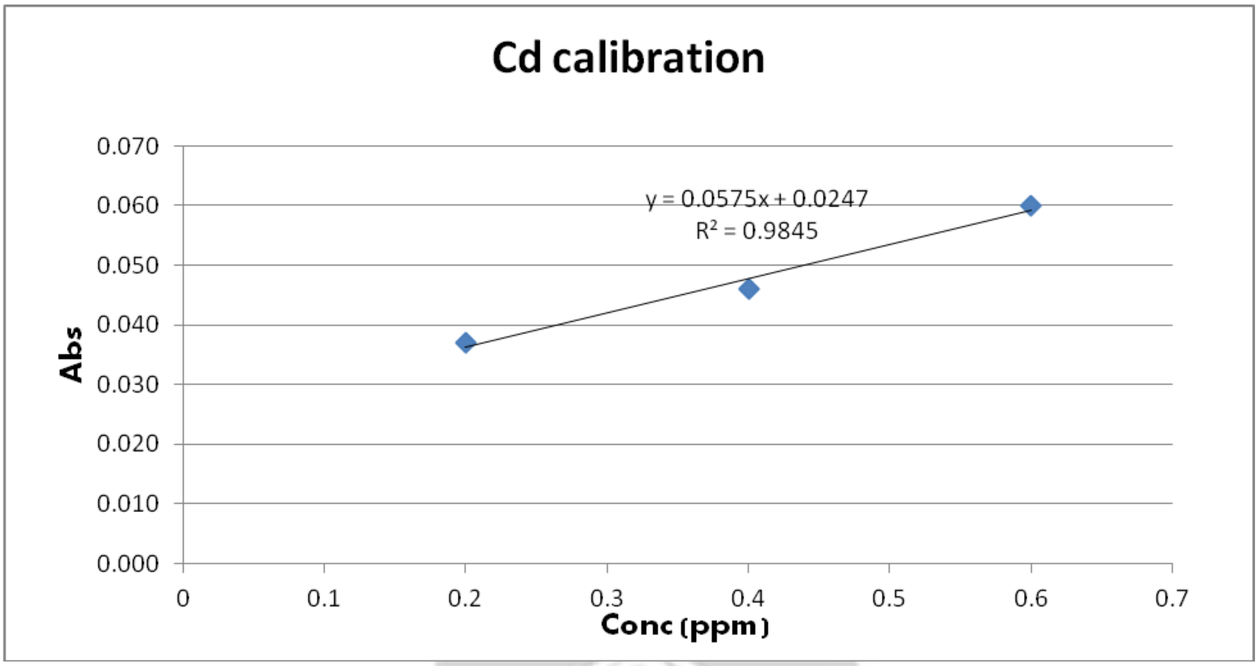


Figure A1-3: Cadmium Calibration Graph

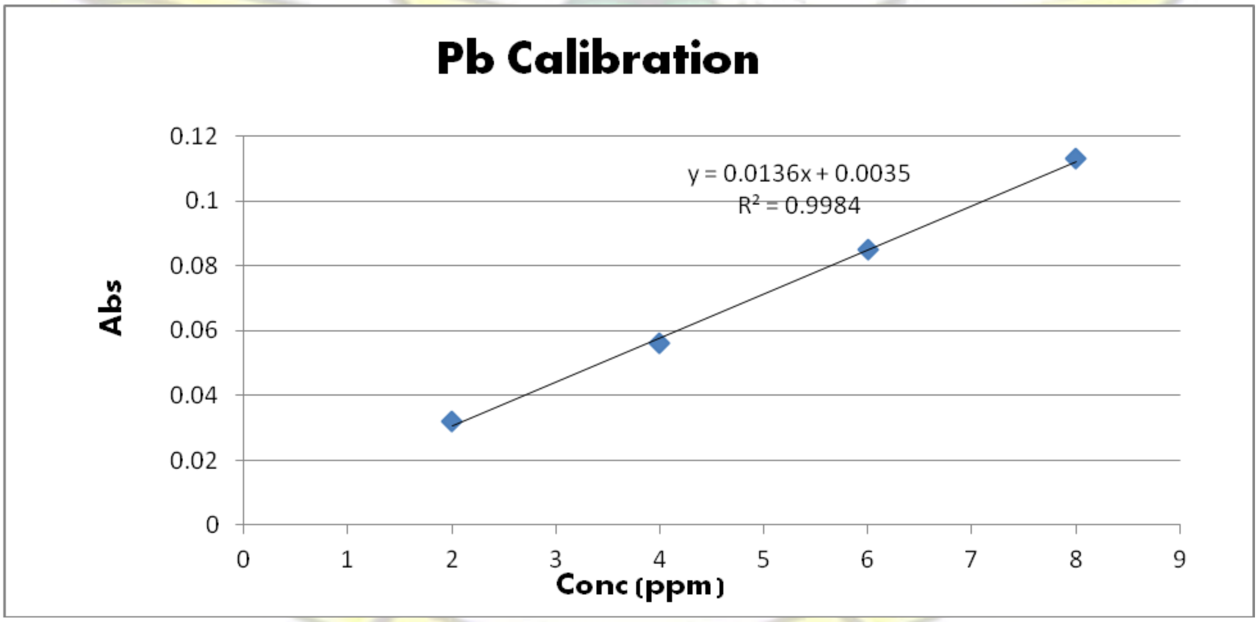


Figure A1-4: Lead Calibration Graph

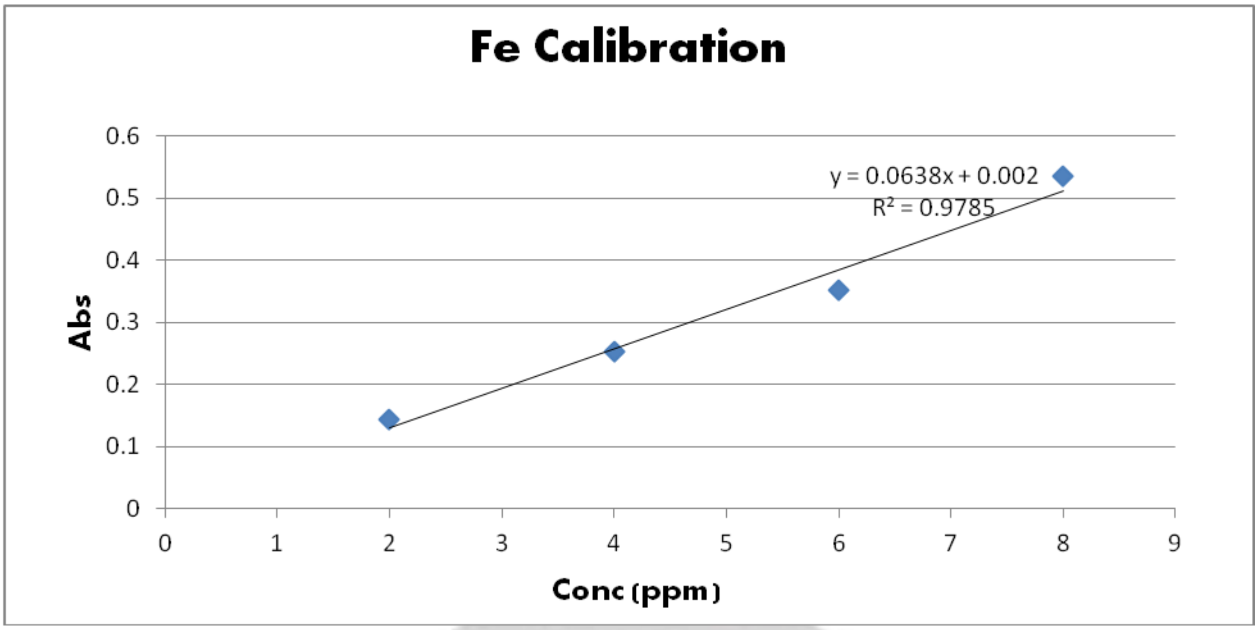


Figure A1-5: Iron Calibration Graph

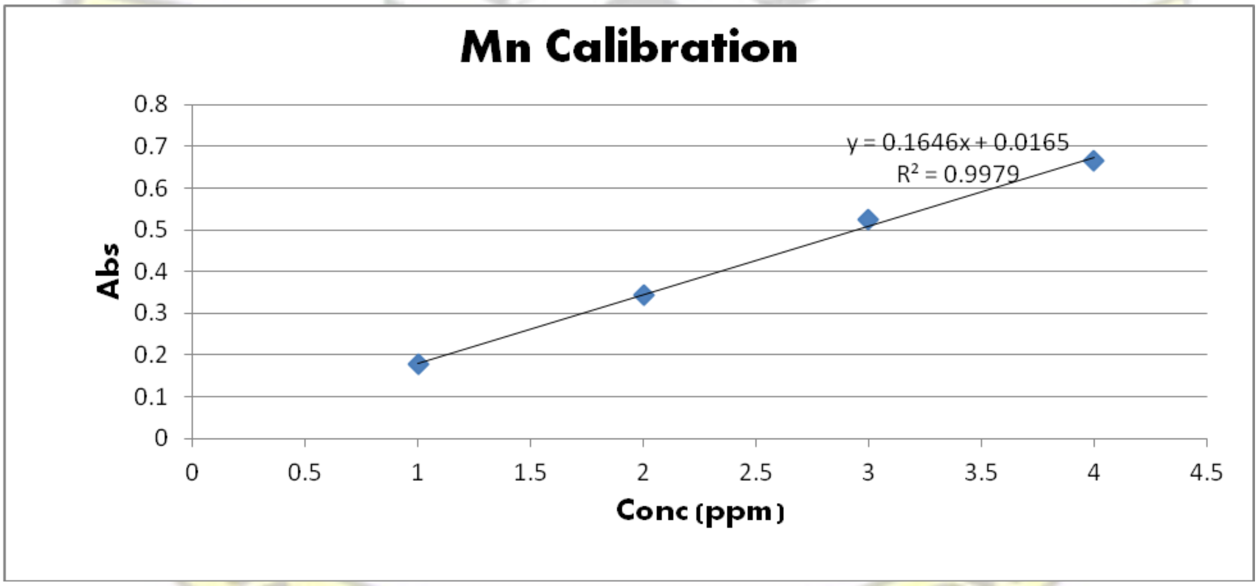


Figure A1-6: Manganese Calibration Graph

APPENDIX B

Description of the use of Image J

The image J programme already installed on the PC was opened to display its application window shown Figure B1-1. On the menu bar, **File** was clicked followed by **Open** to display Figure B1-2. The microscopic image structure of Nyl2 was selected as shown in Figure B1-3 and finally clicked **open** on the same chart to display figure 3.5. On the menu bar again, **Analyze** was clicked followed by **Set Measurement and Set Scale** buttons. These buttons were pressed one after the other to set measurement and image scale prior to measurement as shown in Figures B1-4, B1-5. Following the settings the required distance was drew as shown in Figure B1-6. On menu bar **Analyze** was clicked again followed by **Measure** to yield result shown in Figure B1-7. The result was then saved.

