INVESTIGATING THE PERFORMANCE OF MODIFIED CLAY CERAMIC FILTER FOR WATER TREATMENT

M.SC. THESIS

BY

TARIKU MULUGETA

A THESIS SUBMITTED TO THE DEPARTMENT OF CHEMISTRY, SCHOOL OF APPLIED NATURAL SCIENCES PRESENTED IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE DEGREE OF MASTER'S IN CHEMISTRY

OFFICE OF GRADUATE STUDIES

ADAMA SCIENCE AND TECHNOLOGY UNIVERSITY

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ADAMA, ETHIOPIA

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Approval of Board of Examiners

We, the undersigned, members of the Board of Examiners of the final open defense by Tariku Mulugeta have read and evaluated his thesis entitled ”Investigating the Performance of Modified Clay Ceramic Filter for Water Treatment” and examined the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirement of the Degree of master’s.

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DECLARATION

I hereby declare that this MSc/MA Thesis is my original work and has not been presented for a degree in any other university, and all sources of material used for this thesis/ dissertation have been duly acknowledged.

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This MSc/ MA Thesis has been submitted for examination with my approval as thesis advisor.

Name:

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Date of submission:

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ABBREVIATIONS

AAS	Atomic Absorption Spectroscopy
CF	Ceramic Filters
CWF	Ceramic Water Filter
DOC	Dissolved Organic Carbon
FDRE	Federal Democratic Republic of Ethiopia
FNU	Formazin Nephlometric Unit
FT-IR	Fourier Transform Infra Red
FTU	Formazin Turbidity Unit
HWTS	Household Water Treatment Safe Storage
IAS	Industrial Analytical Service
ISO	International Standards Organization
JTU	Jackson Turbidity Unit
LCD	Liquid Crystal Display
LED	Light Emitted Diode
MF	Microfiltration
MIP	Mercury Intrusion Porosimetry
MoH	Ministry of Health
PFP	Potters for Peace
SEM	Scanning Electron Microscope
TDS	Total Dissolved Solid
TSS	Total Suspended Solids
UF	Ultra filtration
UNICEF	United Nations Children's Fund
USD	United State Dollar
UV	Ultra violet
WHO	World Health Organization
XRD	X-ray diffraction

Abstract

In this study ceramic water filters were developed from different percentage composition of clay and burn-out material. The raw materials were grind, sieved (with 3mm) opening mush sized sieve, mixed with water, molded in pot shape and fired at different sintering temperature.

The sintered filters were evaluated for flow rate, turbidity reduction, microbial removal, color, total porosity and fluoride removal efficiency. The phase identification, the major composition of filters and the surface function group were investigated by scanning electron microscope (SEM), AAS (complete silicate analysis), powder X-Ray diffraction (XRD) and FT-IR. In addition to the removal efficiency of contaminants, their flow rates were also investigated. Performances of ceramic filters were optimized with respect to the percent composition of clay % (50-70) to saw dust % (13-35) and firing temperature (800-950 ^{o}C). The results showed that increasing the burn-out material during production of the filter elements increased the porosity and flow rate but it lowered the removal efficiency of E.coli, turbidity, TDS and color from the contaminated water. The results analysis showed that average removal efficiency of E. coli (98.44 %), fluoride (93.25 %), turbidity (97 %), color (65 %) and flow rate (130.27 mL/h) for ceramic pot filter optimized from clay 70 %, burn out 15 % , grog 15 % at a sintering temperature of 900 ^{o}C and 950 ^{o}C. The study concluded that the pot filters are effective towards E.coli and turbidity removal. The filters also exhibited good flow rate results.

Key words: ceramic filters, water purification, flow rate, *E.* coli, fluoride, turbidity

1. INTRODUCTION

1.1 Background of the Study

According to a report by (UNICEF/WHO, 2012) to providing safe drinking water and sanitation to people in developing countries, nearly 1 billion people – about 1 in 8 – lack access to clean water. More than 3.5 million people die each year from water-related disease, 84% of which are children. Millions of women and children spend several hours each day collecting water from distant, often polluted sources. It is estimated that million school days are lost each year due to water-related illness. In the last 18 years, there has been only a 10% increase in the total population who has access to potable water (WHO, 2010). In 2003, the World Bank predicted that by 2015, 5–10 % of the population of the Middle East, North Africa, Latin America and the Caribbean would still be without reliable potable water. It is estimated that 25% of Sub-Saharan Africa will not have access to potable water resources in 2015.This burdens the countries with enormous financial and social costs to take care of such a huge number of people suffering from these debilitating infections. A number of different water purification systems have been employed, but the ceramic filters have been shown to be low cost, reliable and effective (Sobsey, *et al*. 2007, Lantagne, 2001, Brown *et al*, 2010). Ceramic filtration is one of the recent techniques for water purification and it removes more than 99 % of protozoa and 90 % of bacteria and other chemicals from drinking water in households (Hagan *et al* 2009**)**. It is an economically sound process which requires no chemicals, energy or electricity to purify the water (water pressure used to force the water through the filter).

Membrane technologies such as microfiltration (MF) and ultra filtration (UF) are playing an increasingly important role in the treatment of raw surface water for drinking purposes. 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 processes or to better membrane performance and with lower costs due to technological advances in both membrane materials and configurations (J.G. Jacangelo, *et al*, R.R. Trussell, M. Watson, 1997).

Conventional water treatment may include chemical addition (aluminum sulphate, lime and polymers), coagulation, flocculation, sedimentation, filtration and disinfection usually with chlorine. Indeed all these conventional systems, based on physical and chemical principles, cannot give an absolute guarantee in terms of separation efficiency, while MF and UF can

provide a complete removal of most bacteria and all protozoan cysts of concern as long as the membrane and associated system components are intact and operating correctly. In the case of UF, reduce the burden of water-borne illnesses at an affordable cost. Though other technologies are also available this may eventually meet point-of-use purification requirements. Ceramic pot filter (CF) is a HWTS system developed by the Non-Governmental Organization named Potters for Peace. After installing a production facility in Nicaragua, Potters for Peace has begun to scale up the filter production in other countries. This is done by involving local entrepreneurs to start their own CF factories. Furthermore, CF is implemented by emergency relief organizations including the International Red Cross and Doctors without Borders. CF is manufactured with local materials and skills and is therefore an inexpensive product ranging from USD5 to USD12. A mixture of clay, sawdust and water is pressed into a pot shape with press moulds. Once the filter element has its shape it is fired in an oven. Potters for Peace aims for the filter element to have a maximum pore size of 1μm (PFP, 2001). Since the introduction of the ceramic pot filters many reports have been published on the performance of these filters. Ceramic filters have long lifetimes and can remove all types of harmful material while using primarily local resources. The main problem is insufficient water supply or low flow rate of the technique. Ceramic water filter that is made from local resources have been shown to be effective system for household water treatment in low-income communities (Agbo C et al., 2015). The aim of this research was to develop improved quality ceramic filters from locally available materials by tuning the ratio of raw materials and sintering temperature and study the efficiency of the filter in removing microorganisms, fluoride and other water quality parameters.

1.3 Objectives of the Study

1.3.1 General Objective

The aim of this work is to develop and characterize modified clay ceramic filters (CF) for water treatment that display good flow rate and are capable of removing chemicals as well as microbial contaminants.

1.3.2 Specific Objectives

The specific objectives of the study are the followings:

i. Investigate the effect of the proportion of sawdust, clay and grog on the performance of ceramic filter developed.

ii. Investigate the effect of firing temperature on ceramic filter performance.

iii. Evaluate the flow rate, turbidity, microbial, fluoride, total dissolved solids/TDS, color, odor and taste removal efficiency of the developed filters.

1.4. Significance of the Study

This study will help to transfer knowledge/ technology to the local potters in Ethiopia on the making of water filters, which are expected to be cheap and efficient, using only locally available materials. The results obtained from this research will directly contribute to the socio- economic development of the country (poverty reduction), for creation of employment opportunities for youths (pottery maker) and it helps in providing safe, clean drinking water for citizens. The research can be considered to be of particular interest, being a research as part of the country's focus areas on knowledge transfer. It is also expected to encourage more entrepreneurs and researchers in the area.

2. LITERATURE REVIEW

2.1 Water Treatment Overview

The main reasons of treating water are to remove those contaminants that are harmful to health and that make the water taste or smell bad. There are various water treatment techniques at the home level. All the methods are used to reduce microorganisms and turbidity of water by different mechanisms. Even if reducing microorganisms and turbidity of water are the quality checks of household water techniques, the methods have their own limitations. The most commonly used low-cost water purification systems include, but are not limited to, sand filters, boiling, bio-filters, chlorination units and solar-based systems, most recently clay-based filters with and without colloidal silver and combined filters have been introduced, (Lantagne, (2001) Ceramic filters have been shown to be effective system for point-of-use water treatment in low income communities. The technology is simple, affordable and utilizes local materials and knowledge (Katherine et al, 2008). The filtering effect of the clay eliminates a large portion of water borne pathogens. Ceramic filters have been shown to be reliably effective in removing more than 99 % of protozoan and 90 % of bacterial organisms from drinking water in households (Hagan J et al 2009), but further research is needed on the raw materials ratio and firing temperature to increase the performance of the ceramic filters.

Ceramic filtration is the use of porous ceramic to filter microbes and other contaminants from drinking water. The primary materials used in manufacturing of ceramic filters are clay, combustible material and siliceous materials or grog as a non plastic material used to reduce shrinkage and control the porosity of the ceramic. Studies by (Clasen, T et al. (2005), Lantagne, 2001, du Preez, M. R. (2008), Sagara, (2003), Van Halem, (2006)), and others have suggested that ceramic water filters provide microbiologically improved water to users. Diarrheal disease is caused by the ingestion of protozoan, bacterial or viral organisms. The pathogenic micro organisms are ordered by size. Their sizes vary: typically protozoa are > 4 μm in size, bacteria ~1 μm and viruses are < 1 μm in size (Doris V. 2006). Using methods of purification like chlorination, large scale filtration cannot be afforded by many Ethiopians especially rural people who live below poverty levels. Boiling would encourage cutting down of trees leading to environmental degradation. Ceramic water filtration becomes a cheap and efficient method since

all the materials required are available locally, has a relatively long life time of usage , the technology can work all year round in different climates and does not impart an objectionable taste to the treated water (Vinka et al, 2008, Sakka Y, et al 2003 and UNICEF ,2007). Fabrication of porous ceramics with controlled pore size can be developed by varying the types and relative amounts of the raw materials and processing conditions to improve the filters performance (Lantagne et al, 2010, Dies, 2003, Donachy, 2004).

There are more than 30 technologies for water filtration at point of use in developing countries, ceramic water filters are among the top five promising technologies (du Preez, et al, 2008, Sobsey, 2000). Some major ceramic water filters currently used around the world are summarized in Table-2.1 below.

Table-2.1Some major ceramic water filters currently used around the world

Filters	Materials	Additives	Microbial removal Efficiency (E.coli), %	Flow Rate	Reference
Ceramic Filter , Australia	Clay	Tea leaves/Coffee grounds/ Rice husk	96.4-99.8	0.5 *L*/h	[Holtslag, 2010]
Pelikan/ Indian Candle	white Kaolin clay)	Sawdust	>3.9MPN/100ml	300-840 mL/h	[Sagara,2000]
Terafil disk Filter	Red Terracota Clay	Sawdust, Rice husk Ash	93-99.9	1-1.1 *L*/h	[Low, 2002]
Nepal Candle	White Kaolin clay	Charcoal Powder	99.9	240-400 mL/h	[Dies, 2003]
Disk Filter	Red Clay	Flour/Rice Husk	99.9	756 mL/h	[Low, 2002]
Disk filter	Black Clay	Flour/ Rice Husk	99.3	341 mL/h	[Low 2002]
Filtron/Kosim (frustum Shape)	Clay	Sawdust	99-100	1-2 *L*/h	[Lantagne, 2001,
Klarman tests(Filterpure)	Clay	Coffee husk/Rice husk	96-97.69	5-9 *L*/h	[Klarman, 2009]
Ceramic Pot Filter	Clay	Saw dust	91.30	276.66 mL/h	[Tesfaye,2016]

2.2 Access to Safe Drinking Water

Water is essential to sustain life, and a satisfactory (adequate, safe and accessible) supply must be available to all. Improving access to safe drinking-water can result in tangible benefits to health. Every effort should be made to achieve drinking water that is as safe as practicable. Safe drinking-water, as defined by the Guidelines, does not represent any significant risk to health over a lifetime of consumption, including different sensitivities that may occur between life stages. Securing the microbial safety of drinking water supplies is based on the use of multiple barriers, from catchment to consumer, to prevent the contamination of drinking water or to reduce contamination to levels not injurious to health. The greatest microbial risks are associated with ingestion of water that is contaminated with faeces from humans or animals (including birds). Faeces can be a source of pathogenic bacteria, viruses, protozoa and helminths. Faecally derived pathogens are the principal concerns in setting health-based targets for microbial safety. (WHO, 2017)

The World Health Organization (WHO)/UNICEF) assessed in 2000 that 1.1 billion people do not have access to 'improved drinking-water sources'. Interventions in hygiene, sanitation and water supply make proven contributors to controlling this disease burden. The ambitious target established in the 'Millennium Development Goal1' is "halving the proportion of people without sustainable access to safe water and basic sanitation by 2015" (FDRE, MoH), (2007). Providing more than half a billion people with safe drinking water is a major task, especially because most of them are living in rural areas. Despite major efforts to deliver safe, piped community water to the world's population, the reality is that water supplies delivering safe water will not be available to these people on such a short term. According to the WHO a short-term solution to meet the basic need of safe drinking water can be found in household water treatment and safe storage (HWTS).

2.3 Waterborne Diseases

Infectious diseases caused by pathogenic bacteria, viruses and protozoa or parasites are the most common and wide spread health risk associated with drinking water (WHO, 2008). The major pathogens that cause waterborne diseases are: bacteria (e.g. salmonella, shigella-causing

bacillary of dysentery, cholera) whose diameter varies between 0.3 to 100 μm, viruses (hepatitis A, hepatitis E, rotavirus) whose diameter is much smaller than bacteria, ranging from 0.02 to 0.3 μm, protozoa (cryptospori from a few micrometers to several millimeters and helminthes (WHO/UNICEF, 2014).These pathogens can infect humans via ingestion, inhalation or contact with skin, wounds, eyes, or mucous membrane (WHO/UNICEF, 2014). These pathogens are responsible for thousands of diseases such as diarrhea, intestinal worms, trachoma, schistosomiasis, cholera, amebiasis, giardiasis, stunting and many more (Mattelet, 2006), and thousands of deaths each year. In developing countries of Africa, over 35 % of the population suffers from diseases related to unsafe water supply and sanitation (WHO, 2008). Millions of children in Africa lack even the bare minimum of safe water they need to live (WHO/UNICEF, 2004), while a child dies every hour in Africa from diarrhea and other waterborne diseases. The lack of safe water continues to be one of the major causes of diarrheal diseases and deaths in both developed and developing nations (WHO/UNICEF, 2004).

