ADAMA SCIENCE AND TECHNOLOGY UNIVERSITY

SCHOOL OF MECHANICAL, CHEMICAL, AND MATERIALS SCIENCE AND ENGINEERING DEPARTMENT OF MATERIALS SCIENCE AND ENGINEERING

LOW COST AND EFFICIENT REMOVAL OF PATHOGENIC MICROBES AND FLUORIDES USING CERAMIC WATER FILTER

BY

ALEMAYEHU SOLOMON WORKINEH

A thesis submitted to the department of materials science and engineering in partial fulfillment of the requirements for the degree of master of engineering in materials science and engineering

JUNE 11, 2018

ADAMA, ETHIOPIA

ADAMA SCIENCE AND TECHNOLOGY UNIVERSITY

SCHOOL OF MECHANICAL, CHEMICAL, AND MATERIALS SCIENCE AND ENGINEERING DEPARTMENT OF MATERIALS SCIENCE AND ENGINEERING

LOW COST AND EFFICIENT REMOVAL OF PATHOGENIC MICROBES AND FLUORIDES USING CERAMIC WATER FILTER

BY

ALEMAYEHU SOLOMON WORKINEH

ADVISOR: - PROF. SUNUK KIM

CO-ADVISOR:- DR. DINSEFA MENSUR (PHD)

A thesis submitted to the department of materials science and engineering in partial fulfillment of the requirements for the degree of master of engineering in materials science and engineering

JUNE 11, 2018

ADAMA, ETHIOPIA

SCHOOL OF GRADUATE STUDIES

ADAMA SCIENCE AND TECHNOLOGY UNIVERSITY

As project advisor, we here by certify that we have read and evaluated this project, under our guidance, by Alemayehu Solomon entitled as **low cost and efficient removal of pathogenic microbes and fluorides using ceramic water filter**. I recommend that it be submitted as fulfilling this project requirement

Prof. Sunuk Kim _____ _____

Advisor signature Date

As the member of the board of the MSC thesis open defense examination, we certify that we have read evaluated the project prepared by **Alemayehu Solomon** and examined the candidate. We Recommended that the project be accepted as fulfilling the thesis requirement for the degree of Master of Science in materials science and engineering.

Chairman	Signature	Date
_____	_____	_____
Internal Examiner	Signature	Date
_____	_____	_____
External Examiner	Signature	Date
_____	_____	_____

PRIVACY STATEMENT

By my signature below, I declare and affirm that this manuscript is my own work. I have followed all ethical principles of post graduate guidelines in the preparation, data collection, data analysis and completion of this project manuscript. All scholarly matter that is included in the manuscript has been given recognition through citation. I verify that I have cited and referenced all sources used in this document. Every serious effort has been made to avoid any plagiarism in the preparation of this manuscript. This project manuscript is submitted in partial fulfillment of the requirements for MSC degree from the School of Graduate Studies at Adama science and Technology University. I seriously declare that this manuscript has not been submitted to any other institution anywhere for the award of any academic degree.

Brief quotations from this project manuscript may be used without special permission provided that accurate and complete acknowledgement of the source is made. Requests for permission for extended quotations from, or reproduction of, this document in whole or in part may be granted by the Head of the Department of materials science and engineering or the Dean of the School of Graduate Studies when in his or her judgment the proposed use of the material is in the interest of scholarship. In all other instances, however, permission must be obtained from the author of the project.

Name: **Alemayehu Solomon** Signature: _____

Place: Adama science and technology university, Adama

Date of submission: _____

DEDICATION

I dedicate this project manuscript to all Ethiopian people who are in need to safe drinking water. GOD BLESSES ETHIOPIA!!

ABSTRACT

This project work was aimed to develop a low cost and efficient ceramic water filter on lab scale by using locally available clay and combustible materials to remove pathogenic microbes and fluorides from contaminated ground water sources. Three raw soils and two combustibles were collected for this project purpose. These three soils were tested for their physical properties and characterized for phase identification, elemental chemical composition and thermal stability by using X-ray diffraction (XRD), X-ray fluorescent spectroscopy (XRF) and differential thermogravimetry (DTG) analysis techniques. the two soils were found to be suitable for filter production. Optimum filter processing parameters ranges were determined by using sample test bars and the result was found to be 70wt% to 80wt% clay with 20wt% to 30wt% combustible mixing ratio range, 300 to 600µm clay and 600 to 1200 µm combustible particle size range, and 900ºc to 1000 ºc firing temperature ranges. Based on these results sample laboratory scale ceramic pot water filters (CPWFs) were prepared and their performance evaluated. The experimental result revealed that, these lab scale ceramic pot water filters achieved high flow rate (2 up to 2.5 liter/hr) performance without sacrifice of the microbial removal efficiency. If it was scaled up to large scale, it was expected to provide 25.5 – 36 liters per a day, which was sufficient to provide a safe drinking water for an average five-member household. These filters have s capability of removing more than 99.3 to 100 % of the total coliform bacteria and 100% of the fecal coliform from influent ground water samples. The average reduction result of turbidity from 13 to 1.15 NTU (i.e 91.15% removal efficiency), free residual fluoride ion from 3.4 to 0.053mg/100ml (i.e 99.81% removal efficiency), total dissolved solids from 1245mg/l to 7.4 mg/l (i.e 99.4% removal efficiency) and pH from 8.9 to 8.4 which was within acceptable range. From this experimental investigation result, it was possible to fabricate ceramic water filter in large scale in Ethiopia and to use it as one of a promising future house hold water treatment technology for microbial removal and DE fluoridation of contaminated drinking water sources.