Figure B1-1: Application Window Of Image J

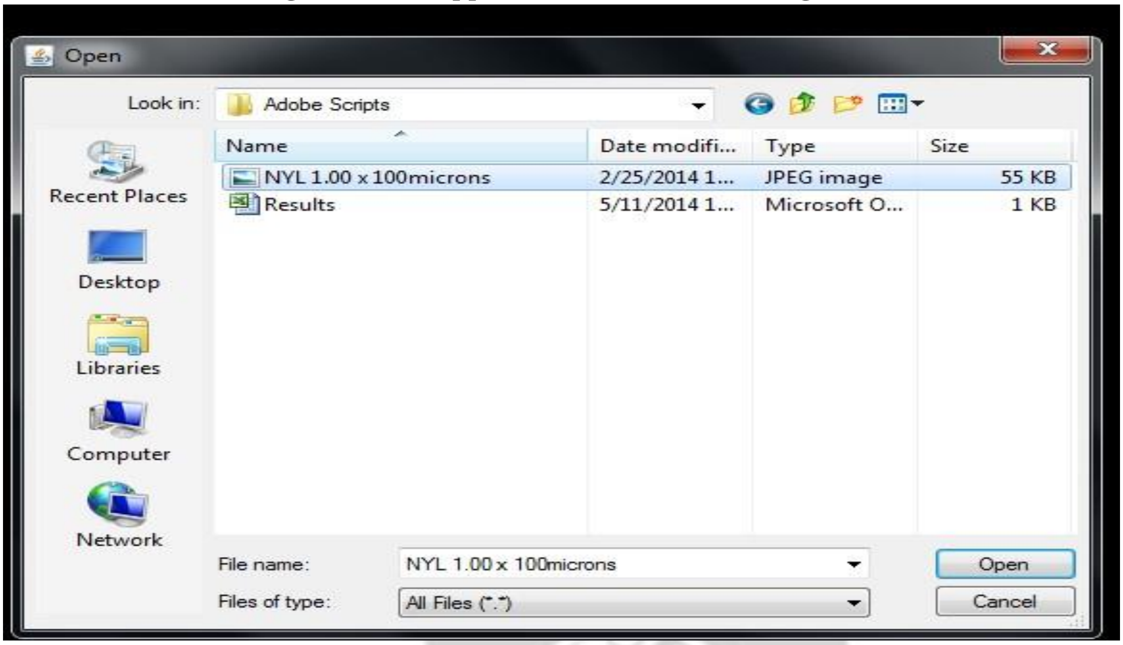


Figure B1-2: Microscopic Image Structure File Selection

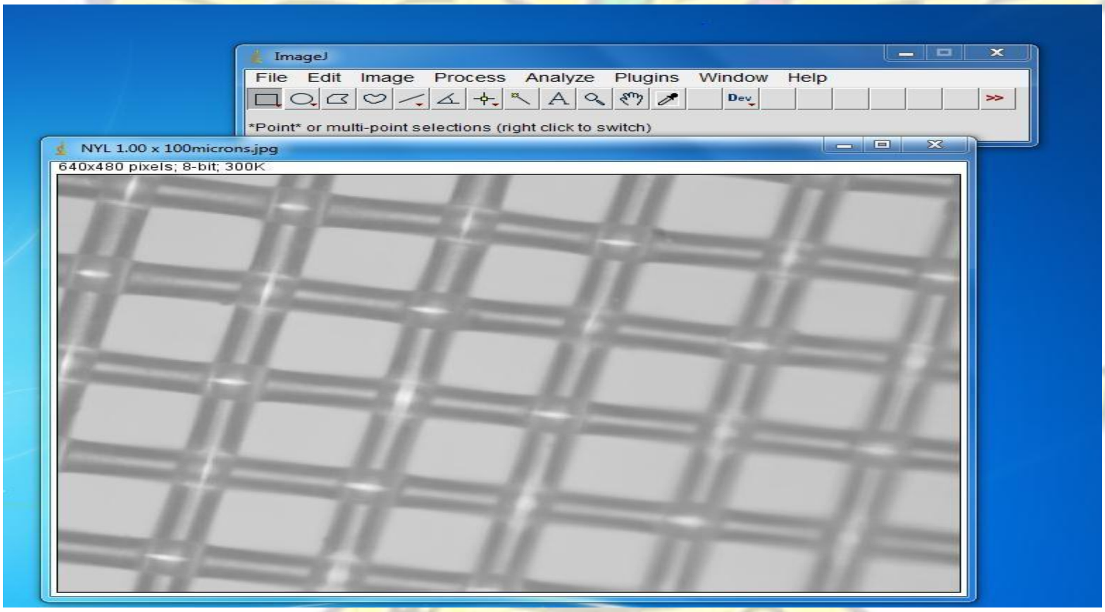


Figure B1-3: Microscopic Image Structure Of Nyl2

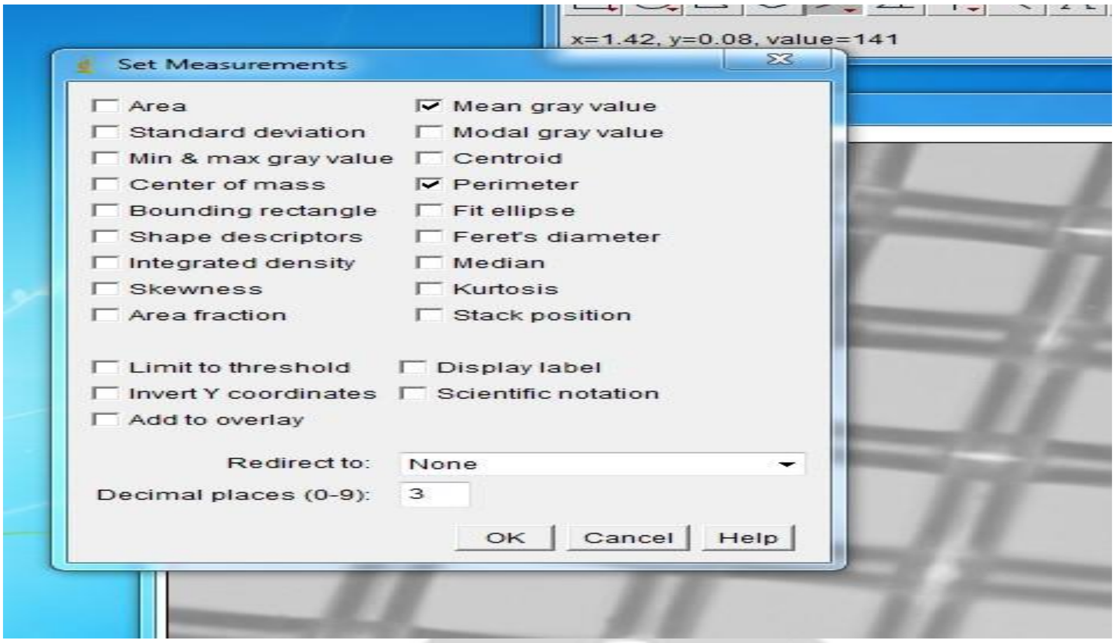


Figure B1-4: Set Measurements

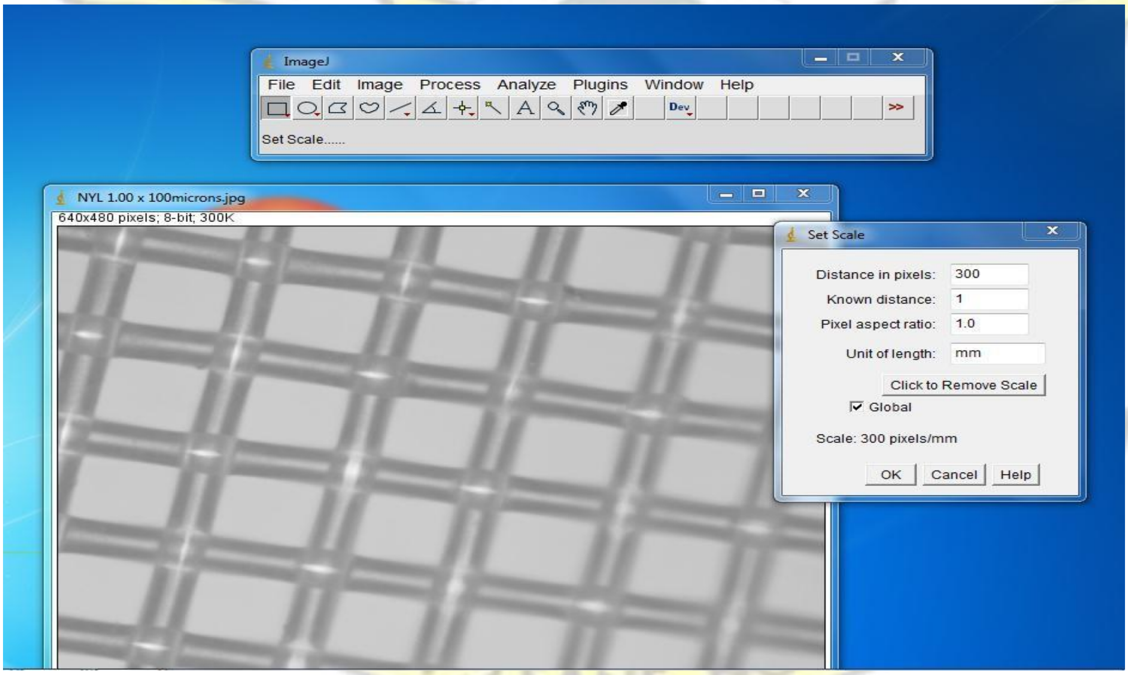


Figure B1-5: Set Scale

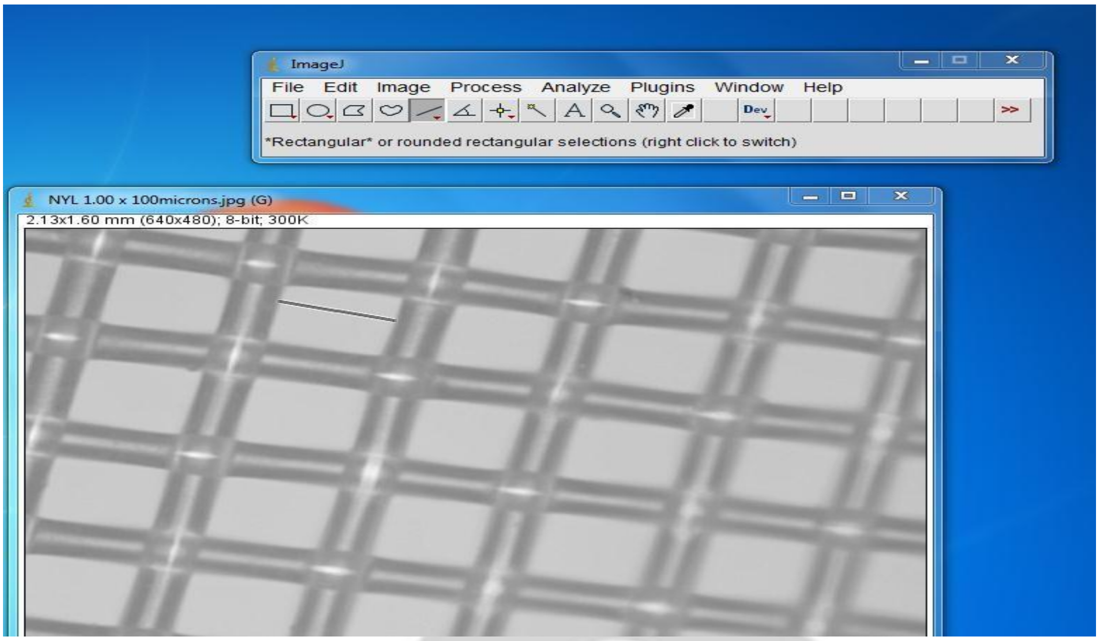


Figure B1-6: Drawn Pore Diameter

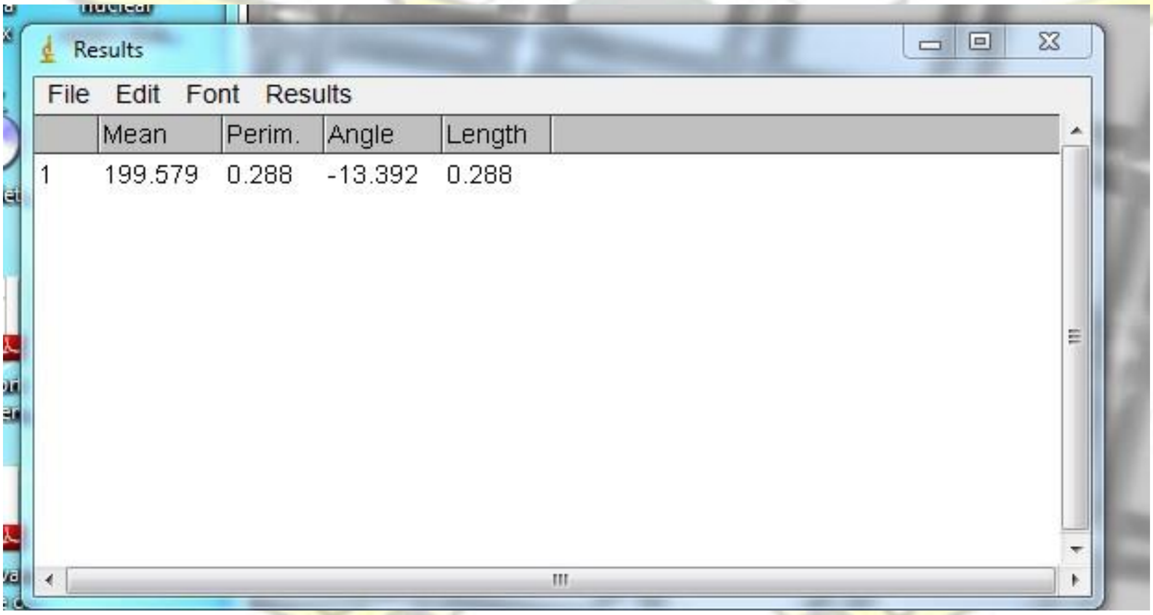


Figure B1-7: Measured Pore Diameter of Nyl2 Fabric

Table B1-1:Nyl pore size distribution

Sample	Perim.(mm)	Angle(degree)	Length(mm)	Pore size(μm)

1	0.015	-126.87	0.015	1.5
2	0.014	-123.69	0.014	1.4
3	0.019	-135.00	0.019	1.9
4	0.015	45.00	0.015	1.5
5	0.012	-146.31	0.012	1.2
6	0.017	-53.13	0.017	1.7
7	0.012	-33.69	0.012	1.2

Table B1-2:Nyl pore size distribution

Sample	Perim.(mm)	Angle(degree)	Length(mm)	Pore size(μm)
1	0.280	-18.00	0.280	28.0
2	0.273	-9.12	0.273	27.3
3	0.267	-13.00	0.267	26.7
4	0.278	-13.87	0.278	27.8
5	0.275	-14.04	0.275	27.5
6	0.274	-13.36	0.274	27.4
7	0.272	-11.31	0.272	27.2

Table B1-3: POL pore size distribution

Sample	Perim.(mm)	Angle(degree)	Length(mm)	Pore size(μm)
1	0.017	0.00	0.017	1.7
2	0.018	-21.80	0.018	1.8
3	0.021	-38.66	0.021	2.1
4	0.021	-38.66	0.021	2.1
5	0.014	-104.04	0.014	1.4
6	0.017	-36.87	0.017	1.7
7	0.012	-123.69	0.012	1.2

Table B1-4:Local Plain Weave(LPW) POL pore size distribution

Sample	Perim.(mm)	Angle(degree)	Length(mm)	Pore size(μm)
1	0.287	-2.66	0.287	5.7
2	0.238	-11.31	0.238	4.8
3	0.265	-10.89	0.265	5.3
4	0.282	-106.50	0.282	5.6
5	0.215	-102.53	0.215	4.3
6	0.186	-111.04	0.186	3.7
7	0.269	-105.07	0.269	5.4

Table B1-5:Local Twill Weave(LTW) POL pore size distribution