2.4 Household Water Treatment

A number of researches (Mattlet, 2006; Clasen*et al.,* 2004; Sobey*et al.,* 2002; Kehoe *et al.,* 2001 and Nath*et al.,* 2006) have proposed point-of-use water purification systems. These points-of-use technologies offer the advantages of being easily maintained and simple to use. The points-of-use technologies cover microbiological and/or chemical or physical water treatment techniques (Mattelet, 2006). Some of the household water treatment techniques are summarized in table 2.2 below.

Table 2.2 General properties of household water treatment systems

Treatment	Availability & Practicality	Technical Difficulty	Cost	Microbial Efficacy
Boiling at 100 ^{o}C	Varies	Low-Moderate	Varies	High
Chemical treatment	High to moderate	Low-Moderate	Moderate	High
Solar disinfection	High	Low-Moderate	Low	Moderate
UV lamp treatment	Varies	Low-Moderate	Moderate-High	High
Coagulation Sedimentation/filtration	Varies	Low-Moderate	Varies	Varies

Source: (Sobsey, 2002)

2.5 Ceramic Water Filters

Since the introduction of the ceramic pot filters many reports have been published on the performance of these filters. Most of these are written on the subject of the performance of CF in the field. Others discuss porosity and removal efficiency of pathogenic micro organisms and elements. This section covers a summary of relevant investigations documented in the past.

Potters for Peace (PFP) aims for the filter element to have a maximum pore size of 1 µm (PFP, 2001). Industrial Analytical Service, Inc. (IAS) investigated the pore size of a sample from the PFP filter using a Scanning Electron Microscope (SEM) with X-ray elemental analysis. The conclusion of these investigations is that the composition of the filter is not uniform, due to both cracks and spaces within the filter. The cracks measure up to 150 µm in length and the spaces up to 500 µm, (Figure 2.1). The pore size in areas not within a crack or space ranges from 0.6 to 3 µm (Lantagne, 2001).

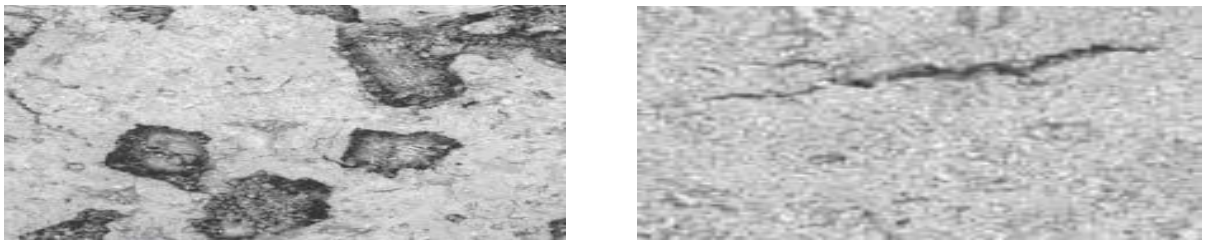


Figure 2.1 (a) Spaces and (b) cracks in CF by SEM (Lantagne, 2001)

2.6 Physical Filter Characteristic

All material behavior is determined by its properties, so that the filter material will be characterized. The parameters chosen to characterize the material are the material porosity, pore size distribution, permeability and total pore area. It is thought that these parameters contribute to the understanding of the filter discharge and the removal efficiency of pathogenic micro organisms.

2.6.1 Mechanism of Filtration

The porosity of the filter is the fraction of the volume that is occupied by pores or void space. In the case of ceramic filters it is important to distinguish several types of void space; one which forms a continuous phase within the porous medium, called 'interconnected' or 'effective' pore space, and another which consists of 'isolated' pores (Figure 2.2). The isolated pores cannot contribute to the flux across the filter. 'Dead-end' pores are interconnected from one side only; the contribution of these pores to the flux is temporary. It should be noted that the dead-end pores can also be connected to the interconnected pores, but as long as the route of these pores is a dead-end it will not contribute to the flux. When the filter is filled with water all pores connected to the inside will fill with water, including the 'dead-end' pores. This will result in a delay before a steady-state discharge of the filter is reached, (Xiaolong, 2005).

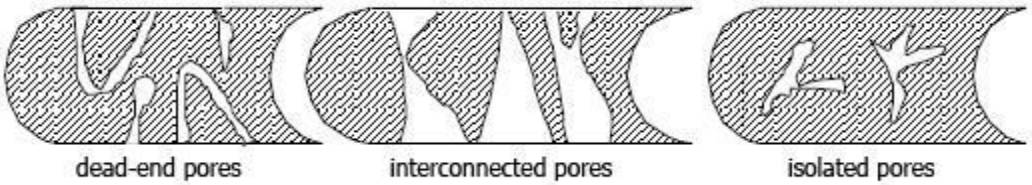


Figure 2.2 Types of pores (Xiaolong, 2005)

The overall removal of impurities associated with the process of filtration, is done by a combination of different phenomena: (i) mechanical screening, (ii) sedimentation, (iii) adsorption, (iv) chemical and (v) biological activity (Huisman, 1996). *Mechanical screening* is the purifying process that includes removing particles of suspended matter that are too large to pass through the pores of the filter material. Clogging of the filter element will reduce pore size and theoretically at least, the screening efficiency will increase in time. *Sedimentation* removes particulate suspended matter of finer sizes than the pore openings by precipitation upon the surface of the clay material. Due to the larger density of the suspended matter than water it will follow a different path resulting from gravitational force. *Diffusion* is the random motion of particles caused by collision with surrounding molecules, which could eventually lead to adsorption on the filter material.

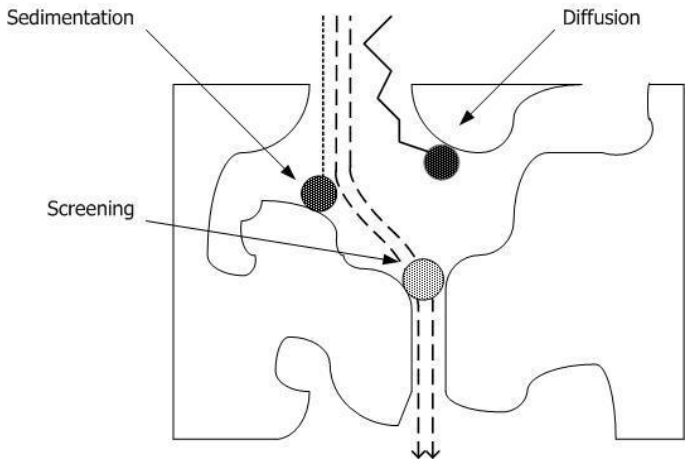


Figure 2.3 Mechanism of filtration (sedimentation, screening and diffusion)

Adsorption is an important purifying action, removing finely divided suspended matter as well as colloidal and molecular dissolved impurities. The forces of adsorption, however, exert their influence over extremely short distances only, not more than 0.01 to 1 μm, while the water film surrounding the filter material has a much greater thickness. This means that purification by adsorption is only possible in combination with a second mechanism to bring the particle in the immediate vicinity of the clay surface. Many of these transport mechanisms are present in flowing water: gravity, inertia, diffusion, hydrodynamic forces and turbulence. The forces responsible for the adsorption of suspended matter at a short distance from the filter material are:

Van der Waal's forces and Coulomb's forces.

Chemical activity is the process in which dissolved impurities are either broken down into simpler less harmful substances or converted into insoluble compounds after which straining, sedimentation and adsorption may remove them from the flowing water. *Biological activity* is the action of micro organisms, living in and on the filter element. Bacteria present in the raw water are adsorbed on the filter material, where they multiply selectively, feeding on the inorganic and organic matter deposited there. This food is partly oxidized to provide the energy these bacteria need for their living processes (dissimilation) and partly converted into cell material for their growth (assimilation).

2.6.2 Porosity of the Filters

Total porosity of a solid is defined as the volume of voids divided by total volume of the solid. Since porosity is a measure of the volume of empty space in a solid, filters showing a greater porosity will allow more water to pass through the ceramic body. However, increasing the pore size may compromise the mechanical screening phenomenon during filtration and therefore important to restrict the sawdust particle size to at least 1mm. The pore diameter from literature for most ceramic water filters has been found to be within the range 0.2-2.5 microns. Filters manufactured using a larger screen size to sieve the sawdust has been shown to reveal no significant difference in flow rates (Klarman 2009). At certain factories, however, filter mix ratios are adjusted to achieve acceptable flow rate ranges according to the particle size of the rice husks received, adding more rice husk to the mixture if it is observed to be smaller (Hagan et al., 2009). This step may indicate probable relationship between burn-out particle size and flow rate. In addition, the use of different burn-out materials, even when sifted to the same screen size, can increase the flow rate but may also reduce total coliform removal efficiency. This emphasizes the need to develop a new ratio when changing the burn-out material (Klarman 2009). The two main methods used in the determination of the porosity is by the mercury intrusion porosimetry (MIP) (Yakub 2012) and direct method (van Halem, 2006).

2.6.3 Flow Characteristics

The materials that are used for producing CWF's are in abundance and environment friendly.

These are clay, bio-diversity (examples sawdust, rice husks, starch); pore generators. Recent improvements have seen noble materials such as silver used as lining in the CWF's for further purification envisaged (Sobsey, purification, et al. 2008). The traditional manufacturing process starts with a combination of clay and fine wood chips (sawdust) taken in the ratio 1:1. This mixture is then moistened with water and pressed into moulds (green-wares) in a hydraulic press. It is then pressed into the required shape. They are kept at room temperature to help green-wares lose water by drying them at room temperature. Once dried these green-wares are fired in a kiln to about 850 °C (temperature dependent on clay composition). The sawdust is burnt off during the high temperature of firing, leaving behind the red colored clay ceramic filter with micro/nano pores in them. If the proportion of sawdust is changed in the mixture, the flow rate will also be affected because of the changes in geometry of the pores formed (Dies 2003; Davies et al., 2010).

2.7 Removal Efficiency of Pathogenic Micro Organisms

The consumption of drinking water contaminated with human and animal excreta is the greatest risk for infection from microbes in water. The pathogens that may be transmitted through contaminated drinking water are diverse. Determining the removal of pathogenic micro organisms in CF is time consuming and risky procedure, and therefore indicator organisms are introduced. The quality of this water body is not comparable to all influent waters present in developing countries. Often a river is not only used as a source of drinking water, but also for washing and bathing. The consequence of these activities is that the waters are often highly contaminated with pathogens. Hence, extremely high concentrations of indicator organisms are dosed to CF to simulate these polluted water bodies.

2.7.1 Pathogenic Micro Organisms in Drinking Water

Micro organisms present in drinking water, which are commonly responsible for infectious diseases in human beings can be divided into three groups; parasites (protozoa and helminthes), bacteria and viruses. Protozoan pathogens of human beings often occur in tropical and subtropical regions. This makes it an important parameter when investigating the performance of CF. There are two protozoa known to be responsible for outbreaks of diseases; Cryptosporidium

and Giardia lamblia. Protozoa form protective stages, known as oocysts, which allow them to survive for long periods in water while waiting to be ingested by a host. Oocysts of Cryptosporidium are round shaped with a size of 4–7 µm. Giardia lamblia is an oval organism, 8-14 µm long and 7–10 µm wide.

Bacteria are the most important group in terms of frequency of isolation in drinking water. The size of bacteria varies from 0.3 to 100 µm, depending on the shape. The most important bacterial diseases are commonly associated with faecal contamination of water. In temperate regions these include; Salmonella, Campylobacter, Shigella, Vibrio cholera, pathogenic Escherichia coli and Mycobacterium (tuberculosis). Salmonella causes acute gastroenteritis with diarrhoea, often associated with abdominal cramps, fever, nausea and vomiting, head ache and, in severe cases, even collapse and possible death (Gray, 1994). The number of organisms that have to be ingested is 10^5–10^7 before illness is developed. Cholera is known for the great outbreak in Europe in the past, but still a large number of people die of the illness in developing countries. Up to 10^8–10^9 organisms are required to cause the disease; sudden diarrhoea, vomiting, suppression of urine, rapid dehydration, lowered temperature and complete collapse. Without treatment the disease has a 60 % death rate, the patient dying within a few hours of first showing the symptoms.

Table 2.3 - Literature on E. coli removal efficiency by ceramic filters

References	Bacterial type	Removal efficiency, %
Coulbert(2005)	Escherichia coli	99.8
Franz(2005)	Escherichia coli	92-100
McAllister(2005)	Escherichia coli	99
Oyanedel-Craver	Escherichia coli	>97.8
Brown &Sbsey(2010)	Escherichia coli	Mean 99

Viruses do not have the structure to reproduce themselves, this makes them the smallest of all disease-causing organisms, at 0.02–0.2 µm. Human enteric viruses are produced in very large amounts by infected individuals and are faecally excreted. Infectious hepatitis, enteroviruses, reovirus and adenovirus are thought to be transmitted via water, (Gray, 1994)

In Figure 2.4 the pathogenic micro organisms are ordered by size. When looking at the screening mechanism in CF only, the figure shows what CF would remove if the pore size diameter is what Potters for Peace aims for (1 µm). If the effective pores measured previously (average 40 µm) have a significant contribution, the removal by CF would be considerably less. In that case, all small bacteria and some protozoa would pass the filter element. In practice, the influence of mechanisms such as adsorption and sedimentation must be taken into account.