Key words: *develop, filters, Optimum, efficient, microbes and DE fluoridation*

ACKNOWLEDGEMENT

First of all I would like to praise the Almighty God for bestowing up on me health, strength,patience and protection throughout the study period.

Secondly, I would like to express my sincere gratitude to my advisor **Prof. Sunuk Kim and** my co-advisor **Dr. Dinsefa Mensur (Phd)** (head of materials science and Engineering Department, ASTU), for their invaluable inputs, guidance, cooperation, enthusiastic encouragement from beginning to the end of this thesis, Without their constant guidance, endless efforts and joyful encouragement, this project would have not been accomplished successful.

On the behalf of all post graduate students, I would like to thank ASTU for offering us this precious free scholarship opportunity for second degree of "MSE adventure". Next, I would like to thank all the lecturers of Materials science and Engineering Department for their financial support , knowledge and company at the time of crisis would be remembered lifelong.

I also thankful to Laboratory Assistants, other staff members of materials science and Engineering Department, ASTU, for their helping hands during carrying out this project.

Special thanks to south water and minerals resource office for their guidance for accessing raw materials, for Muger cement factory and for Oromia self-help organization(OSHO) for permitting me to freely use equipment which was available in their laboratory.

Last but not least, my heartfelt gratitude goes to my colleagues and friends specially Henock Getu, Mohammed Abdella and Biniyam Eshetu for their generous support and contribution in the accomplishment of this work. Thank you for being there to listen when I wanted to talk about the project or needed to complain about it. You were all an inspiration and kept me both encouraged and inspired. I pray to Lord Almighty to reward abundantly everybody who made a contribution whether knowingly or unknowingly, small or big, directly or indirectly and mentioned by name or not.

ALEMAYEHU SOLOMON

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS AND ACRONYMS

ASTM – American Society for Testing and Materials (former name)

CPWF – Ceramic pot water filter

E. coli - Escherichia coli

HTWS - Household Water Treatment and Safe Storage Technologies

LRV - Log Removal Values

NTU – Nephelometric turbidity unit

NGO – Non-governmental organization

OSHO –Oromia self-help organization

PHW – Pure Home Water

PFP – Potters for Peace

SODIS – Solar water disinfection

TNTC – Too numerous to count

UNICEF – United Nations Children Fund

ECRV :Ethiopian Central Rift Valley regions

WHO – world health organization

APHA – American Public Health Association

MF – Membrane filtration

MLSB – Membrane Lauryl Sulphate Broth

CFU – Colony forming units

FC – Feacal coliform

EC – Escherichia coli

CHAPTER ONE

1. INTRODUCTION

Water is a basic need in sustaining life. A safe, reliable, affordable, and easily accessible water supply is essential for good health [1]. Water is primarily crucial for life, health and human dignity; hence, the health of any community is entirely depends on the availability of safe, adequate and sustainable water. Only 0.75% of the total amount of water is fresh and readily available for use [2]. Africa has about 9% of the world's fresh water resources and 11% of the world's population. Sub-Saharan Africa faces numerous water-related challenges that constrain economic growth and threaten the livelihoods of its people. Ethiopia has a large fresh water resource potential. Only about 3% of water resources are used, of which only about 11% (0.3% of the total) is used for domestic water supply [1].

In Ethiopia urban and rural households rely on different sources of drinking water. The three most common sources of drinking water in urban households are water piped into the household's dwelling, yard, or plot (63%); water piped into a public tap/standpipe (13%); and water piped to a neighbor (12%). By contrast, rural households obtain their drinking water mainly from public taps/standpipes (19%), followed by protected springs (14%) and tube wells or boreholes (13%) the rest is from different sources [3]. It was estimated that 57 percent of Ethiopian households have access to improved drinking water sources 93 percent in urban areas and 49 percent in rural areas [4]. In urban areas, 77% of households have piped water on their premises, compared with 6% of rural households [5]. However, still 43% of the total Ethiopian citizens and 51% of the rural population still depends on unimproved drinking water sources for day to day activities [1].