Sample	Perim.(mm)	Angle(degree)	Length(mm)	Pore size(μm)
1	0.024	-8.13	0.024	2.4
2	0.024	15.95	0.024	2.4
3	0.023	0.00	0.023	2.3
4	0.018	21.80	0.018	1.8
5	0.018	21.80	0.018	1.8
6	0.015	26.57	0.015	1.5
7	0.013	0.00	0.013	1.3

Table B2-1:Fabric burn test

Sample/number		***When nearing flame***	***When in flame***	***Out of flame***	***Ash***	***Odour***
Known Polyester	1	pulls away	burns and melt	burn and selfextinguish	hard black bead	sweet odour
	2	pulls away	burns and melt	burn and selfextinguish	hard black bead	sweet odour
	3	pulls away	burns and melt	burn and selfextinguish	hard black bead	sweet odour
Unknown X	1	pulls away	burns and melt	burn and selfextinguish	hard gray-yellowish bead	odour
	2	pulls away	burns and melt	burn and selfextinguish	hard gray-yellowish bead	odour
	3	pulls away	burns and melt	burn and selfextinguish	hard gray-yellowish bead	odour
Unknown Y	1	pulls away	burns and melt	burn and selfextinguish	hard gray-yellowish bead	odour, animal hair like smell
	2	pulls away	burns and melt	burn and selfextinguish	hard gray-yellowish bead	odour, animal hair like smell
	3	pulls away	burns and melt	burn and selfextinguish	hard gray-yellowish bead	odour, animal hair like smell

Table B2-2: Acid test on fabrics

Sample/ number		Sample weight (grams)	Observations
Known Polyester	1	0.19000	Insoluble in 70% Sulfuric acid
	2	0.19000	Insoluble in 70% Sulfuric acid
	3	0.19000	Insoluble in 70% Sulfuric acid
unknown X	1	0.22290	Soluble in 70% Sulfiric acid
	2	0.22290	Soluble in 70% Sulfiric acid
	3	0.22290	Soluble in 70% Sulfiric acid
unknown Y	1	0.05400	Soluble in 70% Sulfiric acid
	2	0.05400	Soluble in 70% Sulfiric acid
	3	0.05400	Soluble in 70% Sulfiric acid