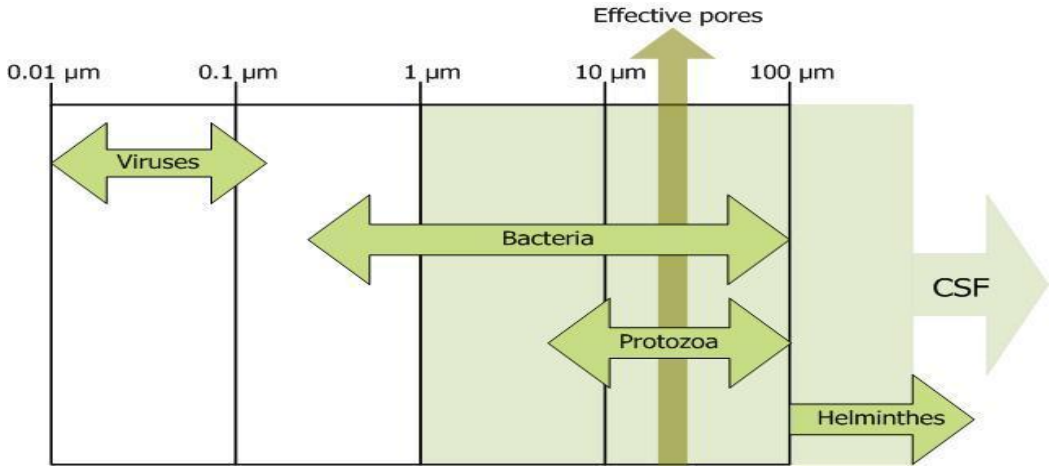


Figure 2.4 Order of magnitude of pathogenic micro organism

2.7.2 Indicator Organisms

Removing pathogenic micro organisms from water is one of the main uses of ceramic filters. The organisms in the influent and effluent are measured to determine the removal efficiency of the filters. Detecting pathogenic micro organisms is complex and risky; therefore the use of 'indicator' organisms is introduced. Criteria for an 'indicator' organism in water bacteriology have been formulated as follows (Olivieri, 1982): it should always be present whenever a pathogen is present, and preferably in much larger numbers; it should only be present in the same source as the pathogens and should not multiply in the aquatic environment; its persistence in the natural environment or resistance to water treatment processes should be similar to that of the pathogens of concern; enumeration should be simple, accurate and inexpensive.

The non-pathogenic organisms that are always present in the intestines of humans and animals are excreted along with pathogens, but in far greater numbers. Several of these coliforms are easily isolated and are ideal for use as indicators of fecal contamination. *Escherichia* coli/ *E.*coli, a member of the coliform group, can survive for several weeks under ideal conditions and are far

more easily detectable than the other indicator bacteria. The dimensions of *E*.coli are 1.0-3.0μm. *E*.coli is almost exclusively of fecal origin and their presence confirms fecal contamination. The general coliform group also includes coliforms found in aquatic environment, in soil and on vegetation. Coliforms are naturally present in canal water and should give an indication of the removal of pathogenic bacteria. The WHO guideline value for all water directly intended for drinking water is that the *E*.coli concentration must not be detectable in any 100 mL sample.

Sulphite-reducing clostridium spores (Figure 2.5) are slightly larger than *E*.coli, with 1 x 1.5 μm and can therefore be used as an indicator for protozoa oocysts. The removal of viruses by CF can be determined by spiking with MS2 bacteriophages (bacterial viruses), with a size of 23-25 nm. As the name indicates, these phages choose bacteria as their host.

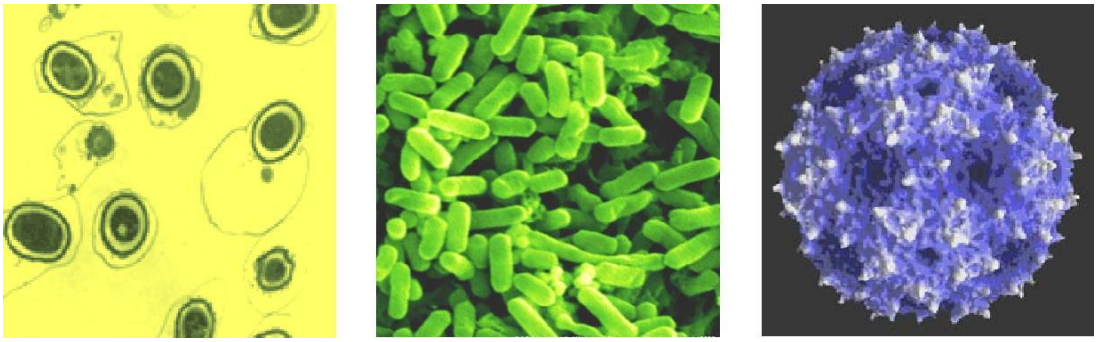


Figure 2.5 (a) Clostridium spores (1 x 1.5 μm), (b) E.coli (0.5 x 1.0-3.0 μm), and (c) MS2 bacteriophage (23-25 nm)

Most chemicals arising in drinking-water are of health concern only after extended exposure of years, rather than months (WHO, 2006). In most household water treatment systems the focus of research has been microbial removal. Nevertheless, the removal of (heavy) metals is an issue no longer deniable. Many waters in developing countries have been heavily polluted over the years by industrial sources, human dwellings and agricultural activities. Not only is the removal of compounds of interest, but also the leaching of harmful substances.

2.8 Clay Surface Properties

The main possible factors that determine the leaching or retention of metals in CF include: (i) changes in acidity of the system; (ii) changes of the systems ionic strength; (iii) changes in the

oxidation-reduction potential of the system; and (iv) formation of complexes (Yong, 2001).

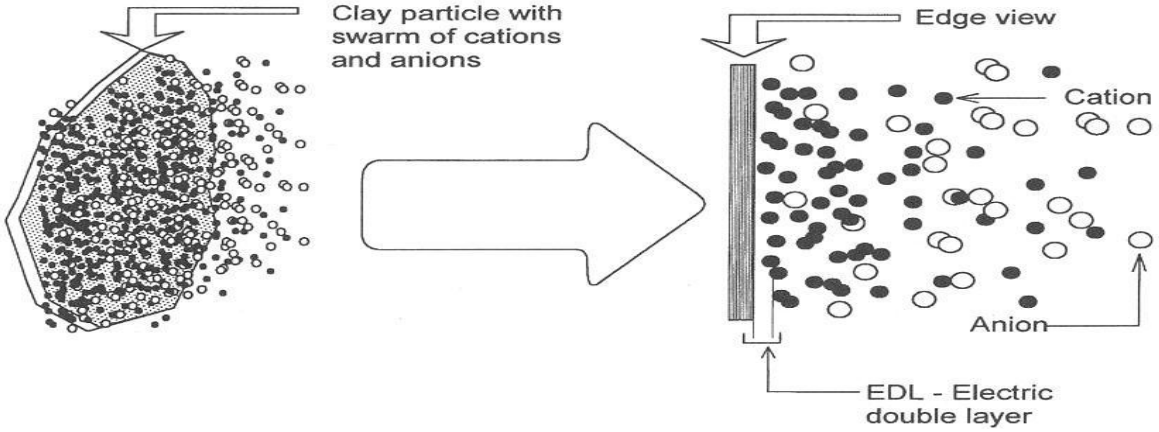


Figure 2.6 Schematic diagram of clay mineral particle with cations and anions (Yong, 2001)

There are several types of adsorption phenomena, one due to *electrostatic attraction* to a charged surface. Clay minerals have a negative surface charge that is relatively constant in magnitude. When clay particles are brought into contact with an aqueous solution, the reactive surfaces of the clay particles will interact with the ions and molecules in the solution. The interaction between a negatively charged clay particle surface and the cations in the pore water will generate an electric double layer. Because the filter material has a negatively charged surface, electrostatic attraction for cations to form the double layer is an important phenomenon and this is usually described in terms of an ion exchange process. In changing environments, these counter ions can be replaced by others. The equilibrium of the reaction depends on the nature of the clay surface and also depends on the nature (principally, charge density), and concentration of the dissolved species adjacent to the clay particle. A second mechanism of retention of metal ions on clay surfaces is associated with *specific adsorption*. Here the adsorption depends on the degree of the chemical environment as opposed to the electrostatic affinity between the surface and the adsorbed metal ions.

Under slightly alkaline conditions, *precipitation* of metals as hydroxides and carbonates can occur. Various sorption mechanisms and precipitation all result in the removal and release of metals from the water. It is not easy to distinguish these various processes responsible for the removal. The primary factors that influence formation of precipitates include the pH of the clay and water, type and concentration of metals, availability of inorganic and organic ligands, precipitation and pH of the metal. The effect of pH is shown in the solubility precipitation

diagram (Figure 2.7) for a metal hydroxide complex.

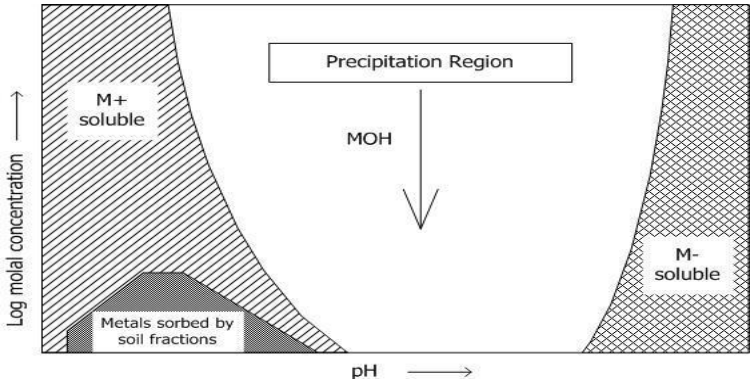


Figure 2.7 Solubility-precipitation diagrams for a metal hydroxide complex showing sorption of metals by soil fractions in relation to pH (Yong, 2001)

2.9 Structure of Clay Minerals

Clay minerals are phyllosilicates that belongs to three principal groups. These are Montmorillonite, Illite and Kaolinite. Montmorillonite layered silicate (MLS) has 2:1 layered structure, Illite also has 2:1 layered structure and kaolinite 1:1 layered structure. Phyllosilicates are two-dimensional arrays of silicon-oxygen tetrahedral and two-dimensional arrays of aluminum or magnesium-oxygen-hydroxyl octahedral. For silicon-oxygen sheets, silicon atoms are coordinated with four oxygen atoms. With silicon atom at the center, oxygen atoms are located on the four corners of a regular tetrahedron (Figure 2. 8). In the sheet, three neighboring tetrahedral share three of the four oxygen atoms of each tetrahedron and the fourth oxygen atom of each tetrahedron is pointing downward.

In the case of Al-Mg-O-OH sheets (Figure 9), the Al or Mg atoms are coordinated with six oxygen atoms or OH groups. A regular octahedron has its corners occupied by oxygen or OH groups and Al or Mg at the center. Sharing of oxygen (or OH groups) with neighboring octahedron results in a sheet structure. The sheet is called an octahedral sheet or the alumina or magnesia sheet. The tetrahedral and octahedral sheets have similar symmetry and identical dimensions, which helps in sharing of oxygen atoms between these sheets. If the sharing occurs between one silica and one alumina sheet, it is called 1:1 layer minerals. When one alumina sheet

shares two oxygen atoms from silica sheets, it is called 2:1 layered mineral. Within each layer there is a repetition of structure and therefore it is referred as a unit cell. The distance between a certain plane in the layer and the corresponding plane in the next layer is referred to us the basal or d-spacing.

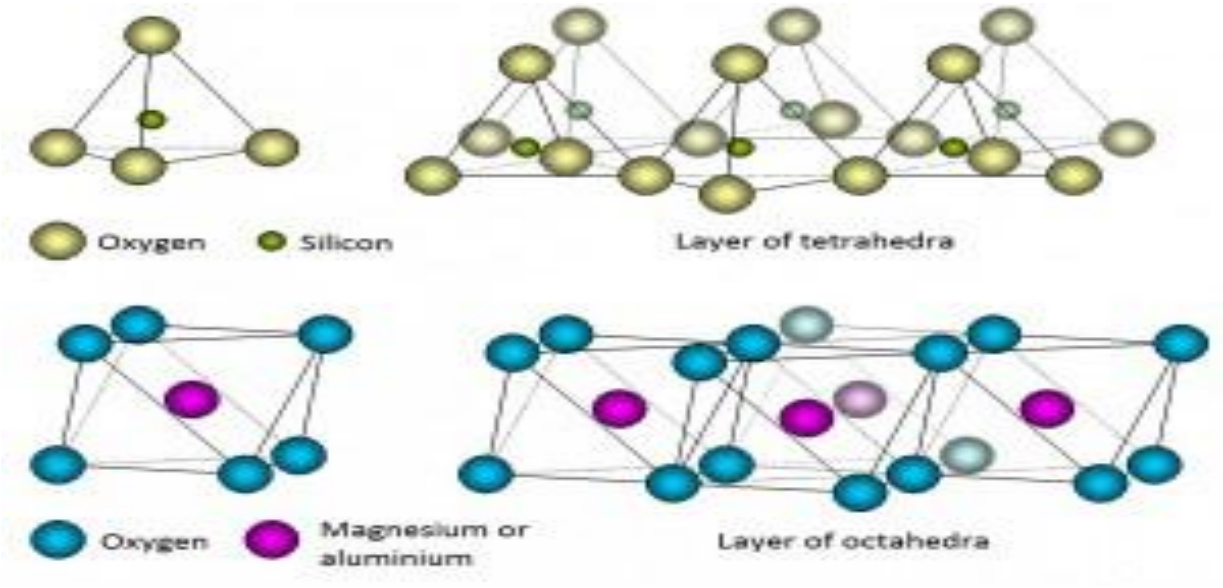


Figure 2.8: A single Si–O tetrahedron and the structure of the tetrahedral sheet and a single Al–O octahedron and the structure of the octahedral sheet.