Currently, between 0.7 and 1.8 billion people do not have access to clean water, the majority of whom live in rural areas of developing countries[6]. These areas are difficult to reach and tend to be far from infrastructure such as roads, water treatment plants, hospitals and other support services [7]. Therefore, providing water to the 1.8 billion people who are in

need requires solutions that can be implemented by locals without relying on large-scale density-dependent projects.

Local technologies that can be utilized in the home to retrieve and store water are known as Household Water Treatment and Storage (HWTS) technologies. A wide variety of technologies are classified under HWTS, each of which has strengths and weaknesses. Ceramic pot water filters (CPWFs) are one of the leading technologies that are ideal for use by fragmented populations in locations where neither clean water sources nor adequate infrastructure areavailable. This is because of their simplicity to operate and manufacture, making them a culturally appropriate technology for rural residences of developing countries.

Ceramic water filter pots are clay pots that contain colloidal silver, a well-known antibacterial. The porous nature of the pot, combined with the antibacterial properties of the silver nano-particles, reduce the incidence of disease in the field [9][10] and are preferred over comparable water filtration technologies [8][11]. Furthermore, CWFPs are a low tech and low-cost water filtration solution that offers significant protection to the user, can be made almost entirely from locally procured materials and empowers users to look after themselves and their families [12].

The scope of this project is to study the existing water filtration methods, and use the knowledge to design and construct ceramic pot water filter (CPWF) as one of house hold water treatment technology. This water filtration system will focus on cutting down the cost while maintaining filter effectiveness. The primary goal is to be legally certified from Ethiopian drinking water quality control and to provide rural communities and urban households with point-of-use water treatment to improve health and quality of life. The long-term goal of this project is to create a successful model ceramic pot water filter producing factory in in Ethiopia for the first time and then to expand by creating additional filter factories in other vulnerable regions of other developing countries.By providing affordable water filters to third world countries will greatly improve people’s quality of living, and reduce the risk of any waterborne diseases therefore saving lives.

1.1 STATEMENT OF THE PROBLEM

1. Around 43 % of Ethiopian people Lack of safe drinking water (most people use ponds, rivers and lakes, streams, rainwater, unprotected springs and wells as a drinking water source, which are highly contaminated)[1].
2. The high mortality rate due to water-borne disease in developing countries like Ethiopia (around 60 % -80 % mortality rate accounts to water-borne disease in Ethiopia)[1]
3. The high fluoride concentration in drinking water resources of Ethiopian Central Rift Valley (ECRV) regions results in both dental and skeletal fluorosis. (around 8 million people are exposed to high levels of naturally occurring fluoride)
4. Government and many non- governmental organizations (NGOs) are still spending a lot of money to alleviate this problem each year.
5. Lack of cost effective alternative house hold water treatment technologies in the market.

1.2 OBJECTIVE

1.2.1 GENERAL OBJECTIVE

The overall objective of this project is to fabricate ceramic water filter by using locally available clay and combustible materials to remove pathogenic microbes and fluorides.

1.2.2 SPECIFIC OBJECTIVES

1. To characterize raw materials for their phase identification, elemental chemical composition and thermal analysis
2. To determine the physical properties (particle size distribution (PSD) and Atterberg limits) of three locally available clay soils
3. To investigate the effect of variation in filter processing parameters and to determine the optimum filter processing parameter range
4. determine the optimum filter processing parameter range
5. To fabricate sample ceramic pot water filter and to make cost analysis
6. To determine average filtration rate, physiochemical and microbial removal efficiency of lab developed ceramic pot water filters and to compare the result with the previous filtration rate literature result and to the WHO / Ethiopian drinking water guidelines.

1.3 GOAL

1. To produce the most efficient water filter technology which Will satisfy all the requirement of Ethiopian and WHO standard drinking water guideline and expected to remove almost all microbes, fluoride and heavy toxic metals with high filtration rate which will accounts around 2-3 liter/hour and 36 liter/day. This filter technology will cost the least in price in filter market and which will be affordable to purchase by any family in developing country.
2. To provide the best alternative of house hold water filter treatment system for the developing countries.
3. To improve accessibility of safe drinking water for both urban and rural society of developing country including Ethiopia
4. To reduce the number of mortality related to water born disease and its prevalence in developing countries
5. To save the money expense provided by both the government and NGOs which aimed to decrease the problem of water born disease in developing country.