Table B2-3: Alkali test on fabrics

Sample/ number		Sample weight (grams)	Observations
Known Polyester	1	0.19000	Insoluble in 70% Sodium hydroxide
	2	0.19000	Insoluble in 70% Sodium hydroxide
	3	0.19000	Insoluble in 70% Sodium hydroxide
unknown X	1	0.22290	Insoluble in 70% Sodium hydroxide
	2	0.22290	Insoluble in 70% Sodium hydroxide
	3	0.22290	Insoluble in 70% Sodium hydroxide
unknown Y	1	0.05400	Insoluble in 70% Sodium hydroxide
	2	0.05400	Insoluble in 70% Sodium hydroxide
	3	0.05400	Insoluble in 70% Sodium hydroxide

Table B2-4:Microscopic appearance of fabrics

Sample/number		Appearance(single fiber) longitudinal view	Appearace (bulk) longitudinal view
Known Polyester	1	smooth dark,snake-like appearance	dark apperance
	2	smooth dark,snake-like appearance	dark apperance
	3	smooth dark,snake-like appearance	dark apperance
Unknown X	1	silver like colour, rod shape	silver-like colour
	2	silver like colour, rod shape	silver-like colour

	3	silver like colour, rod shape	silver-like colour
Unknown Y	1	dark apperance and rod-like shape	dark apperance
	2	dark apperance and rod-like shape	dark apperance
	3	dark apperance and rod-like shape	dark apperance

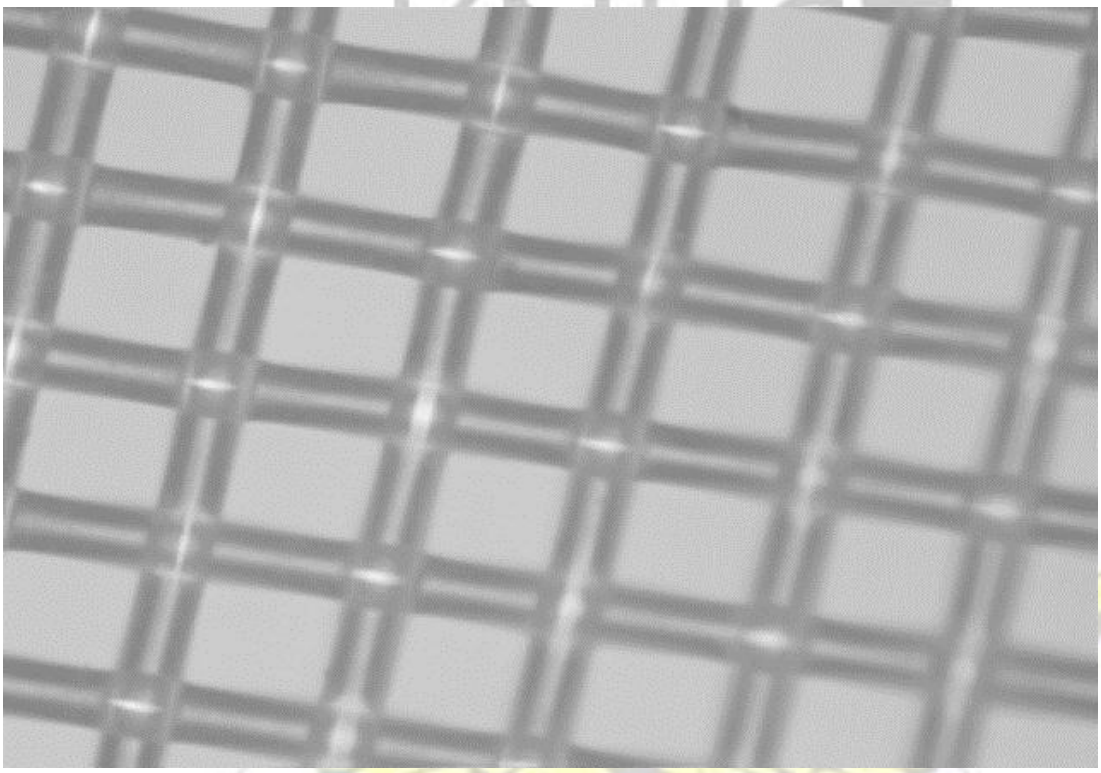


Figure B1-8: Microscopic Image Structure Of Nylon2 (Nyl2)

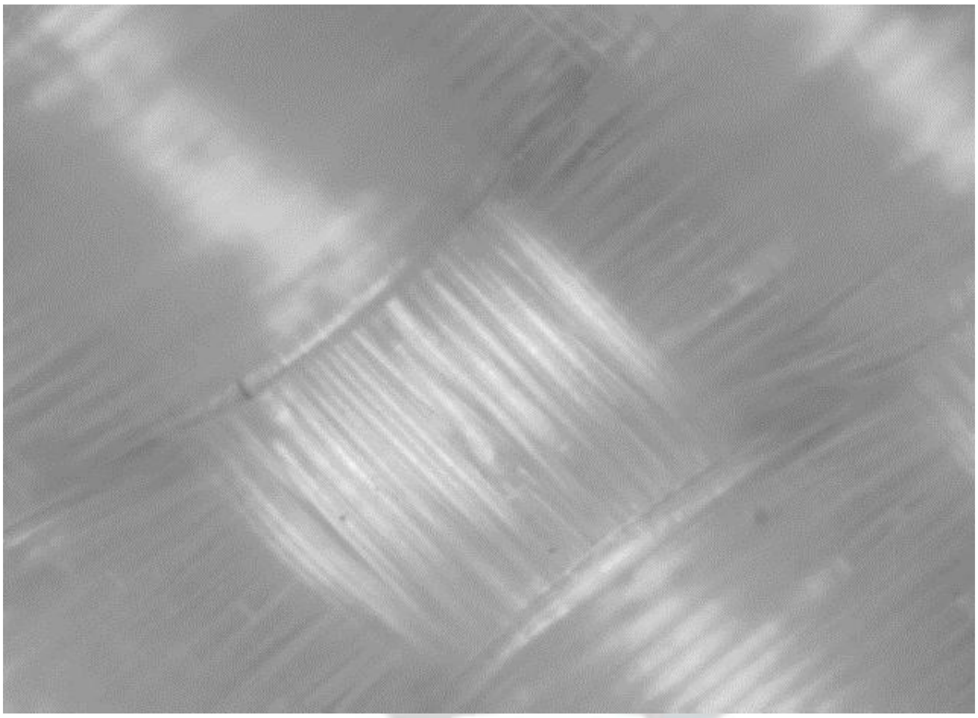


Figure B1-9: Microscopic Image Structure Of Nylon (Nyl)