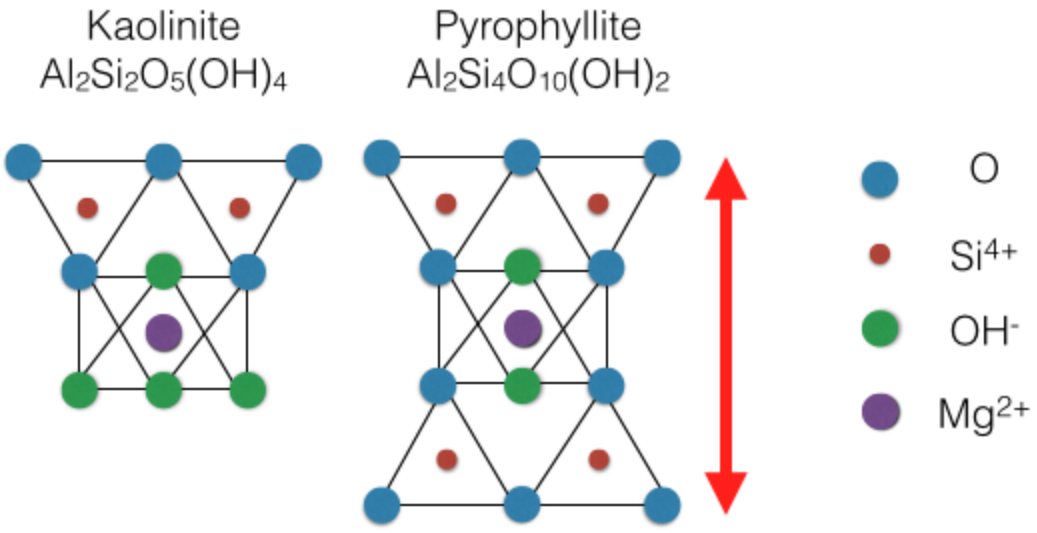


Figure 2.9- Schematic representation of the structure of kaolinite and pyrophyllite

Table 2.4 Chemical composition and crystallography of some clay minerals

	Kaolinite	Pyrophyllite	Mica
Chemical formula	$Al_2Si_2O_5(OH)_4$	$Al_2Si_4O_{10}(OH)_2$	$KAl_3Si_3O_{10}(OH)_2$
Mineral formula	$Al_2O_3.2SiO_2.2H_2O$	$Al_2O_3.4SiO_2.H_2O$	$K_2O.3Al_2O_3.6SiO_2.2H_2O$
Crystal class	Triclinic	Monoclilnic	Monoclilnic
Space group	P1	C2/c	C2/c
Density	2.6 g/cm^3	2.8 g/cm^3	2.8 g/cm^3
c-Lattice parameter	2.7 Å	18.6 Å	20.1 Å

2.10 Water Quality

Water quality describes the chemical, physical and biological conditions of drinking water. There are different parameters that are used to describe the quality of water. Some of these parameters are: the amount of turbidity, pathogenic microbial, total dissolved solid/TSD, color and odor. Quality drinking water should be free from any of the contaminants described above. (WHO,2017).

2.10.1 Turbidity

Turbidity is a visible indicator of the water quality, but unfortunately even if water looks pure and clear it may be heavily polluted with invisible contaminants. As a consumer it is impossible to test water daily for these invisible pollutants, but one does look in his cup before taking a sip. If the water looks turbid one may decide not to drink it, even if it is possibly free from all harmful substances. Turbidity in open water may be caused by growth of phytoplankton. Human activities that disturb land, such as construction, mining and agriculture, can lead to high sediment levels entering water bodies during rain storms due to storm water runoff. Areas prone to high bank erosion rates as well as urbanized areas also contribute large amounts of turbidity to nearby waters, through storm water pollution from paved surfaces such as roads, bridges and

parking lots. Certain industries such as quarrying, mining and coal recovery can generate very high levels of turbidity from colloidal rock particles. (U.S. (EPA) November 2005).

In drinking water, the higher the turbidity level, the higher the risk that people may develop gastrointestinal diseases. This is especially problematic for immunocompromised people, because contaminants like viruses or bacteria can become attached to the suspended solids. The suspended solids interfere with water disinfection with chlorine because the particles act as shields for the virus and bacteria. Similarly, suspended solids can protect bacteria from ultraviolet (UV) sterilization of water. (A.G. Mann, C.C. Tam, C.D. Higgins, & L.C. Lodrigues. 2007).

2.10.1.1 Flow and Turbidity

Turbidity describes the level of suspended particles in water. The more turbid a water is, the lower the flow rate, thus slowing permeability. This is due to the clogging of the pores by particles during filtration. It is therefore advisable to use clean white cotton cloth (or recommended pre-filtration cloth) before the usage of ceramic water filters. Water turbidity will also affect the ceramic water filter sustainability. Heavy turbid water used will require more regular cleaning of the filter. In a whole the volume of filtered water discharged will be less as compared to less turbid water. Although scrubbing temporarily increased flow rates, ceramic water filters did not achieve their original flow rate and even with scrubbing, flow rates continually diminished (van Halem 2006). Fahlin (2003) found that clogging impeded his research into the hydraulic conductivity of filters. However, some field investigations users have reported that filters provided enough water for additional uses and only 5 % of filter disuse was attributed to unsatisfactory flow rates (Brown and Sobsey 2006).

2.10.2 Total Dissolved Solids (TDS)

TDS is a measure of the combined content of all inorganic and organic substances contained in a liquid in molecular, ionized or micro-granular (colloidal sol) suspended form. Generally the operational definition is that the solids must be small enough to survive filtration through a filter with two-micrometer (nominal size or smaller) pores. Total dissolved solids are normally

discussed only for freshwater systems, as salinity includes some of the ions constituting the definition of TDS. The principal application of TDS is in the study of water quality for streams, rivers and lakes, although TDS is not generally considered a primary pollutant (e.g. it is not deemed to be associated with health effects) it is used as an indication of aesthetic characteristics of drinking water and as an aggregate indicator of the presence of a broad array of chemical contaminants.

Primary sources for TDS in receiving waters are agricultural and residential runoff, clay rich mountain waters, leaching of soil contamination and point source water pollution discharge from industrial or sewage treatment plants. The most common chemical constituents are calcium, phosphates, nitrates, sodium, potassium and chloride, which are found in nutrient runoff, general storm water runoff and runoff from snowy climates where road de-icing salts are applied. The chemicals may be cations, anions, molecules or agglomerations on the order of one thousand or fewer molecules, so long as a soluble micro-granule is formed. More exotic and harmful elements of TDS are pesticides arising from surface runoff. Certain naturally occurring total dissolved solids arise from the weathering and dissolution of rocks and soils. The United States has established a secondary water quality standard of 500 mg/L to provide for palatability of drinking water. Total dissolved solids are differentiated from total suspended solids (TSS), in that the latter cannot pass through a sieve of two micrometers and yet are indefinitely suspended in solution. The term "settleable solids" refers to material of any size that will not remain suspended or dissolved in a holding tank not subject to motion, and excludes both TDS and TSS. DeZuane, John (1997). Settleable solids may include larger particulate matter or insoluble molecules.

2.10.3 Color

Color in the effluent water is not only caused by the clay filter element, but also due to the water quality of the raw water The color is most likely caused by dissolved organic carbon (DOC), which is present in high concentrations in the water; averagely 15 mg/L (Sheng, 2006). Ultraviolet (UV) light is used to measure the presence of DOC in the water, because a strong correlation may exist between UV absorption and organic carbon content and color (Clesceri, 1998). UV-absorbing organic constituents in a sample absorb UV light in proportion to their concentration.

2.10.3 Fluoride

Fluoride is a naturally occurring element in minerals, geochemical deposits, and natural water systems and enters food chains through either drinking water or eating plants and cereals (Sushree et al. 2006). It is found to occur naturally as sellaite (MgF_2), fluorspar (CaF_2), cryolite (Na_3AlF_6) and fluorapatite [$3Ca_3(PO_4)_2Ca(F,Cl_2)$]. According to the World Health Organization (WHO), the tolerance limit of fluoride content of drinking water is 1.5 mg/L (WHO, 1993). Fluoride concentrations in the range (1.5-4) mg/L result in dental fluorosis whereas with prolonged exposure within 4-10 mg/L progresses to skeletal fluorosis. Fluoride which is nearly insoluble in water has been found in many ground water bodies at levels around 30 mg/L, notably in Africa, USA, and Asia (Wang et al., 2002; Agarwal et al., 2003; Moges et al., 1996; Gaciri and Davies, 1992; Chernet et al., 2002; Mjengera and Mkongo, 2002; Moturi et al., 2002). The main methods used in defluoridation from aqueous solutions are membrane techniques and adsorption techniques (alumina based adsorbents, Clays and Soils, Carbon, Zeolites and layered double hydroxides (M. Mohapatra et al. 2009).

3. MATERIALS AND METHODS

3.1 Materials

3.1.1 Chemicals

Clay material feedstock, grog (fired clay), ground saw dust, distilled water, water sample, stock fluoride solution (1000mg/l fluoride solution) and total ionic strength adjustment buffer/TISAB.

3.1.2 Equipments and Instruments

Large water tight tank, filter element racks, timer with alarm, measuring cylinder, sterilized plastic bottles, glass wares, permanent marker, sterile filter paper, forceps, E. coli plate, syringe, filter paper holder, pipette, vessel with hot water, vessel for discharge, incubator, reference electrode, fluoride electrode, magnetic stirrer, 500mL beaker, micro pipette and expanded scale or digital pH meter, screen mesh, X-ray diffractometer/ XRD, Atomic Absorption Spectrometer/ AAS, Fuorier Transform Infra Red Spectrometer/FT-IR, scanning electron microscope (SEM) and muffle furnace.

3.2 Methods

3.2.1 Preparation of Ceramic Filter

The clay ceramic filters were prepared at Kechene Potters' Association found in Addis Ababa. The manufacturing process of the ceramic filters began by grinding dry clay in a hammer mill and sieving it through a screen mesh (3 mm). Sieved sawdust (3 mm) and sieved grog (3 mm) were prepared. The pot filters were prepared according to the procedure reported by (Kabagambe Musa, 2010). Sieved clay powder, grog and saw dust were taken in the required proportion for the production of ceramic filters. For different batch of the ceramic filter, dry ingredients of the three basic materials with required proportions were taken in accordance to Table-3.1. Clay, saw dust and grog were mixed for 45 minutes in dry. Then, water was added uniformly on a dry mixture of clay, saw dust and grog and mixed again in wet by wedging and rolling for 45 minutes to get a homogenous consistency and the wet mixture was divided into blocks. The blocked clay mixtures were molded in to pot shape. The pot filters were allowed to dry for 15 days. Once the filters were completely dry they were taken to Adama Science and Technology

University/ASTU Applied Chemistry Post Graduate Laboratory and then fired in muffle furnace at 800 °C, 850 °C, 900 °C and 950 °C for a period of 6 h gradually starting from 100 °C at a temperature rate of 10^{o}C/min. During the heating process, the carbonaceous materials are burnt at temperatures between 400 and 500 ^{O}C and sintered between 800 ^{O}C and 900 ^{O}C (Yakub and Soboyejo 2013; Yakub et al. 2013; Van Halem et al. 2009; Brown et al. 2009; Brown et al. 2010; Oyanedel-Craver and Smith 2008; Van Halem 2006). Afterwards, the filters were left to cool gradually at a temperature rate of 10 ^{o}C/min until their temperature reached room temperature. Once cooled, the filters were soaked in water for 24 hours and tested for their clean water flux and finally a total of 12 filters were selected. The pots have comparable volume, (176 mL). The selected filters were washed with distilled water, dried in oven at 100 ^{o}C, packed properly in plastic bags to protect them from any contamination and were made ready for the tests.

Table-3.1The percent composition of clay, sawdust and grog

Filter Code	Percentage clay by (wt)	Percentage of saw dust by (wt)	Percentage grog by (wt)	Firing temperature (^{o}C)	Thickness (cm)
T-13	70	15	15	800	1
T-23	70	15	15	850	1
T-33	70	15	15	900	1
T-43	70	15	15	950	1
T-11	60	25	15	800	1
T-21	60	25	15	850	1
T-31	60	25	15	900	1
T-41	60	25	15	950	1
T-12	50	35	15	800	1
T-22	50	35	15	850	1
T-32	50	35	15	900	1
T-42	50	35	15	950	1

Key: In the filters' codes the two numbers represent firing temperature and composition of the filters respectively; for instance in the code T-12 the number 1 represents 800 ^{o}C and the number 2 represents composition of the filter.

3.2.2 Characterization of the Ceramic Filter

Characterization refers to the use of techniques such as scanning electron microscope (SEM) to study the topography, morphology and composition of the materials with much higher resolution, X-ray defractometer (XRD) to investigate detailed structures and properties of a material. FT-IR is used to identify the surface functional groups on the filter. XRD is used to identify the dominant mineral phase in the clay. Silicate analysis for determination of major and minor oxides was conducted at Ethiopian Geological Survey, Geometrical Laboratory, Addis Ababa. FT-IR and XRD tests were conducted at Addis Ababa University Chemistry Laboratory.

3.2.2.1 Scanning Electron Microscopy (SEM) Analysis

The scanning electron microscopy (SEM) is a useful technique to study the topography, morphology and composition of the materials with much higher resolution. Filter materials surface morphology, microstructures and the presence of larger cracks were checked by using ZEISS EVO Series Scanning Electron Microscope EVO-50 and EVO-18 after a thin layer of gold was coated by using Auto Fine Coated for 90 seconds in the (Department of Nanotechnology, Karunya University, India). The ZEISS EVO 50 is a versatile analytical microscope with a large specimen chamber. The EVO 50 series can handle large specimens at the analytical working distance of 8.5 mm owing to a combination of the inclined detectors and the sharp conical objective lens. The class leading x-ray geometry allows for the addition of a detector.

3.2.2.2 Silicate Analysis

Silicate analysis is a technique used to determine the composition of the modified clay ceramic filter. The filter's major and minor oxides were analyzed by using Analytical Methods: LiO_2 Fusion, HF attack, Gravimetric, Colorimetric and AAS techniques in Geological Survey of Ethiopia: Geochemical Laboratory, Silicate Analysis Section, Addis Ababa.

3.2.2.3 XRD Analysis

The modified clay ceramic material was characterized by X-ray diffractometer (Bruker D8 Advance Diffractometer). Small amount of powdered clay was placed on the standard sample holder. The analysis was run until result was obtained. XRD spectrum was recorded from 10^0 to

80^0 with 2θ angles using CuKα (λ =1.54 Å) radiation operated at 40 kV and 30 mA, (in Addis Ababa University, Chemistry Laboratory).

3.2.2.4 FT-IR Analysis

Perkin Elmer, 65 Spectrophotometer FT-IR Spectrophotometer was used to analyze and detect surface functional groups of the modified clay ceramic filter at the scanning range of 4000 – 400 cm^{-1},(in Addis Ababa University Organic Chemistry Laboratory). Small amount of the clay sample was placed on one of the KBr plates. The second KBr plate was placed on top and turned a quarter to obtain a nice even film. The plates were placed into the sample holder and a spectrum was run.

3.2.2.5 Total Porosity

The total porosity of the filter gives an indication of the buildup of the microstructure. The direct method is a simple procedure to determine the total porosity of the complete filter element.