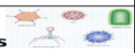
CHAPTER TWO

2 LITRATURE REVIEW

2.1 Water Borne Pathogens and Diseases

Infectious diseases caused by pathogenic bacteria, viruses and protozoa or by parasites are the most common and widespread health risks associated with drinking water. The wide variety of water-borne diseases and their public health impact is an important concern with far-reaching implications. About 3.4 million people, mostly children, die annually from water related diseases. Out of this number, 2.2 million people die from diarrheal diseases (including cholera) [13]. Water-borne diseases are typically caused by enteric pathogens which are mainly excreted in faeces by infected individuals and ingested by others in the form of faecally contaminated water or food. These pathogenic organisms include many types of bacteria, viruses, protozoa and helminthes, which differ widely in size, classification, structure and composition.

Table 2. 1: General category of Water-borne diseases causing pathogenic microbial organisms and their size range

Water borne pathogenic microorganisms	Size Range	Some of the Health effect
protozoa e.g cryptosporidium, giardia, toxoplasma and helminthes	2 – 50µm (CDC,2011).	➢ Cryptosporidium: can cause **gastrointestinal illness** (e.g., diarrhea, vomiting, cramps).  ➢ Giardia lamblia : can cause symptoms such as **nausea, cramps, diarrhea, and associated headaches** 
Bacteria e.g. Legionella,salmonella, shigella – causing bacillary dysentery, diarrhea, typhoid, cholera etc	0.3 to 100 µm (FMOH, 2011)	➢ Legionella: can result in a type of **pneumonia** known as **Legionnaires disease**. 
Viruses e.g Enteroviruses(coxsackieviruses, echoviruses, and other enteroviruses.)hepatitis A, Hepatitis E, rotavirus etc	0.02 – 0.3 µm (Claire M. 2006).	➢ **rotavirus and norovirus** can cause **gastroenteritis**  ➢ **Echovirus**: can cause **meningitis**

The average pores diameter ceramic pot water filter (CPWF) is 0.2-2.5 µm [14].

2.2 OTHER DISEAS BY CHEMICAL CONTAMINANTS

2.2.1 FLOURIDE AND FLOURISIS IN ETHIOPIA

In Ethiopia, well water, spring water, and Tap water are the common water supply source used in both urban and rural areas [16]. The amount of fluoride present naturally in non-fluoridated drinking water is highly variable, being dependent upon the individual geological environment from which the water is obtained , the tolerance limit of fluoride content of drinking water is 1.5 mg/L [17]. Fluoride concentrations in the range(1.5-4) mg/Lresults in dental fluorosis whereas with prolonged exposure within 4-10mg/L progresses to skeletal fluorosis.

Figure 2. 1: fluorosis diseases by high fluoride consumption a) Dental fluorosis and b) and c) are skeletal fluorosis (Source: http://www.appropedia.org/Water_Defluoridation)

Table 2. 2: Fluorosisdiseases by high fluoride consumptionFluoride concentrations that have exceeded more from WHO guideline in the drinking water source of different parts of Ethiopia [18]

Region	Zone, wereda or another village	Source of Sample	Fluoride Concentration (mg/L)
Addis Ababa	Kotebe w2	well	3.35
	Yeka sub-city (Medeksu)	well	3.36
Afar	Hugub (Awash 7 kilo)	well	8.5
	Awash 7thCamp	well	7.25
	Segento	well	10.3
	Metehara Suger Factory	well	16.25
Amhara	Dalecha D. birhan	well	5.53
	Hara dembele	well	7.88
	Malima Biri	well	15.2
Somali	Afder, Bare town Kebele 01	well	12.12
	Afder, Bare	well	3.23
Oromia	Wonchi Gadam	Spring	7.75
	Arsi	Spring	8.5
	Wonji- xabel	Spring	14.2
	Gilgel gibe	Tap	5.5
	Salini gibe district	Tap	8.5
	Dugdaworeda Tejitu	Well	8.67
	Dodo woreda, Jerme bora, East Shoa and Abo no2	Well	10
	Gedema Kufa (Adama)	Well	26.25
	Dugda woreda Jido	Well	33.67
	Dugda woreda Urgi Mechefera	Well	36
	Meki Bole Elementary School	Well	40
SNNPR	Wondogenet	Spring	7.75
	Awassa Aw-1	Spring	11.25
	Hawassa Lake	Tap	9.45
	Hawassa (Doga)	Well	13.32
	Hawassa 01(HD1)	Well	24
Tigray	Atsgede Tsimbla	Spring	6.52

2.3 HOUSEHOLD WATER TREATMENT AND SAFE STORAGE OPTIONS

WHO acknowledged several point-of-use technologies that bridges the shortages of different infrastructures. These technologies fall into **three categories**:

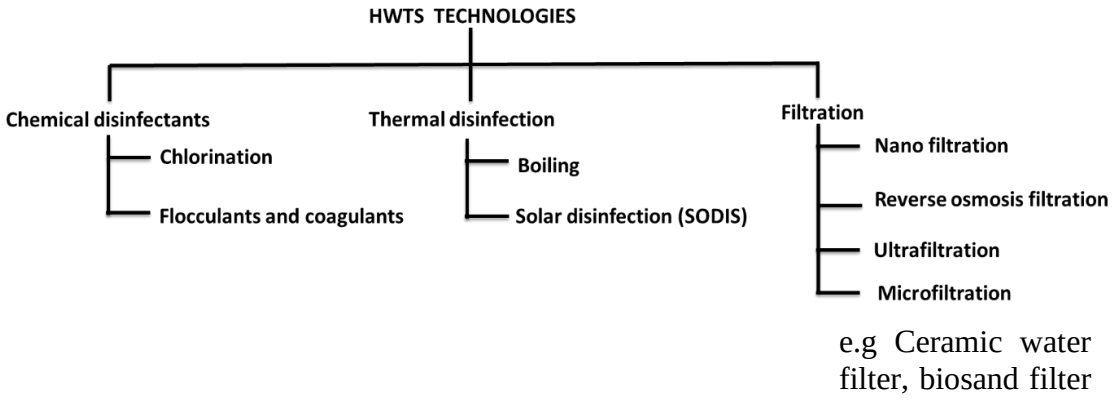


Figure 2. 2: Classification of HWTS technologies [19]

Point of use technologies to provide access to safe drinking water for people in the rural/urban areas of developing countries depend on : ease of use, accessibility locally, low cost, Removal efficiency and durability (its service life time).

2.3.1 CERAMIC FILTERS AS HWTS

Ceramic water filters are porous clay material that water can flow through, while preventing solid material, bacteria and some viruses from passing through. Three main geometrical shapes are often reported and adopted in literature: disk, candle and pot/frustum geometrical shapes [20].

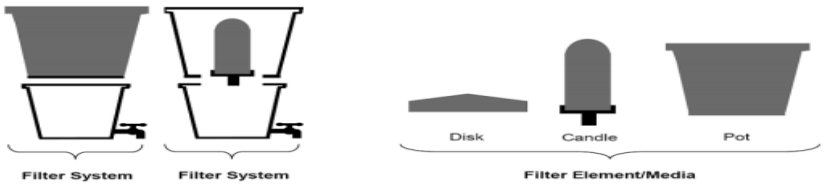


Figure 2. 3: Geometrical Classification of ceramic water filters

These filters are typically made from a mixture of clay and a combustible material (sawdust, coffee husk, rice husk etc.).The raw materials that are used for producing CWF's are in abundance and eco-friendly, and low cost.

Table 2. 3: List of raw materials Used in the Production of Ceramic Water Filters

Material	Brief Description	Examples
Clay	➢ Clays are fine-particulate materials with a unique property of plasticity when wet and hard when fired. ➢ Their plasticity allows to form shapes that maintain their form before being fired. But Once fired, the clay hardens and the shape becomes permanent	➢ Ansho clay and ➢ Babawuha kaolin clay ➢ or other kind of clay mineral
Water	➢ Used to make clay workable /plastic enough to be shaped (serves as a mixing solvent media)	➢ any uncontaminated water
Combustible Material	➢ It will burn off during the firing, leaving behind pores or voids through which water will travel. ➢ Used to create porosity and to control its volume (amount) and its geometry (shape and size of the pore) in the filter product.	➢ Sawdust (e.g.: oak, pine, acacia), ➢ Rice husk ➢ Flour (e.g.: wheat flour, corn flour) ,
Temper or Grog	➢ They defined as all non-plastic and pre-fired ceramic material used as a filler agent used to reduce shrinkage/warpage and to control porosity to some extent.	➢ Ground bricks , ➢ Pre-fired ceramic disk, tiles or pots which will be ground and sieved

2.3.1.1 MECHANISMS OF FILTRATION IN POROUS MEDIA

The first one is the interconnected or effective pore space. Here, the void space forms a continuous phase within the porous medium. The next one is the isolated pores. In this case, the void space has no link with each other and is usually separated by an area of no pores. Isolated pores cannot contribute to flux across the filter. The last kind of pore is the dead-end pores. These pores are connected from only one side and their contribution to flux is temporal. Sometimes, the dead-end can also be connected to the interconnected pores, but for as long as the route is a dead-end they will not contribute to the flux. During the process of filtration, when the filter is filled with water, all the pores that are connected to the inside of the filter are first of all filled with water. These include the dead-end pores. This results in a delay in the discharge of the water and this is then followed by a steady-state discharge of water [21].