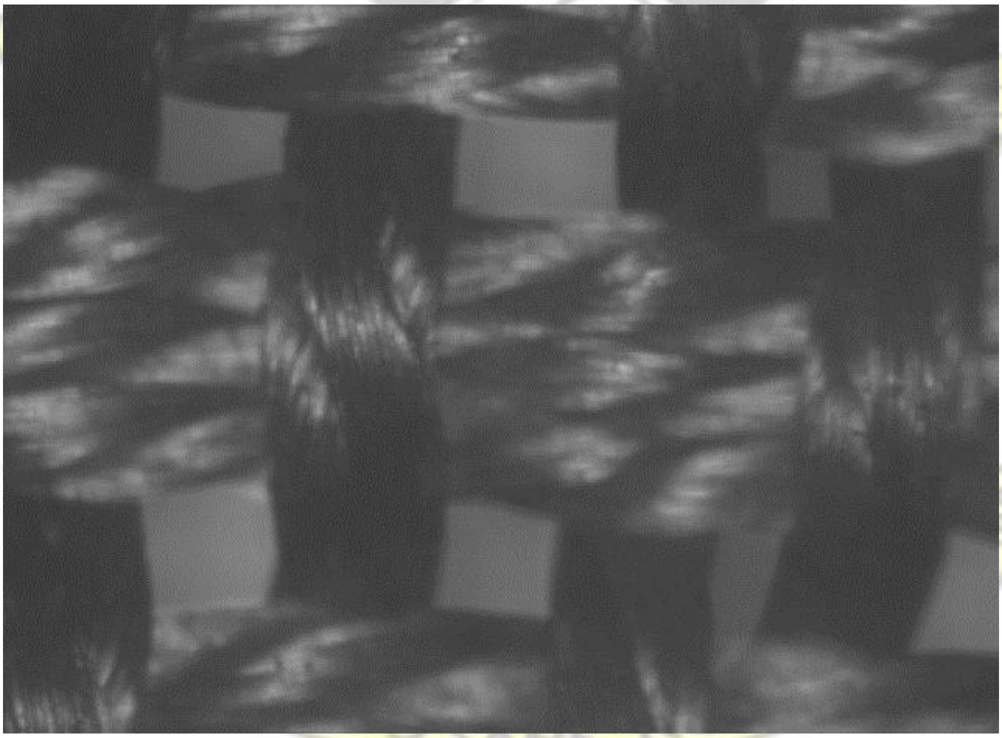


Figure B1-10: Microscopic Image Structure Of LPW POL

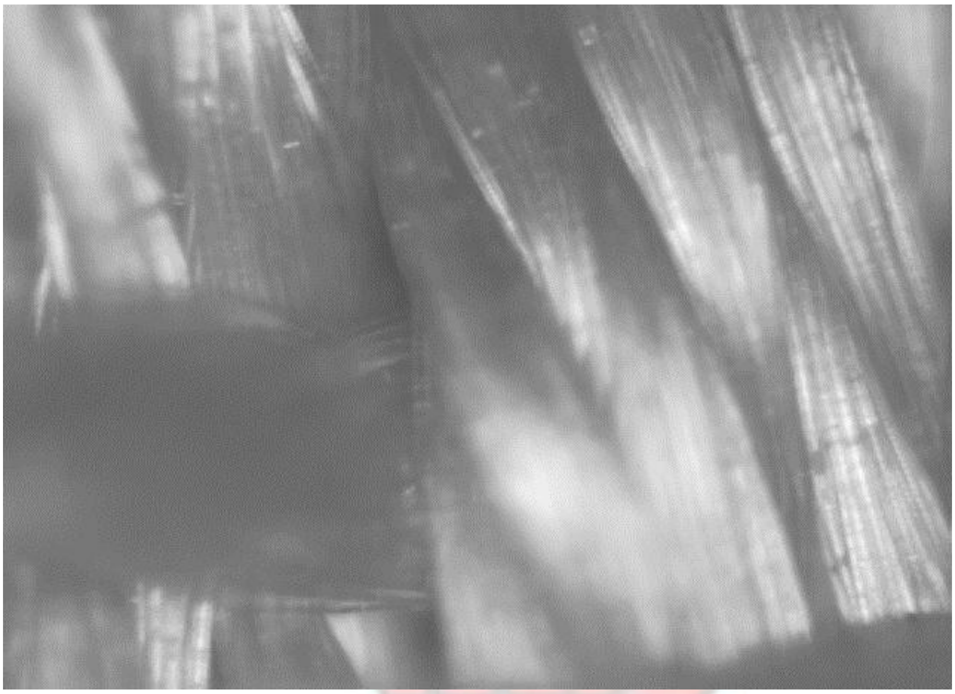


Figure B1-11: Microscopic Image Structure of LTW POL

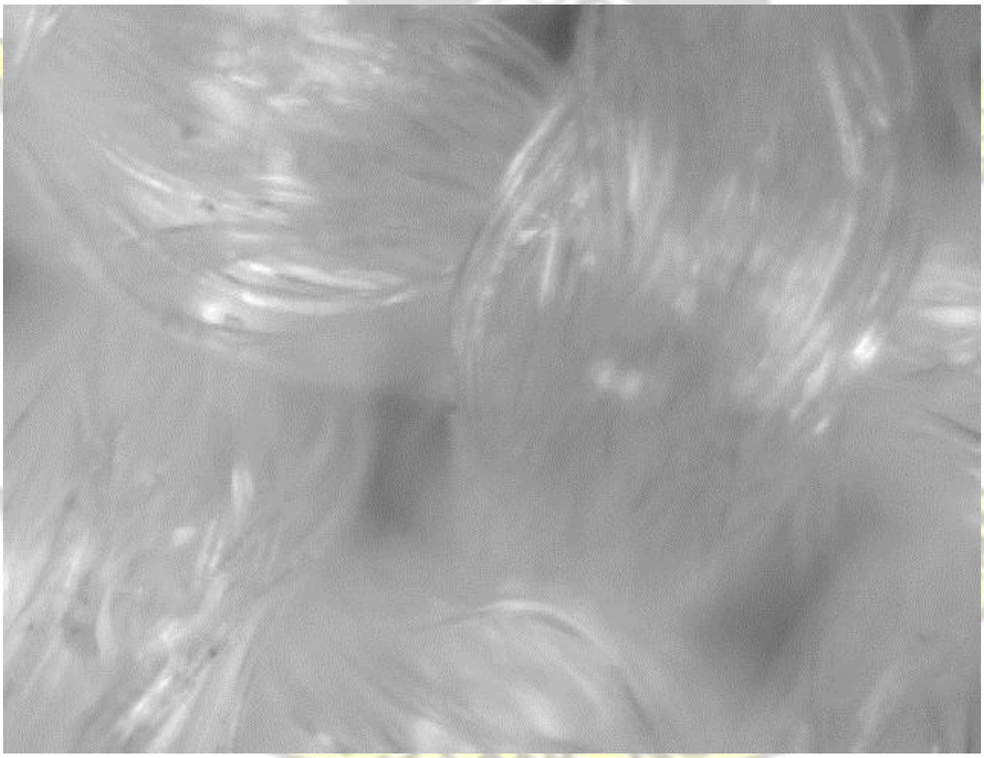


Figure B1-12: Microscopic Image Structure of Polyester (POL)

Table B3-1: Design summary of micofilter construction

Description	***S.I units***	***Specification/ Value***	***Specification/ Value***	

Filter		***CSWFF-Nyl***	**CSWFFPOL**	**WFACF-POL**
Filter medium		Nylon	Polyester	Polyester/ activated carbon
Average pore size of filter medium	µm	1.5	1.7	1.7
Weight of activated carbon	g	N/A	N/A	447.4
Average size of activated carbon	mm	N/A	N/A	8
Sealant or Adhesive		RTV silicone	RTV silicone	RTV silicone
Spacer material		Polymeric	Polymeric	Polymeric
Module /membrane diameter	cm	53	53	32
Spacer diameter	cm	50	50	29
Module surface gross area	cm^2	333.052	333.052	201.088
Module surface active area	cm^2	295.348	295.348	163.384
Flexible hose material	cm	Polymeric	Polymeric	Polymeric
Flexible hose diameter	cm	1.27	1.27	1.27
Flexible hose length	cm	45	45	45