3.2.2.5.1 Direct Method

Porosity of the ceramic filters was determined using the water absorption test (direct) method in Adama Science and Technology University/ASTU Applied Chemistry Post Graduate Laboratory. The total porosity of the filters is determined by the 'direct method' which includes weighing the filter dry and saturated. Complete saturation will be achieved after 24 hours, (Nederstigt, 2005). The filters were washed thoroughly and dried in oven. The dry mass of the filters was measured. The filters were soaked in distilled water for 24 hours for saturation. After this period all air was released from the filter and the interconnected and dead-end pores were filled with water. The isolated pores were taken into account when weighing the filter dry, but this was not the case when weighing it saturated. The saturated masses of the filters were measured. The total porosity (P) was calculated by the following equation:

$$Porosity\ of\ filter\ \ = \frac{Mass\ of\ saturated\ filter - Mass\ of\ dry\ filter}{Density\ of\ water\ x\ Volume\ of\ filter} - - - -— (eq-1)$$

Where: P = total porosity; m_d = mass of dry filter; m_s = mass of saturated filter; p_w = density of water and V_{ft} = volume of filter

The volume of the filter was determined by weighing the filter under water. In that case the upward force equals the displacement of water. Figure 3.1 shows the experimental set-up to weigh the filter element in water. The total porosities of eight filters were determined using eq-1, (Table-4.23). The volume of the filter was calculated by the formula:

$$Volume\ of\ filter = \frac{Mass\ of\ saturated\ filter - Mass\ under\ water}{Density\ of\ water} ----(eq-2)$$

Where: V_f = volume of filter; m_s=mass of saturated filter; m_{uw} = mass of filter underwater and ρ_w = density of water

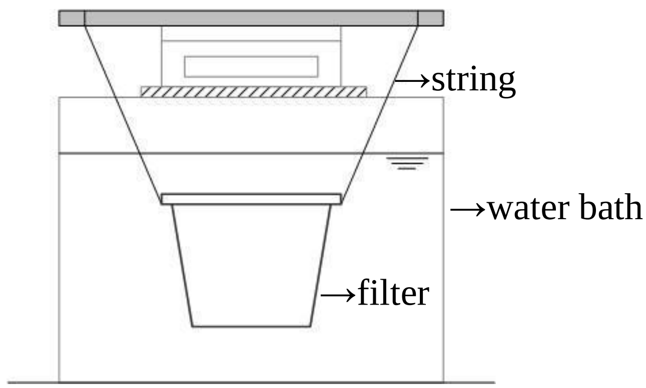


Figure 3.1 Determination of the filter volume

3.2.3 Test for Water Treatment

Flow rate, microbial removal efficiency, fluoride removal efficiency, total dissolved solid/TDS removal efficiency, turbidity, taste, color and odor tests and conductivity test were conducted. The tests were performed at ASTU Applied Chemistry PG Laboratory and Oromo Self Help Organization/OSHO Laboratory at Modjo.

Removal efficiency of the filters was determined in accordance with the equation:

$$E = \frac{Co - Cf}{Co} ------------------------------(eq-3)$$

Where: C_o is initial concentration of a mentioned parameter in the water sample at $\mathbf{t_o}$, C_f is the final concentration of the mentioned parameter and E is the efficiency of the water filter.

3.2.3.1 Flow Rate

Flow rate testing is an important quality assurance step which indicates the rate at which water passes through the filter element. Once the raw materials' ratio and production process has been established, flow rate testing is conducted on every filter element that is produced to ensure its viability. Schweitzer et al. 2013 have modeled the flow through ceramic water filters. In their analysis, they assumed uniform thickness for the walls and bottom of the frustum-shaped ceramic water filter. (Bear 1972). The pots were fully immersed in water and soaked for 24 hours to ensure full saturation of filters at the beginning of the test and to achieve standardized results. Once soaked, the filters were transferred onto a flow testing rack. These were designed to drain the water away and most importantly, to stop water from dripping into the filters below and thus altering the flow rate readings. Each of the filters was filled to the brim with water. Once the filter was filled to the brim, a timer was started for 1 h. After an hour, the filter was removed from the rack and the flow rate of each filter was measured with a measuring cylinder. The same procedure was used to measure the flow rate of each filter at 0.75 h, 0.5 h and 0.25 h. Finally the flow rate of each filter was recorded in terms of mL/h and the obtained data were analyzed and interpreted.

3.2.3.2 Removal Efficiency of Escherichia coli/E.coli

The water used for bacterial test was collected from Modjo River which is highly contaminated with pathogenic bacteria. The collected sample was taken to Oromo Self Help Organization Laboratory for the bacterial test. The test was conducted in accordance with the following procedures. A triplicate sample analysis was conducted for each of the twelve (12) filters.

3.2.3.2.1 Collection of Water Sample

Contaminated river water sample was collected from Modjo River, which is found in Modjo Town by purposive sampling techniques (Ilker.E et al., 2016). Sufficient amount of contaminated water sample, (i.e.10 L) that was used for E. coli test was collected from the river and it was taken to Oromo Self Help Organization/ OSHO Laboratory which is found in Modjo Town.

3.2.3.2.2 The Sampling Process

The sample bottles were cleaned thoroughly with a suitable detergent and hot water, rinsed with hot water and finally rinsed with distilled water. The sample bottles were sterilized for an hour at a temperature of 170 °C, loosen caps before autoclaving to prevent distortion, (if it is plastic bottle).The sterilized bottle was opened; it was held by the lower part and was submerged to a depth of about 20 cm with the mouth facing slightly upwards and filled with sample water leaving ample air space in the bottle (at least 2.5 cm) to facilitate mixing by shaking before examination. The bottle was capped and placed in a clean plastic bag and transported to OSHO Laboratory for the bacterial/ *E*. coli test.

3.2.3.2.3 Incubation of the E. coli Plate

Since the water was highly turbid, a 10 mL syringe was used to avoid clogging the filter paper. The syringe was sterilized by sucking hot water in to the discharge vessel and after 10 seconds the water was discarded to the discharge vessel. The filter paper holder was pasteurized by submerging its upper part in the hot water and the water of the filter paper holder was drained to the discharge vessel. A clean glass was also sterilized in the same manner. The pasteurized glass was filled with the water to be analyzed. A sterilized filter paper was taken with pasteurized forceps holding it by the edge and was placed on the pasteurized filter paper support. The filter paper support was closed with the cap carefully and tightly to avoid leakages during filtration. 10mL water sample was drawn from the water sample by the syringe and put on the filter paper then the syringe was fixed with the filter paper support and then the syringe handle was pulled slowly to filter the 10 mL water sample through the filter paper; finally the filtered water was discarded in to the discharge vessel. The filter paper support was opened and the filter paper was removed carefully from the filter paper holder by pasteurized forceps. The filter paper was placed carefully on the E. coli plate to avoid air pockets between the nutrient path and the filter paper and covered tightly, marked then placed in incubator for 24 hrs of incubation at a temperature of 25-35 °C. After 24 hrs the number of blue spots (E. coli colonies) were counted and recorded for a total of 37, 10 mL water samples including the raw sample. *E*. coli concentration for 100 mL of water sample is counted by multiplying the count of 10 mL sample by 10.

3.2.3.3 Fluoride Removal Efficiency

The main methods used in defluoridation from aqueous solutions are membrane techniques and adsorption techniques (alumina based adsorbents, Clays and Soils, Carbon, Zeolites and layered double hydroxides (M. Mohapatra et al. 2009). In this test Ion-Selective Electrode/ISE method was used to determine the fluoride removal efficiency of the filters. Two electrodes were used to conduct the test: Fluoride Ion-Selective Electrode/FISE and a reference electrode containing KCl solution. The ion-selective works based on the principle of a galvanic cell. The transport of ions from an area of high concentration to low concentration through the selective binding of ions with the specific sites of the membrane creates a potential difference, which is measured with respect to a stable reference electrode having a constant potential and a net charge is determined. The difference in potential between the electrode and the membrane depends on the activity of the specific ion in solution (Kalwinder, 2013). Six pot filters were selected for the fluoride test. Two of the filters were filters fired at low temperature (i.e. fired 500 ^{o}C).

3.2.3.3.1 Preparation of TISAB

500 mL distilled water was placed in 1 L beaker and 7 g trisodium citrate ($Na_3C_6H_5O_7.H_2O$), 56 gm sodium chloride and 2 gm ethylenediaminetetraacetic acid/EDTA were added to it and stirred to dissolve. 57 mL glacial acetic acid was added then 5 M sodium hydroxide was added until the pH was reached 5.3 and transferred to a 1 L volumetric flask and distilled water was added to the mark.

3.2.3.3.2 Calibration of the Electrode

20 mL of fluoride solutions with different fluoride concentrations were prepared: 1mg/L, 2 mg/L, 3 mg/L, 4 mg/L, and 5 mg/L. 2 mL TISAB was added to each solution. The potential reading of each concentration was taken and the graph of potential (E in mv) verses the logarithm of concentration (Log c in mg/L) was drawn then the slope of the graph and r^2 were calculated to check the accuracy of the measurement.

3.2.3.3.3 Sample Preparation and Fluoride Measurement

10 mL of sample was put into a 50 mL plastic beaker and 10 mL distilled water and 2 mL TISAB were added. The sample solution was placed on magnetic stirrer. The electrodes were immersed in to the sample solution & the developed potential was measured while stirring on a magnetic stirrer. The electrodes remained in solution until the milivolt reading was constant or no drift sign was visible on the liquid crystal display/LCD screen. The electrodes were withdrawn from the solution and rinsed with distilled water and blotted dry between readings (blotting may poise electrode if not done gently). The potential readings of all the samples were entered in excel spread sheet program and the potential reading was converted to concentration.

3.2.3.4 Conductivity and Total Dissolved Solid/TDS Tests

3.2.3.4.1 Calibration Procedure of Conductivity Meter HI9033 (Hanna Instrument)

The two principal methods of measuring total dissolved solids are gravimetric analysis and conductivity, (EPA 1999).A beaker was filled with 8cm^3 of conductivity calibration solution and the probe of the conductivity meter was immersed in to the beaker. The instrument was turned on and the appropriate range of measurement was selected. The probe was tapped repeatedly on the bottom of the beaker and the solution was stirred to ensure that no air bubbles were trapped inside the sleeve. The calibration timer was turned on until the proper conductivity value was displayed at 25 °C and the calibration was completed and the instrument was ready for use. The electrical conductivity (EC) correlates with the total dissolved solids (TDS):

TDS [mg/L] = 0.5 x EC [µS/cm] = 0.5 x 0.1 x EC [mS/m] ---------- (eq-4)

The electrical conductivity and TDS values were measured for the raw water sample and the water samples filtered by four selected ceramic filters and the results were recorded.

3.2.3.5 Color and Turbidity Tests

The most widely used measurement unit for turbidity is the Formazin Turbidity Unit (FTU). International Standards Organization/ ISO refers to its units as FNU (Formazin Nephelometric Units). ISO 7027 provides the method in water quality for the determination of turbidity. It is

used to determine the concentration of suspended particles in a sample of water by measuring the incident light scattered at right angles from the sample. The scattered light is captured by a photodiode, which produces an electronic signal that is converted to turbidity. Open source hardware has been developed following the ISO 7027 method to measure turbidity reliably using an Arduino microcontroller and inexpensive LEDs (B. Wijnen, et al, G. C. Anzalone et al, J. M. Pearce, (2014).

The turbidity of water is determined photo electrically using the palintest photometer. In many samples both color and turbidity will be present. In order to separate the effect of turbidity and color the sample is compared against a filtered portion of the same water. The palintest method has been calibrated against the widely recognized formazin turbidity solutions. Turbidity is expressed in terms of formazin turbidity units (FTU). These units are broadly equivalent to Jackson turbidity units (JTU).A portion of the sample was filtered through a GF/B filter paper. A test tube was filled with the filtered sample and used as blank. A photometer reading was taken for the blank then color and turbidity of the raw water sample and the filtered water samples were measured to obtain raw data.

3.2.3.6 Odor and Taste Tests

Next to the visible water quality, sensing a neutral smell and taste is important to most consumers. The odor and taste of the raw water sample and the filtered water sample were compared and the results were recorded.

3.2.4 pH

The pH of the raw water and filtered water samples were analyzed with pH Meter, Metrohm, (pH Electrode, Metrohm 6.0220.100) in OSHO laboratory. The pH value of 4 and 8 buffer solutions were used to sustain the measurement of pH of the raw and filtered water.

4. RESULTS AND DISCUSSION

The results of the experiments used to evaluate the performances of the developed ceramic pot filters are summarized in the figures and tables below. The filters used in this research are very small pot filters prepared by varying clay-to-saw dust ratio and firing temperature. Current manufacturing practice suggests that average minimum flow rate ranged from 1.0 –3.0 L/h in the first hour while the average maximum flow rate ranged from 2.0 –5.0 L/h in the first hour (Rayners, 2013; CMG, 2009). The flow rate of the pot filters in this study is measured in mL /h because the pots are very small pots. Filters with larger surface area have greater flow rate whereas filters with small surface areas have lower flow rates (Halem, 2006).

The pot filters have an average volume of 176 mL; as a result of this the flow rate of the pot filters was measured in milliliter per hour. The pot filters generally exhibited good performances in flow rate tests, removing *E.* coli, fluoride, turbidity, color, odor and taste from raw water sample. Therefore the pot filters are robust and capable of providing safe water to users better than pot filters currently available on market, if they were made to have comparable volume with the already available ones.

4.1 Effect of Temperature on Flow Rate

Figures 4.1-4.4 show the flow rate results of the pot filters with respect to firing temperature for the same ratios of raw materials and processing conditions. The flow rates of the ceramic filters depend on the porosity of the filter elements especially with interconnected pores. The flow rate of the pot filters increased from 126.33 mL to 139 mL/h for 1 h flow time; from 67 mL to 77.67 mL/h for 0.75 h flow time; from 49 mL to 52 mL/h for 0.5h flow time and from 25.67 mL/h to 30 mL/h for 0.25 h flow time as the firing temperature was increased from 800 ^{o}C to 950 ^{o}C. This increase in flow rate with an increase in firing temperature is due to an increase in porosity of the pot filters as more and more saw dust is burned away leaving more and more pores.