Figure 2. 4: Schematic diagram of the types of pores [22]

The phenomena that enhance the removal of impurities and microbes in the filtration process include;

a. **Mechanical screening**: In this process, the particles that are too large to pass through the pores of the filter are trapped by the filter.
b. **Sedimentation:** is responsible for the precipitation of this very small particulate matter having large density on the surface of the clay material.
c. **Adsorption:** This is an important purifying action. It removes finely divided suspended matter as well as colloidal and molecular dissolved impurities by the electrostatic columbic and Vander walls force of interaction b/n adsorbate and filter sorbent surface due to unique adsorption nature filter surface.

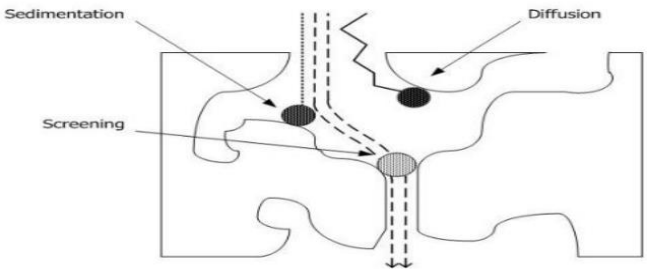


Figure 2. 5: Mechanism of filtration (sedimentation, screening and diffusion) [21]

2.4 PREVIOUS RESEARCH ON CPWF PERFORMANCE

The level of removal depends on the size of the pores and the size of the organisms. The size of bacteria varies from 0.3 to 100 µm, depending on the shape. Protozoa are range in size from 8 – 100 µm [21]. Viruses do not have the structure to reproduce themselves, which makes them the smallest of all disease-causing organisms, at 0.02 – 0.2 µm(20-200 nm).The pore diameter from literature for most ceramic water filters has been found to be within the range 0.2-2.5 µm. Potters For Peace(PFP) aims to have a maximum pore size of 1µm .

Unfortunately, in reality the size of the pores in ceramic filter are measured between 0.6 – 3 micron [11]. So this size is viruses (20–100 nm) ineffective diameter.

Virus removal efficiency of ceramic pot filters does not meet the WHO standards for being 'Protective' (LRV3). No critical parameter is yet found to enhance the virus removal efficiency [23].

Table 2. 4: Summary on Bacterial removal efficiency of CPWF from Field Studies

Country	Number of Households		Indicator Tested	Filtered Water Quality			Time in use
	Filters	Control		% Reduction	LRV	% of filters & risk level[a]	
Guatemala (AFA 1995)	343[b]	337[c]	TTC			91% of filtered water samples conformed to WHO guidelines	Up to 1 year
Nicaragua (Lantagne 2001b)	24		*E. coli*			Samples from 53% (8) of 15 households with *E. coli* in source water conformed to WHO guidelines	6 to 18 months
Cambodia (Roberts 2003)	686		*E. coli*			98%-99% low risk	Up to 1 year
Cambodia (Brown *et al.* 2007)	80	80	*E. coli*	Mean 95.1%[d]; up to >99.99%	Mean: 1.3-log	66% low risk; 40% conformed to WHO guidelines	Up to 2 or 4 years
			TC	90%	1-log		
Cambodia (Brown *et al.* 2008)	120	60	*E. coli*	Mean 96%	1.4-log	60% low risk; 39% conformed to WHO guidelines	18 weeks
Ghana (Johnson *et al.* 2008)	25[e]	16	*E. coli*	99.7% (traditional); 85% (modern)		Average filter effluent low risk	Up to 1 year
			TC	99.4% (traditional); 90% (modern)			

a: No detectable TTC or *E. coli* per 100 mL sample: conforms to WHO drinking water quality guidelines; 1-10 Low risk; 10-100 Intermediate risk; 100-1000 High risk; >1000 Very high risk.
b: Households with filters only and with both education and filters.
c: Control households and education only; no filters.
d: Water samples were not tested under challenge conditions; therefore, results potentially underestimate performance.
e: Includes traditional and modern households.

Limitations to this theory are that stored water might not be from the same source as filtered water [24].

Table 2. 5: Testing done on low cost ceramic water filter (CWF) effectiveness in bacterial and viral removal efficiency for period 2000-2010 are given below [25]:

References	Bacterial type	Reduction	
		%	LRV(log10)
Dies(2001)	Escherichia coli	>98	
Sagara(2000)	Escherichia coli		4.6
Lantagne(2001)	Cryptosporidium parvum		4.3
Roberts(2004), Duke et al (2006) & Hwang (2003)	Escherichia coli Diarrhoeal disease Total coliform	GM98 Mean 46 94-99.9	
Dies 2003	Escherichia coli	>98	
Coulbert(2005)	Escherichia coli	99.8	
Franz(2005)	Escherichia coli	92-100	
McAllister(2005)	Bacteria Viruses	99 20	
Clasen et al(2006) Halem (2006)	Escherichia coli Clostridium spores		3-6.8
Oyanedel-Craver &Smith (2008)	Escherichia coli Viruses	>97.8 <90	3.3-4.9
Brown &Sbsey(2010)	Escherichia coli MS2 Bacteriophages	Mean 99 90-99	2.1-2.9 1.2-4.1
USEPA(1987) &NSF(2003)	Bacteria Viruses Protozoa		6 4 3
Brazil ABNT NBR 14908	Escherichia coli Viruses		2

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 [20].Filters manufactured using a larger screen size to sieve the sawdust has been shown to reveal no significant difference in flow rates [26].However, filter mix ratios are adjusted to achieve acceptable flow rate ranges according to the particle size of the rice husks received [27].