Table B3-2: Design summary of micofilter construction

Description	***S.I units***	***Specification/Value***	***Specification/Value***
		SFFF-Nyl	**CFFF-POL/Nyl**
Filter medium		Nylon	Polyester/Nylon
Average pore size of filter medium	µm	1.5	1.7/1.5
Sealant or Adhesive		RTV silicone	Polyeurethane
Frame		PVC	
Module /membrane size	cm	33x31	33x31
Frame size	cm	33x31	33x31
Frame thickness	mm	8.83	8.83
Module surface gross area	cm^2	2046	2046
Module surface active area	cm^2	1785.432	1785.432
Flexible hose material		Polymeric	Polymeric
Flexible hose diameter	cm	1.27	1.27
Flexible hose length	cm	45	45

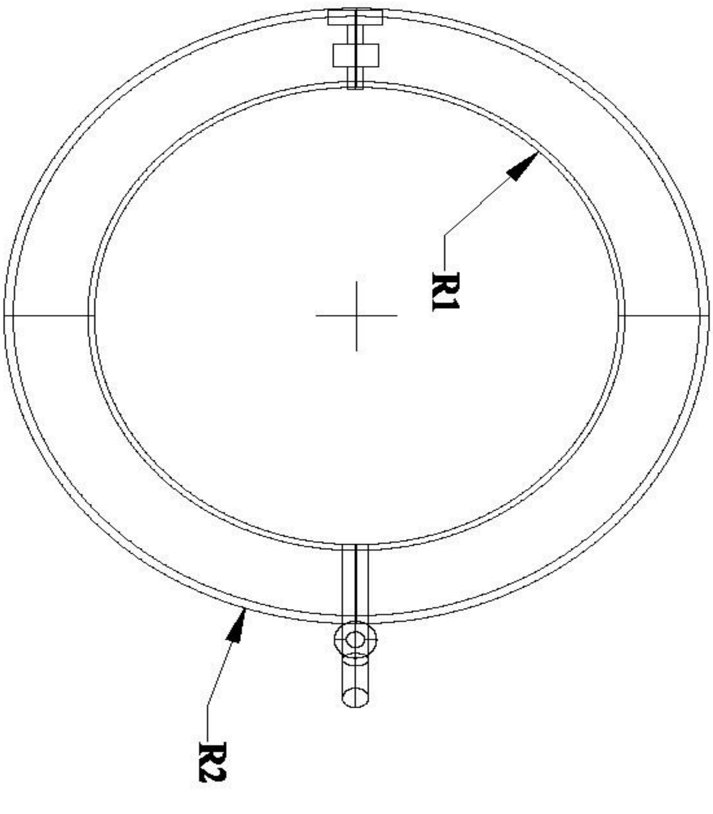
Table B3-3: Design summary of tank and fittings construction

Description	***S.I units***	***Specification/Value***
Tank material		PVC
Tank capacity	L	100
Permeate exit valve material		PVC
Drain valve material		PVC
Valve holder material		brass
Tank connector material		PVC
Permeate exit valve diameter	cm	1.27
Drain valve diameter	cm	1.27
Valve holder diameter	cm	1.27
Tank connector diamter	cm	1.27

Table B3-4: Module gross and active area calculations

Description	***S.I units***	***Symbol***	***Equation***	***Specification /Value***
Module diameter of CSWF-Nyl	cm	***DCN***		53
Module diameter of CSWF-POL	cm	***DCP***		53
Module diameter of WFACF-POL	cm	***DWP***		32
Diameter of permeate exit plus gasket	cm	***DPG***		4
Assumption				Circular
Gross area of CSWFNyl	cm^2		2□*DCN*	333.052
Gross area of CSWFPOL	cm^2		2□*DCP*	333.052
Gross area of WFACF-POL	cm^2		2□*DWP*	201.088
Active area of CSWF-Nyl	cm^2		2□(*DCN*□4)□□*DPG*	295.348

Active area of CSWF-POL	cm^2		2□(*DCP*□4)□□*DPG*	295.348
Active area of WFACF-POL	cm^2		2□(*DWP*□4)□□*DPG*	163.384
Module size of SFFF/CFFF		**L**		33
Module size of SFFF/CFFF		**B**		31
Gross area of SFFF/CFFF	cm^2		$2LB$	2046
Active area of SFFF/CFFF	cm^2		2(*L*□2)(*B*□2)□□*DPG*	1785.432

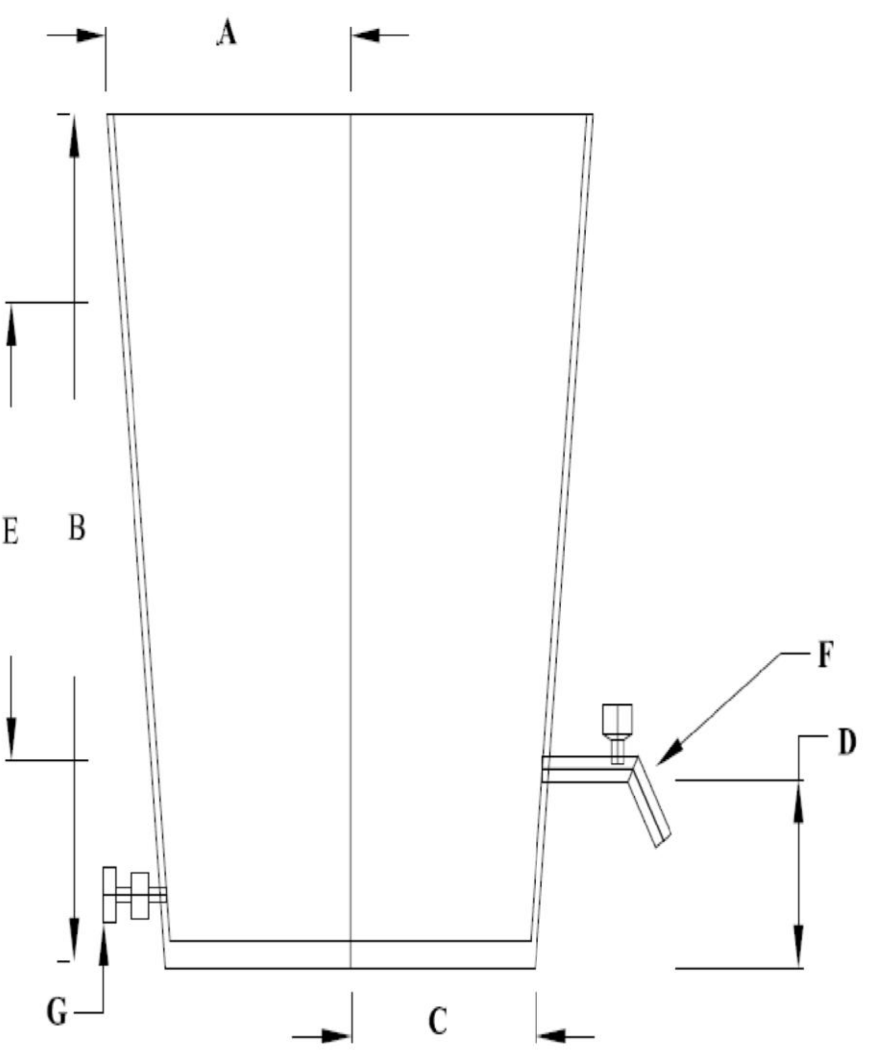


RADIUS OF TANK BOTTOM:

R1=20.32cm RADIUS OF TANK TOP:

R2=26.67cm

Figure B3-1: Top view of water treatment system

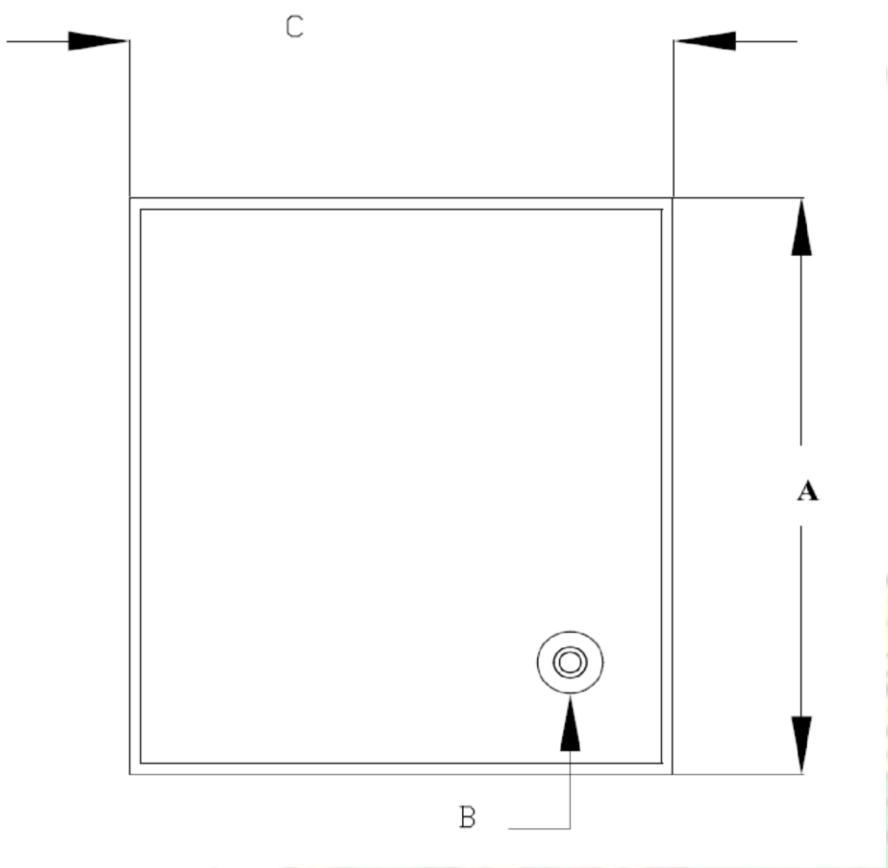


A
E
B
F
D
G
C

UPPER TANK RADIUS: **A**= 26.67cm
TANK HEIGHT: **B=**64.01cm

LOWER TANK RADIUS: HEIGHT FROM BOTTOM TO PERMEATE VALVE**C=**20.32cm **: D=**13.21cm
FILTRATION HEIGHT: **E=**30.99cm
PERMEATE VALVE SIZE: **F=**1.27cm
DRAIN VALVE SIZE: **G**=1.27cm

Figure B3-2: Front view of water treatment system

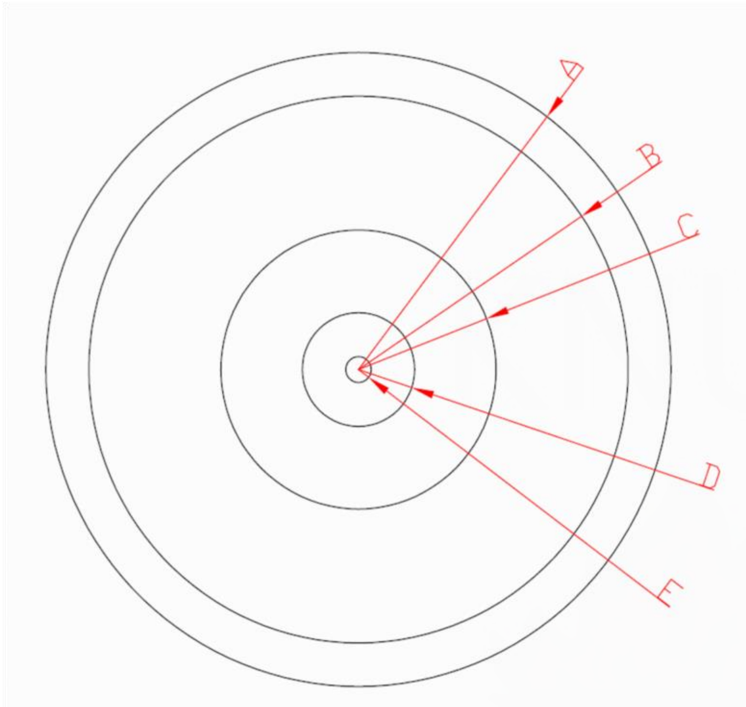


LENGTH OF FILTER: **A**=31.75cm

BREATH OF FILTER: **B**=29.72cm

DIAMETER OF WASHER (GASKET): C=4.32cm

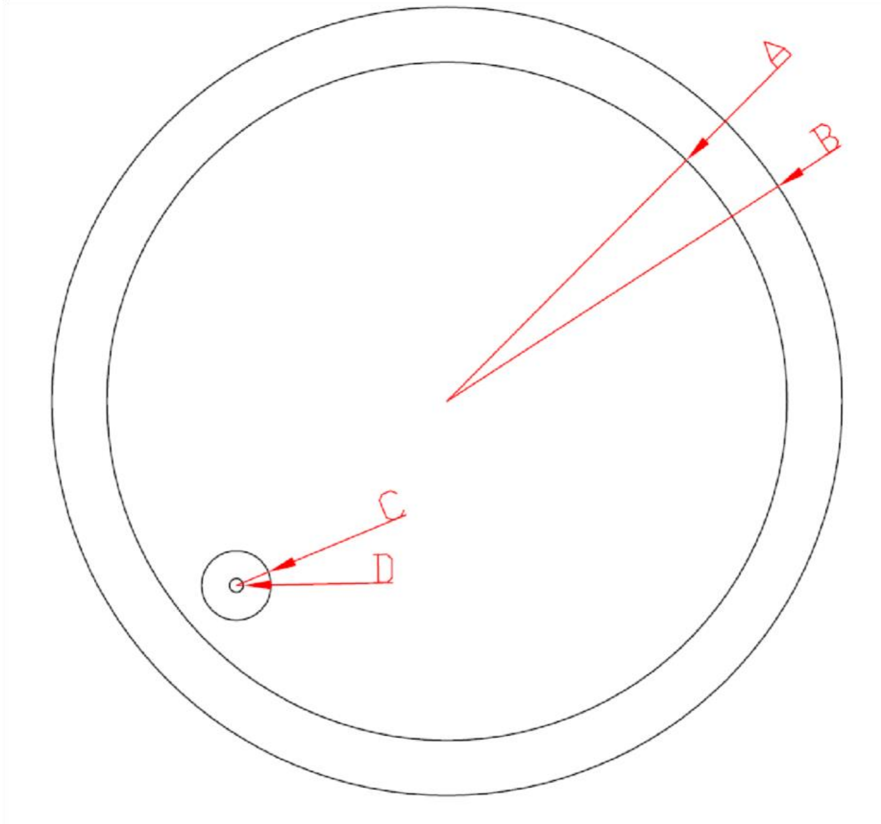
Figure B3-3: Front view of CFFF/SFFF media



CSWFF **WFACF**

A=25.00cm A=14.50cm
B=24.37cm B=13.87cm
C=4.45cm C=4.45cm D=2.54cm D=2.54cm
E=0.64cm E=0.64cm

Figure B3-4: Front view of 50cm and 29cm spacer



CSWFF	**WFACF**
A=24.5cm	A=14cm
B=26.5cm	B=16cm

Figure B3-5: Front view of CSWFF and WFACF