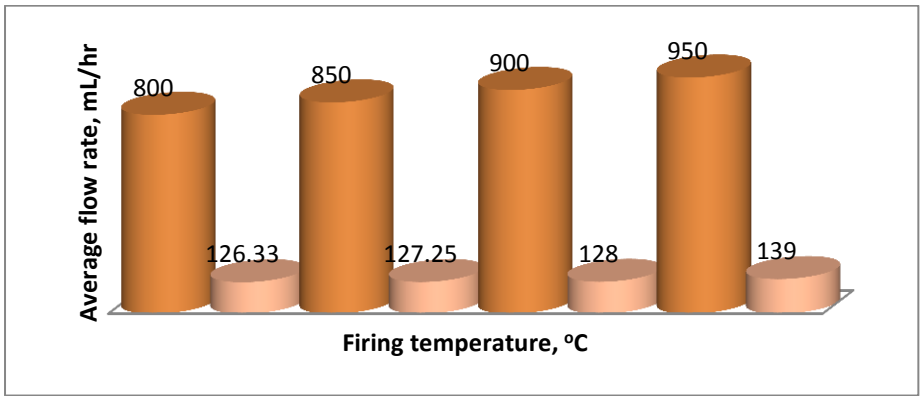


Figure-4.1 Average flow rate results with respect to firing temperature for t = 1 h

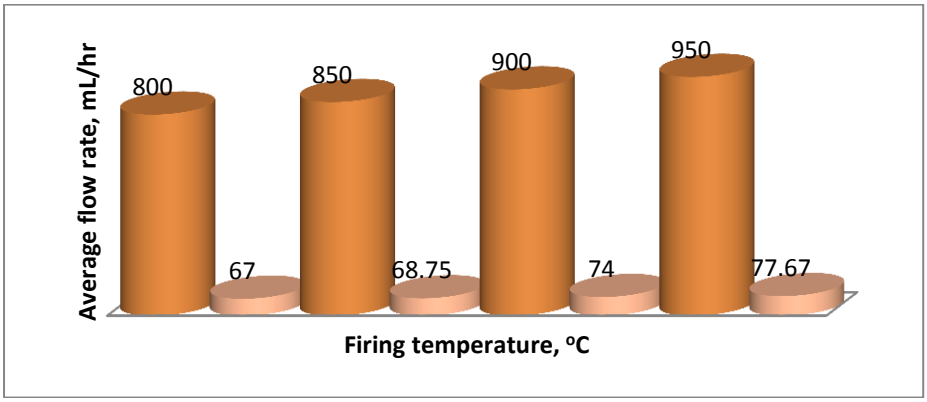


Figure-4.2 Average flow rate results with respect to firing temperature for t = 0.75 h

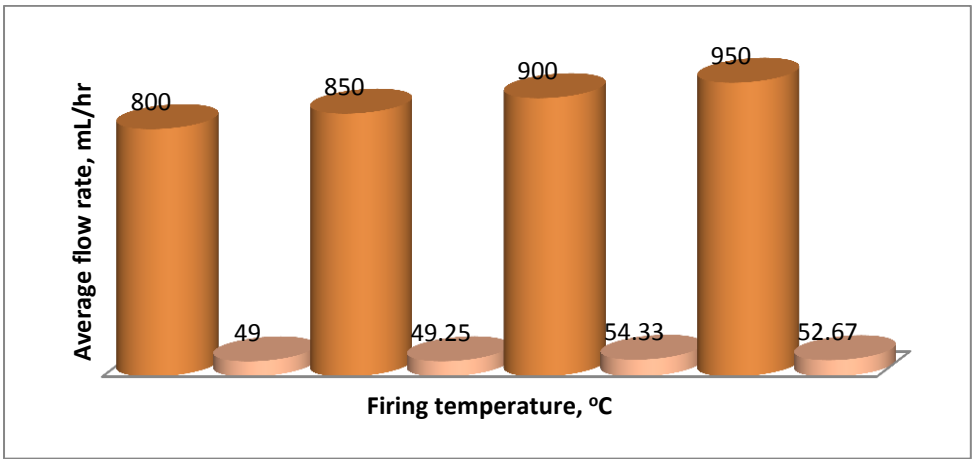


Figure-4.3 Average flow rate results with respect to firing temperature for t = 0.5 h

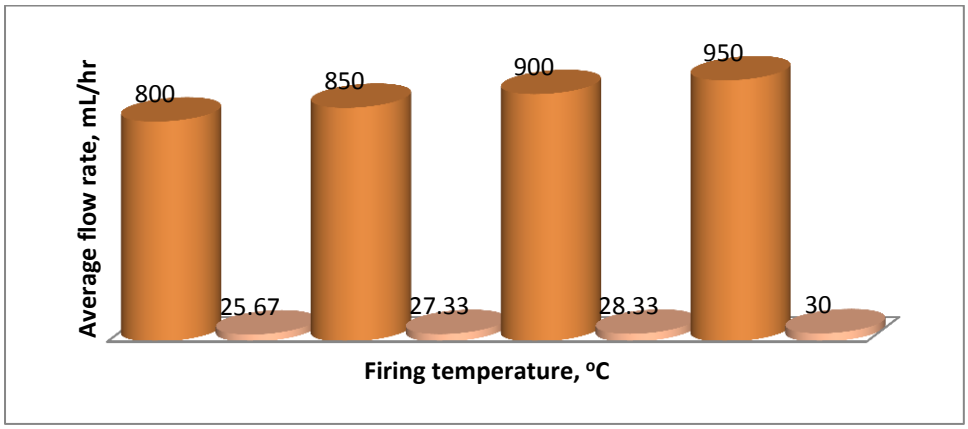


Figure-4.4 Average flow rate results with respect to firing temperature for t = 0.25 h

4.2 Effect of Composition on Flow Rate

Figures- 4. 5-4.8 represent flow rate results of the pot filters with respect to composition of the pot filters. The flow rate of the filters varied with clay-to-saw dust ratios. If the proportion of sawdust is changed in the mixture, the flow rate will also be affected because of the changes in geometry of the pores formed (Dies 2003; Davies et al., 2010). The filters exhibited highest flow rate results were those filters whose composition was represented as C-2 (filters with highest saw dust-to-clay ratio.) and the filters exhibited least flow rate results were those filters whose composition was represented as C-3 (filters with least saw dust-to-clay ratio), (Appendix-A) because porosity of the filters increases with an increase in the amount of the saw dust.

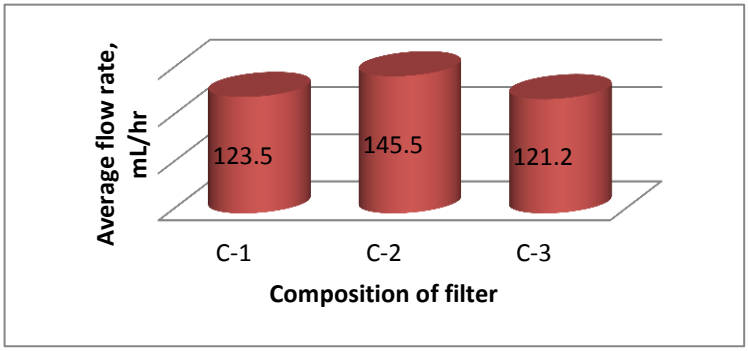


Figure-4.5 Average flow rate results with respect to composition for t = 1 h

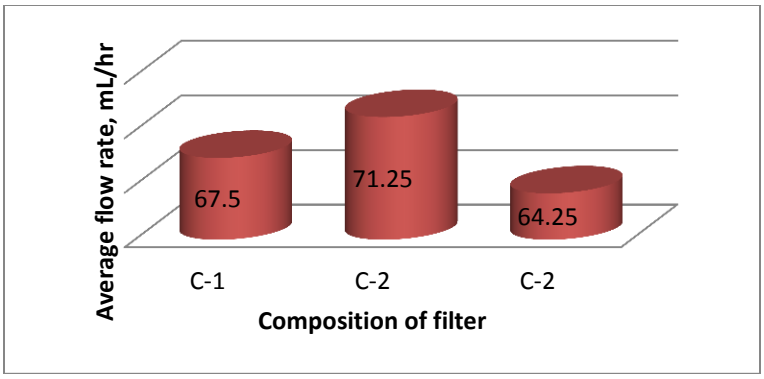


Figure-4.6 Average flow rate results with respect to composition for t = 0.75 h

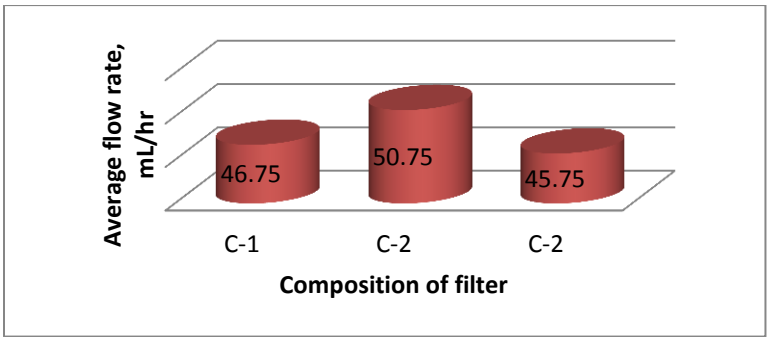


Figure-4.7 Average flow rate results with respect to composition for t = 0.5 h

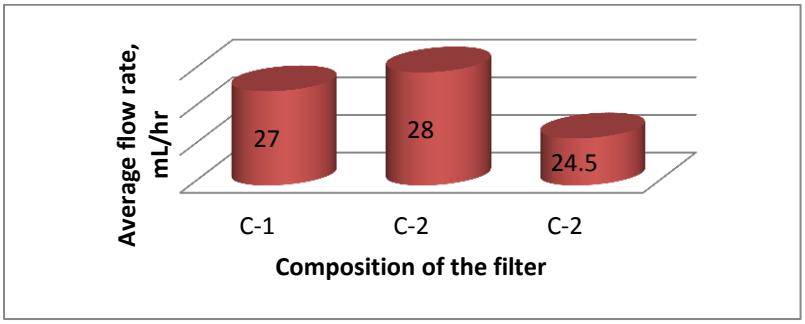


Figure-4.8 Average flow rate results with respect to composition for t = 0.25 h

4.3 Efficiency of the Pot Filters towards *E*. coli Removal

Figure-4.9represents *E*. coli removal efficiency results of the pot filters from real or natural water sample. Generally, the microbial removal efficiency of the ceramic filters increase with increase in the percentage composition of clay and firing temperature. Ceramic water filters with relatively low porosity have good efficiency in removing microbial from bacterially contaminated water sources (Clasen T et al., 2007). When microorganisms pass through the pores of ceramic filters, there might be strong suffocation on their path due to the tourtosity of the path. The *E*. coli removal efficiency of the pot filters was ranged from 90.33 % for filter T-22 to 100 % for filters T-33 and T-42. Filters with high porosity (T-11, T-22 and T-32) exhibited low *E*. coli removal efficiencies, whereas filters with relatively low porosity (T-33 and T-42) exhibited high *E*. coli removal efficiencies. Generally, the average *E*. coli removal efficiency of the pot filters was calculated to be 98.44 %. This result indicates that the pot filters are better in *E*. coli removal efficiency than the currently available pot filters, (Table-1.1). This result approached WHO standard which is zero concentration of *E*. coli in drinking water. Therefore, the pot filters are efficient in removing *E*. coli from contaminated water.

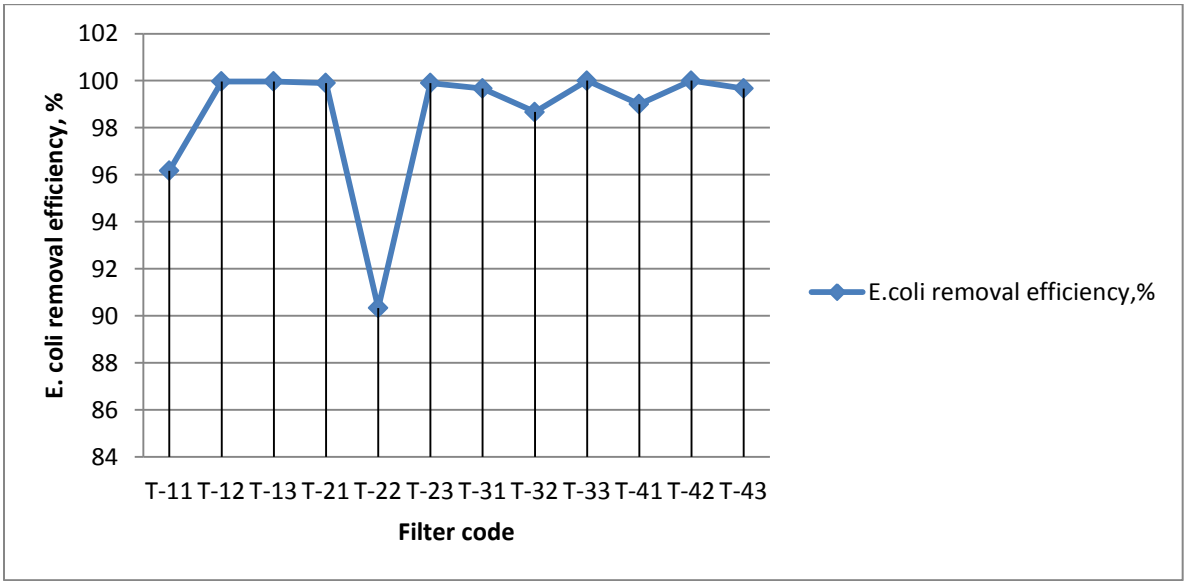


Figure-4.9 Average E. coli removal results

4.4 Efficiency of the Pot Filters towards Fluoride Removal

Figure-4.10 shows results on fluoride removal efficiency of the pot filters from laboratory water sample. Six selected filters, on the basis of flow rate and E. coli removal efficiency, were used including two (i.e.NF-1 and NF-5) filters fired at lower temperature, 500 ^{o}C. The main methods used in defluoridation from aqueous solutions are membrane techniques and adsorption techniques (alumina based adsorbents, Clays and Soils, Carbon, Zeolites and layered double hydroxides (M. Mohapatra et al. 2009). On an average the pot filters reduced the original content of 10 mg/L in the untreated/unfiltered water sample to 0.68 mg/L in the treated/filtered water which is 93.25 % removal efficiency. The filtered water met the WHO recommended limit of 1.5 mg/L. The pot filters fired at lower temperatures showed high fluoride removal efficiencies: T-11, T-13, NF-1 and NF-5 with fluoride removal efficiencies of 96.8 %, 98 %, 97.7 % and 98.2 % respectively. At lower temperatures only small number of hydroxide ions are removed from the filter surface, therefore there will be higher extent of fluoride ions and hydroxide ions exchange between the water and the filter, which can increase the removal efficiency of the filter. Pot filters with high concentration of saw dust: T-12 and T-32 showed fluoride removal efficiencies of 83.8 % and 85 %. This is because as the amount of the saw dust increases the porosity of the filters increases and the extent of adsorption of fluoride on the filter surface decreases. This is due to short contact time between the filter surface and fluoride.