The need to develop a new raw material mixing ratio, when using 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 [26]. As the mixed ratio and density of the combustible material is increased, there is increased probability that pores may become connected, and larger than desired [26]. The size, the type and amount of the combustible material affect filtration rate; clay type will also affect the filter's hydraulic conductivity and removal efficiency [28].

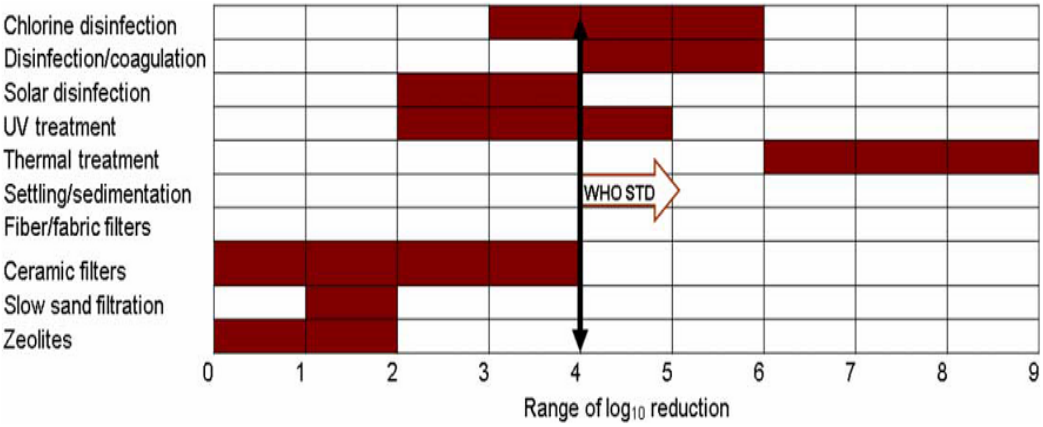
Table 2. 6: summarized data on relative comparison of different De-fluoridation filters

De-fluoridation techniques	Advantage	limitation
➢BONE CHAR FILTERS: ▪ Made of powdered cow bones ($Ca_3(PO_4)_2$, 57- 80 %, $CaCO_3$ 6- 10 % and activated carbon 7-10 %) (Fawell et al., 2006)	▪ Have large specific surface area enables high adsorption capacity (Chidambaram et al., 2004; Kaseva, 2006). ▪ High fluoride removal efficiency	▪ requires much larger dose of alumina ▪ Large waste sludge disposal (Shrivastava and Vani, 2009) ▪ Has problem of odor and taste ▪ Socially un acceptable for cultural reasons ▪ Relatively lower cost ▪ Can be only used at accominity level ▪ has lower removal efficiency to other chemical contaminant and microbial organisms
➢ NALGONDA FILTER: ▪ Utlize aluminium sulphate ▪ Mechanism of adsorption by Sedimentation (by Coagulating and flocculating agent)	▪ Relatively have high removal efficiency at low input concentration ▪ High fluoride removal efficiency	▪ requires frequent addition of chemicals ▪ Relatively Highest cost ▪ Large waste sludge disposal ▪ has lower removal efficiency to other chemical contaminant and microbial organisms (Fawell et al., 2006; Nigussie et al., 2007).
➢CERAMIC WATER FILTERS : ▪ Utilize clay and combustible material ▪ Mechanism of adsorption by Sedimentation (by density) and chemically desorb by ion echange	▪ least cost (Prepared by locally available raw materials ▪ Has high removal efficiency of both most chemical contaminants and microbial organisms ▪ reduce odor and bad tastes ▪ Used for personal house hold treatment	▪ Mechanical breakage ▪ Require continuous

Table 2. 7: Summarized data on relative comparison of different HWTS technologies