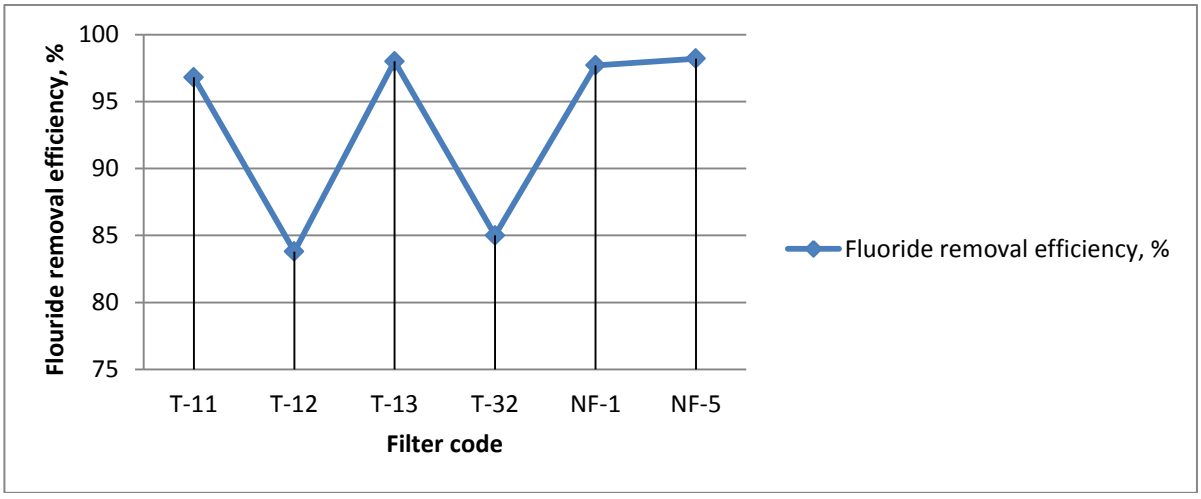


Figure-4.10 Fluoride removal efficiency in percent

4.5 Color Removal Efficiency of the Pot Filters

Results from Figure-4.11 showed color reduction from source water/ raw water by four selected pot filters which ranged from 20 % up to 100 %. The average color removal efficiency of the pot filters was 8.75 mg/L Pt /65 % which was within the levels recommended by WHO of less than 15 mg/L Pt. Therefore, the pot filters are efficient enough in removing color from raw water.

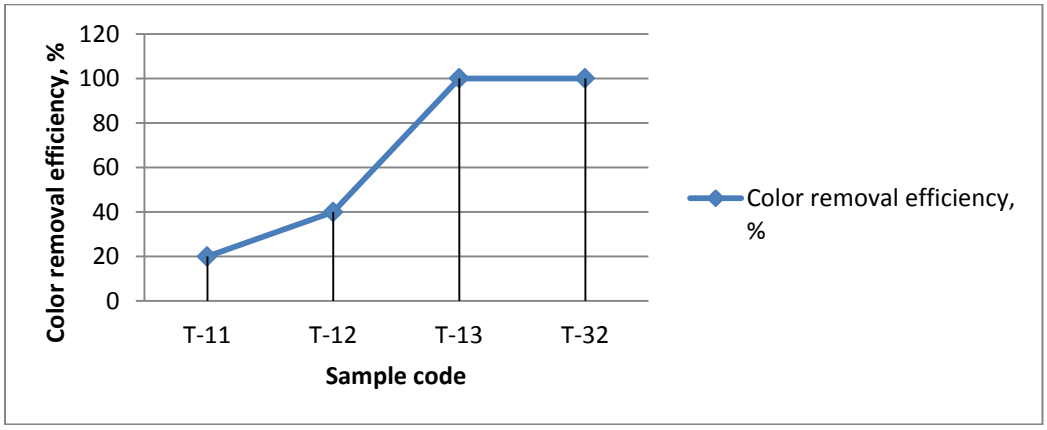


Figure-4.11 Color removal efficiency in percent

4.6 Turbidity Removal Efficiency of the Pot Filters

Table-4.2 represents the results in turbidity removal efficiency of the pot filters. Systems that use filtration other than the conventional or direct filtration must follow state limits, which must include turbidity at no time exceeding 5 NTU. Many drinking water utilities strive to achieve levels as low as 0.1 NTU, (EPA. 2009). The European standards for turbidity state that it must be no more than 4 NTU. The WHO, establishes that the turbidity of drinking water should not be more than 5 NTU, and should ideally be below 1 NTU. Turbidity removal efficiency of filters T-11and T-12 was 100 % or 0 FTU which was less than the WHO recommended limit of 5FTU. However, turbidity removal efficiencies of filters T-13 and T-32 were 94.5% and 93.5 %. Therefore, the pot filters can be considered as efficient in removing the turbidity of raw water.

Table-4.1 Turbidity removal efficiency in percent

Sample code	Turbidity removal efficiency, %
T-11	100
T-12	100
T-13	94.5
T-32	93.5

4.7 Total Dissolved Solid/TDS Removal and Electrical Conductivity Tests Results

Table-4.2 represents results from total dissolved solids/TDS removal efficiency and conductivity of the pot filters. Because the threshold of acceptable aesthetic criteria for human drinking water is 500 mg/L, there is no general concern for odor, taste, and color at a level much lower than is required for harm. A number of studies have been conducted and indicate various species' reactions range from intolerance to outright toxicity due to elevated TDS. The numerical results must be interpreted cautiously, as true toxicity outcomes will relate to specific chemical constituents. (EPA, 1999). The TDS concentration and electrical conductivity of the filtered water samples were found to be greater than that of the unfiltered water sample. Even though the TDS concentrations of the filtered water samples were greater than that of the unfiltered water sample, all of the TDS results including the unfiltered water sample are less than the WHO recommended limit of ≤ 500 ppm. The greater concentration of TDS in the filtered water samples may be due to leaching of ions from the pot filters. (Lantagne, 2001)

Table-4.2 TDS removal and conductivity tests results

Sample code	TDS, ppm	E.C., µs
RS	176	346
T-11	344	673
T-12	288	566
T-13	351	699
T-32	250	499

4.8 Odor and Taste Results

The odor of the river water was strong and unpleasant. After filtration this odor was completely removed, no longer perceptible to the human nose. The taste of the water after filtration was pleasant.

4.9 FT-IR Analysis

The FT-IR spectrum of modified clay ceramic material was characterized and illustrated in Figures-1a and b (Appendix- K). The shift in stretching frequency observed between 3600 and 4000 cm^{-1} to between 3600 and 3800 are assigned to the involvement of hydroxyl groups. The two peaks at 3620 and 3696 cm^{-1} were associated with the strong hydrogen bonded O-H stretching groups (Fig1b) (Appendix-K), (A, Ravikumar, et al, S.M.M.Nazeeb-Khan, 2015). The adsorption bands at 3430 cm^{-1} show the characteristics of –OH group. FT- IR spectrum revealed that the OH groups on the filter surface were involved in the sorption of fluoride. Anion exchange and electrostatic interaction were suggested as the main mechanisms involved in the sorption of fluoride on filter.

4.10 Silicate Analysis

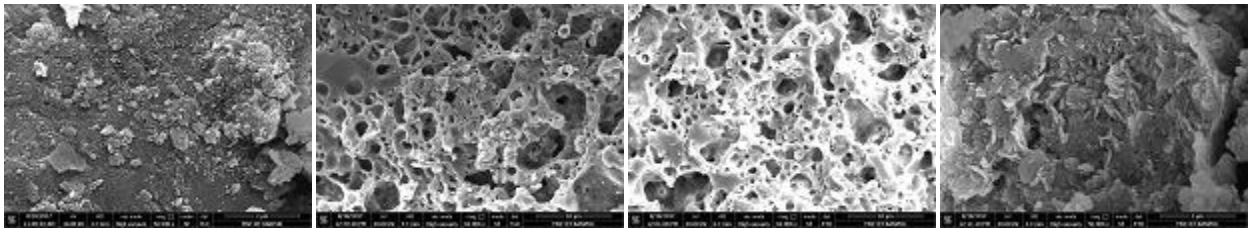
Table- 4.4 indicates silicate analysis results of the unfired pure clay (PC), fired clay (grog), FC and the filter material clay (FCBC). These results show that the dominant components of the filter material are SiO_2, 51.42 %, Al_2O_3, 20.32 %, Fe_2O_3, 11.64 % and CaO, 9.40 %. The amount of silica, SiO_2 is large compared to the other oxides. This indicates that the filter material is composed of mainly sandy clay. The color of the fired clay material is red; this might be due to the presence of relatively greater amount of iron, 11.64 %. The presence of 9.40 %CaO and 1.24 %MgO is also responsible for the leaching of the filter material.

Table-4.4 Major and minor oxides of the ceramic filter

Field No	Lab No	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	TiO_2	H_2O	LOI
FC	1501/17	58.12	23.58	8.22	1.40	0.72	2.12	2.72	0.06	0.10	0.41	0.23	2.68
FCBC	1502	51.42	20.32	11.64	9.40	1.24	1.00	0.20	0.08	2.46	0.27	0.09	0.54
PC	1503	44.34	21.88	11.6	0.44	<0.01	7.16	1.48	<0.01	0.07	0.31	2.20	11.55

4.11 SEM Analysis

Figure-4.12 indicates SEM images of four selected filters on the basis of their flow rates and E. coli removal efficiency. The selected filters are T-11, T-22, T-32 and T-41. Filter T-11 exhibited relatively low flow rate (110 mL/h) as indicated in Table-4.1 and low E. coli removal efficiency (96 %) as indicated in Figure-4.9. The flow rate of Filter T-11 is the lowest of all filters this is due to the lowest porosity of the filter as indicated in Figure 4.12. It also indicated low E. coli removal efficiency due to the presence of a very small crack on the filter as indicated on its SEM image in Figure 4.12. Filter T-22 is one of the filters that showed good flow rate (140 mL/h) as indicated in Table-4.1 and the lowest E. coli removal efficiency (90 %) as shown in Figure-4.9. This is due to the highest porosity of the filter as indicated on the SEM image of the filter in Figure 4.12. Filters T-32 and T-41 are the filters that exhibited the highest flow rates (145 mL/h) and (140 mL/h) respectively, as shown in Table-4.1 and E. coli removal efficiency of (98.67 %) and (99 %) respectively. This is as a result of high porosity of filter T-32 and the presence of small crack on filter T-41 as indicated by their SEM images in Figure 4.12. Ceramic filters made in the laboratory had relatively rough surface and the existence of cracks in some of the filter elements might be due to the large sized saw dust and clay particles that created pores as well as the cracking after firing the green filter elements.



T-11 T-22 T-32 T-41

Figure-4.12 SEM images of filters with codes T-11, T-22, T-32 and T-41

4.12 XRD Analysis

Figure-4.13 represents the XRD analysis results of the ceramic filter material. The results obtained from the XRD analysis and previously determined results from literature show that the ceramic filter material is mainly composed of quartz, kaolinite and montmorillonite which shows

an increase in the quartz content with a notable decrease in kaolinite and montmorillonite contents (A. Tawfik, 2011).

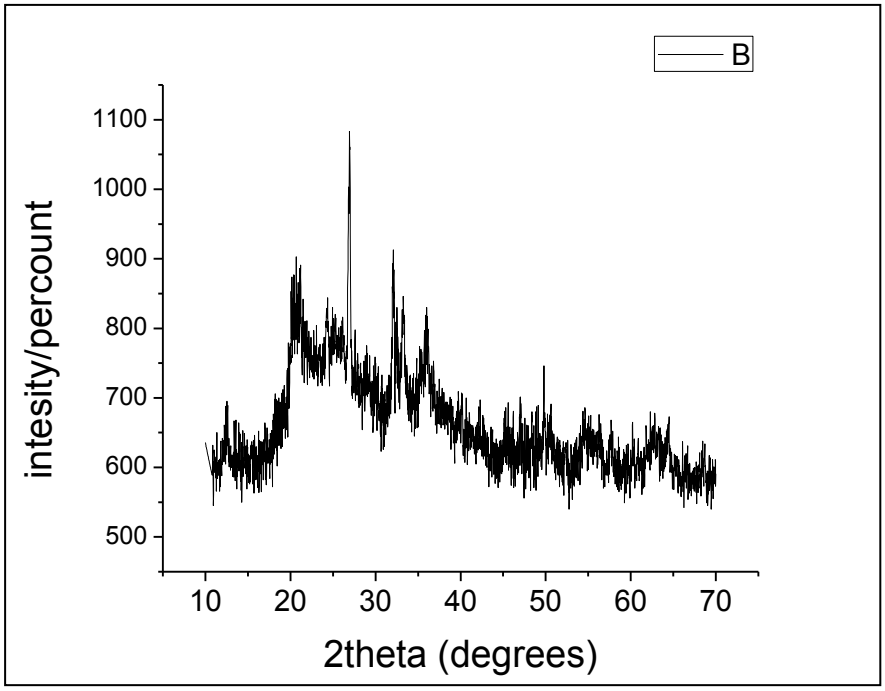


Figure-4.13 XRD result of the ceramic filter material

4.13 Porosity Test

The porosity of the filter is the fraction of the volume that is occupied by pores or void space. In the case of ceramic filters it is important to distinguish several types of void space; one which forms a continuous phase within the porous medium, called ‘interconnected’ or ‘effective’ pore space, and another which consists of ‘isolated’ pores (Figure 2.2). The isolated pores cannot contribute to the flux across the filter. ‘Dead-end’ pores are interconnected from one side only; the contribution of these pores to the flux is temporary. It should be noted that the dead-end pores can also be connected to the interconnected pores, but as long as the route of these pores is a dead-end it will not contribute to the flux.

The porosity formed in the ceramic filter is mainly affected by the firing temperature in the production of the filter element and the percent composition of the burn-out materials. It is also affected by the type of combustible material used, the micro size of the clay and burn-out mixed. As shown in Figure 4-12, generally, filters with the largest saw dust-to-clay ratio exhibited highest porosity. The porosity of the ceramic filters was decreased with decrease in the percentage composition of saw dust used for different code of the filter elements. Filters with more combustible materials have more void space (Watters 2010). The porosity of the fired mass is roughly proportional to the volume of combustible matter added (Kabagambe, 2007).

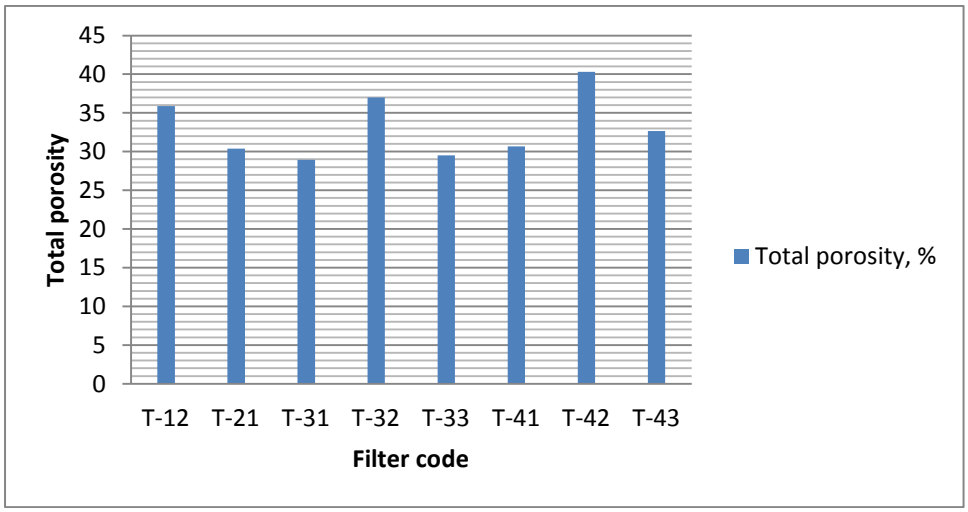


Figure-4.14 Porosity of the ceramic filters

4.13.1 Effect of Porosity on Flow Rate

Table-4.4 represents the effect of porosity on the flow rate of the ceramic filters. Porosity in a ceramic water filter allows for water to flow through the element. High porosity means there are larger number of void space in the ceramic filters that will allow the water to pass through the filter elements. If there are more pores in the filter, then water might flow through the ceramic filter faster, (Yoko et al., 2002). As indicated in Figure-4.13, generally, the flow rate of the ceramic filters increased as the porosity of the filters was increased. The minimum flow rates were exhibited by filters T-31 and T-33 with 28.95 % and 29.5 % porosities and 114 mL/h and 125 mL/h flow rates respectively while higher flow rates were exhibited by filters T-12, T-32 and T-42 with flow rates of 155 mL/h, 145 mL/h and 142 mL/h and porosities of 35.89 %, 37 % and 40.32 % respectively.

Table-4.4 Porosity and flow rate of ceramic filters

Filter code	Total porosity, %	Flow rate(mL/h)
T-12	35.89	145
T-21	30.37	135
T-31	28.95	114
T-32	37	145
T-33	29.5	125
T-41	30.67	135
T-42	40.32	142
T-43	32.65	140

4.13.2 Effect of porosity on E. coli removal efficiency

Table-4.5 displays the relationship between E.coli removal efficiency with porosity of the ceramic filters. Microorganisms with large size are blocked within pore and retain from flowing through the ceramic element (Doulton, 2009). All ceramic filters had different porosity but they were not different significantly in removing total E.coli from the contaminated raw water. This might be due to the presence of different kinds of pores on the filter microstructure.

Table-4.5 Porosity and E. coli removal efficiency of the ceramic filters

Filter code	Total porosity, %	E.coli removal efficiency, %
T-12	35.89	99.97
T-21	30.37	99.9
T-31	28.95	99.67
T-32	37	99.67
T-33	29.5	100
T-41	30.67	99
T-42	40.32	100
T-43	32.65	98.67

4.13.3 Effect of porosity on Turbidity Removal Efficiency of the Filters

Figure-4.6 indicates the effect of porosity on turbidity removal efficiency of the ceramic filters. The turbidity removal efficiency of a filter is affected by different factors such as the porosity of the filter element and the turbidity of the source water. Turbidity of water will be caused due to

insoluble suspended solid and soluble solid particles. The ceramic pots manufactured by PFP have a potential to reduce turbidity by 30 % to 100 % as reported by (Lantagne et al., 2006).

Table-4.6 Porosity versus turbidity removal efficiency of the ceramic filters

Filtor code	Total porosity %	Turbidity removal efficiency,%
12	35.89	100
32	37	93.5

5. CONCLUSIONS

The objective of this study is to provide reliable performance data under laboratory conditions for ceramic pot filters, because ceramic water filtration is one of the points of use water treatment methods to provide safe and clean drinking water and it also provides immediate solution in solving the problem of contamination of water, especially for low income community. In this research finding, ceramic pot filters were developed with different compositions of clay, saw dust and fired at different temperatures in the laboratory scale. The efficiency of the developed ceramic filters was evaluated for different parameters: flow rate, *E.*coli removal, fluoride removal, turbidity removal, total dissolved solid/ TDS removal, color, taste, odor removal and conductivity of source and filtered water samples. Generally the ceramic filters were showed good average efficiency in removing *E.* coli (98.44 %), fluoride (93.25 %), turbidity (97 %), color (65 %) and flow rate (130.27 mL/h) for ceramic pot filter of volume 176 mL in the analysis.

The filters also exhibited good performances in removing bad taste and odor of the source water. The ceramic filters effectively removed contaminants from the source water to the quality recommended by WHO. Effects of composition of the ceramic filters, the preparation of the raw materials and firing temperature are the factors that affect the flow rate, removing *E.*coli, fluoride, turbidity, TDS, color, odor and taste of water of the ceramic filter elements. Based on the results observed in the previous part, more efficient removal were observed at high percentage of clay, 70 %, at a firing temperature of 900 ^{o}C and 950 ^{o}C and lower porosity of the ceramic filter elements. High flow rates were observed at high percentage of saw dust, 25 % and at high firing temperatures, 900 ^{o}C and 950 ^{o}C. High fluoride removal was observed at lower firing temperatures. The pot ceramic filters are efficient enough in providing safe and clean drinking water for households and they can be the substitutes of the filters imported from abroad.

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APPENDICES

Appendix-A

Data from the preparation of the ceramic filter
Table-1 Filter code, composition, volume and firing temperature of the filters

Filter code	Composition /clay-to-saw dust ratio/ by volume, cm^3	Volume(mL)	Firing temperature (^oC)
T-11	6:1.5:2.5 / C-1	176	
T-12	5:1.5:3.5 / C-2		
T-13	7:1.5:1.5 / C-3		800
T-21	6:1.5:2.5 / C-1		
T-22	5:1.5:3.5 / C-2		
T-23	7:1.5:1.5 /C-3		850
T-31	6:1.5:2.5 / C-1		
T-32	5:1.5:3.5 /C-2		
T-33	7:1.5:1.5 / C-3		900
T-41	6:1.5:2.5 /C-1		
T-42	5:1.5:3.5 / C-2		
T-43	7:1.5:1.5 /C-3		950

Where T-1, T-2, T-3 and T-4 are temperatures 800 ^oC, 850 ^oC, 900 ^oC and 950 ^oC respectively;
1, 2 and 3 are codes of pots with respect to composition and C-1, C-2 and C-3 are composition 1, 2 and 3 respectively.

Appendix-B

b.Data from flow rate experiments
Table-2 Flow rate results

Sample code	Flow rate (mL/hr), t=1h	Flow rate /mL/hr, t=0.75h	Flow rate /mL/hr, t=0.5h	Flow rate /mL/hr, t=0.25h
T-11	110	56	39	20
T-12	145	80	60	32
T-13	114	65	48	25
T-21	135	60	40	28
T-22	140	55	38	23
T-23	130	58	45	25
T-31	114	78	57	30
T-32	145	70	50	26
T-33	125	75	56	29
T-41	135	76	51	30
T-42	142	80	55	31
T-43	140	77	52	29

Appendix-C

Data from microbial removal tests

Table-3 E. coli removal results

	First Trial	Second Trial	Third Trial
Samp. code	Ec(cfu/100ml)	Ec(cfu/100ml)	Ec(cfu/100ml)
RS	>1000	>1000	>1000
T-11	30	45	40
T-12	0	0	1
T-13	0	1	0
T-21	0	0	3
T-22	20	30	10
T-23	100	100	90
T-31	0	10	0
T-32	0	0	10
T-33	0	0	0
T-41	0	20	10
T-42	0	0	0
T-43	0	30	10

Appendix-D

Data from fluoride removal experiments

Table-4 Fluoride removal test results

Sample code	F^- concentration in unfiltered water, mg/L	Fluoride removal, mg/L			
		Trial-1	Trial-2	Trial-3	Average removal, mg/L
T-11	10	0.32	0.68	0.29	0.43
T-12	10	1.62	1.45	1.5	1.52
T-13	10	0.2	0.17	0.18	0.18
T-32	10	1.5	1.65	1.6	1.25
NF-1	10	0.23	0.24	0.27	0.24
NF-5	10	0.18	0.16	0.19	0.17

Appendix-E

Data from color, turbidity, TDS and electrical conductivity tests

Table-5 Color, turbidity, TDS and conductivity tests results

Sample code	Color, mg/l Pt	Turbidity, FTU	TDS, ppm	E.C., µs
RS	25	>>	176	346
T-11	20	0	344	673
T-12	15	0	288	566
T-13	0	22	351	699
T-32	0	26	250	499

NB: >>means much more greater than 400 FTU

Appendix-F

Results of flow rate tests

a. Flow rate results with respect to firing temperature of the ceramic filters

Table-6 Average flow rate results with respect to firing temperature

Firing temperature, °C	Average flow rate, mL/hr, t=1h	Average flow rate, mL/hr, t=0.75h	Average flow rate, mL/hr, t=0.5h	Average flow rate, mL/hr, t=0.25h
800	126.33	67	49	25.67
850	127.25	68.75	49.25	27.33
900	128	74	54.33	28.33
950	139	77.67	52.67	30

Table-7 Average flow rate results with respect to composition

Composition of filter	Average flow rate, mL/hr, t=1h	Average flow rate, mL/hr, t=0.75h	Average flow rate, mL/hr, t=0.5h	Average flow rate, mL/hr, t=0.25h
C-1	123.5	67.5	46.75	27
C-2	145.5	71.25	50.75	28
C-3	121.2	64.25	45.75	24.5

Appendix-G

Results of microbial tests
Table-8 Average microbial removal results

Filter code	Average removal efficiency/EC cfu
T-11	38.33
T-12	0.33
T-13	0.33
T-21	20
T-22	96.66
T-23	1
T-31	3.33
T-32	13.33
T-33	0
T-41	10
T-42	0
T-43	3.33

(a) Results in number

Filter code	E.coli removal efficiency,%
T-11	96.17
T-12	99.97
T-13	99.97
T-21	99.9
T-22	90.33
T-23	99.9
T-31	99.67
T-32	98.67
T-33	100
T-41	99
T-42	100
T-43	99.67

(b) Results in percent

Appendix-H

Results from fluoride removal tests

Table-9 Fluoride removal efficiency in percent

Sample code	Fluoride removal efficiency, %
T-11	96.8
T-12	83.8
T-13	98
T-32	85
NF-1	97.7
NF-5	98.2

Appendix-I

Color and turbidity removal tests results

Table-10 Color removal efficiency in percent

Sample code	Color removal efficiency, %
T-11	20
T-12	40
T-13	100
T-32	100

Table-11 Turbidity removal efficiency in percent

Sample code	Turbidity removal efficiency, %
T-11	100
T-12	100
T-13	94.5
T-32	93.5

4.5 Total dissolved solid/TDS removal and conductivity tests results

Table-12 TDS removal and conductivity tests results

Sample code	TDS, ppm	E.C., µs
RS	176	346
T-11	344	673
T-12	288	566
T-13	351	699
T-32	250	499

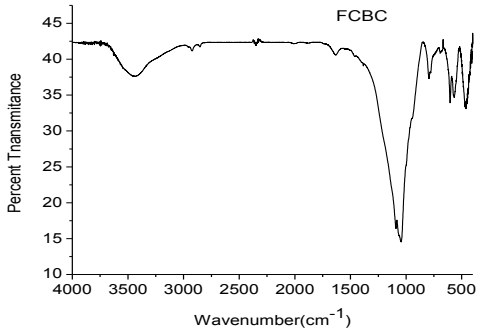
Appendix-J

Table- 14 Total porosity and flow rate results

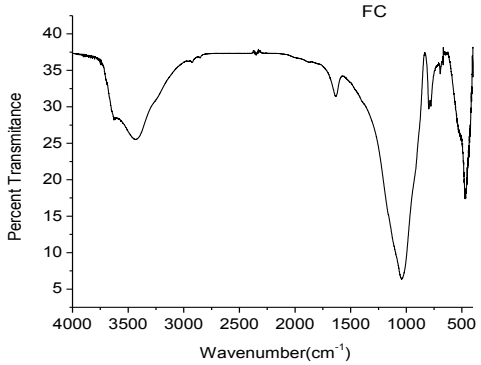
Filter code	Total porosity, %	Flow rate(mL/h)
T-12	35.89	145
T-21	30.37	135
T-31	28.95	114
T-32	37	145
T-33	29.5	125
T-41	30.67	135
T-42	40.32	142
T-43	32.65	140

Appendix-K

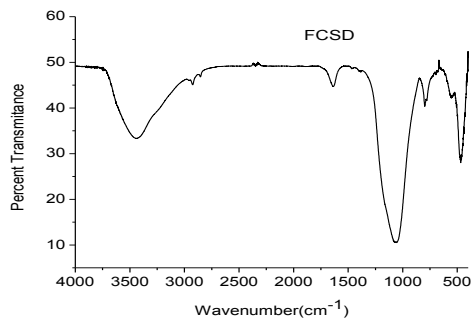
FT-IR Results



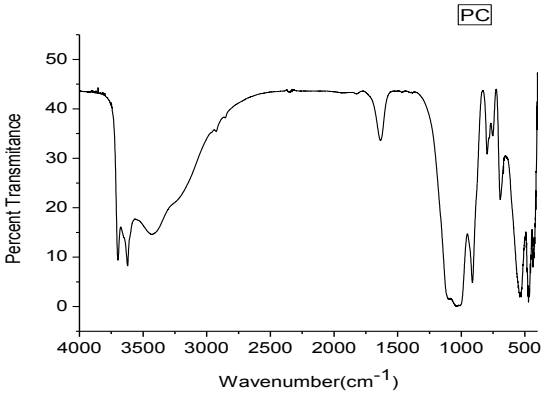
(a)



(c)



(b)



(d)