	Benefits	Drawbacks
Boiling	▪ High bacteria, viruses and protozoa inactivation efficiency, even in turbid or contaminated water; and, ▪ Has high socio-cultural acceptance of boiling for water treatment in some cultures.	▪ lack of residual protection against contamination; ▪ potential for burn injuries ▪ potentially high cost of carbon based fuel source (with concurrent deforestation risk) and ▪ potential user taste objections;
Solar disinfection	▪ reduce viruses, bacteria, and protozoa in water; ▪ documented reduction of diarrheal disease in users; ▪ Socio- culturally acceptable ▪ Low cost and No taste change after treatment ▪ Low recontamination due to safe storage.	▪ the need for pretreatment (filtration or flocculation) of waters of higher turbidity; ▪ Supply limited volume of water that can be treated at once; ▪ the lack of aesthetical improvement
Household chlorination	▪ reduce most bacteria and viruses in water; ▪ residual protection against contamination; ▪ acceptability to some users because of ease-of-use; ▪ scalability; and, low cost	▪ relatively low protection against parasitic cysts; ▪ lower disinfection effectiveness in turbid waters; ▪ potential user taste and odor objections; ▪ necessity of ensuring quality control of solution by technicians ;
Flocculant / disinfectant powders	▪ Reduce bacteria, viruses, and protozoa in water; and some heavy metals and pesticides; ▪ residual protection against contamination; ▪ acceptability to users because of visual improvement in the water;	▪ requires multiple steps of demonstration to use the product in order to teach new users; ▪ the need for users to have, employ, and maintain two buckets, a cloth, and a stirring device; and, ▪ the higher relative cost per liter of water treated compared to other household water treatment options.
BioSand Filtration	▪ Can remove protozoa and bacteria; ▪ acceptability to users because of high flow rate (~20 liters/hour), ease-of-use, and visual improvement in the water; ▪ production from locally available materials; ▪ one-time installation with low maintenance requirements; and, long life.	▪ comparatively low inactivation of viruses; ▪ absence of post-filtration residual protection leads to recontamination; and, ▪ the difficulty in producing and transporting a 100-350 pound filter housing ▪ the high initial cost that make scalability more challenging
Ceramic filtration	▪ Has high reduction potential to microbes(i.e bacteria, protozoa and some extent to virus) ; ▪ Has high aesthetic improvement in treated water; ▪ Socio-culturally acceptable and the simplicity to users makes it one of the choice in the market of HWTS technologies know a days. ▪ documented reduction of diarrheal disease among users; ▪ potentially long life if the filter remains unbroken; and, ▪ Low cost and one-time cost/payment	▪ low effectiveness against viruses; ▪ Has problem of recontamination if treated water is stored unsafely; ▪ filter breakage and need for spare parts; ▪ Require regular cleaning of both filters and its receptacles, especially when using turbid source waters; and, ▪ a low flow rate of 1-3 liters per hour (slower in turbid waters).

Table 2. 8: The effectiveness of different technologies in removing microbial pathogens from polluted drinking water including viral removal [29].



Log reduction value microbial removal efficiency is calculated by using the following formula given on equation 2.1 below [29]:

$$\text{Log Reduction Value (LRV)} = \mathbf{log}\frac{[\boldsymbol{untreated\ raw\ water}]}{[\boldsymbol{treated\ water}]} \quad \text{.....(2.1)}$$

The Categories for microbial removal efficacy are <1 $\log_{10}$ (<90%) is low, 1to 2 $\log_{10}$ (90-99%) is moderate and >2 $\log_{10}$ (>99% is high).

Ultraviolet treatment, Reverse osmosis filters, nano-filtration, electro dialysis and electro coagulation are the best method to inactivate bacteria and viruses. They require more technical support for operation, maintenance and high capital investment cost, and high energy consumption, so that it is not affordable third world countries.

The ceramic filter systems are the most effective household water treatment than Bio-sand, Solar Disinfection (SODIS) and chlorination, especially on the long term.

Ceramic water filters would filter out most bacteria, viruses, sediments, most heavy metals, fluoride, radon, and reduce odor and bad tastes in water and it is the most effective filtering media. Thus, is chosen to be the focus of this project.

2.5 UNRESOLVED ISSUES REGARDING ON CPWF

1. It was just for the first time that, CWF will be analyzed for De-fluoridation.
2. The effect of combustible materials variation on the filter product performance is not analyzed in any paper before.
3. The effect of variation of processing parameters (mixing ratio, particle size, and firing temperature) on the filter performance is not analyzed in any paper before.

This project is expected to solve a country level problem. Besides to these, it just to contribute to the manufacturing and production understanding of CPWF. These are the main reason why this project is chosen and carried out.

CHAPTER THREE

3 METHODOLOGY

3.1 PARTICLE SIZE DISTRIBUTION ANALYSIS

The grain size of the study area soil was determined based on ASTM D 422 Standard test method [30]. Among the different types of clay available in Ethiopia, the present study used clay samples which were taken from three randomly selected locations in south nation nationalities peoples region (SNNPR) Ethiopia. Thus are namely: Babawuha soil from Babawuha zone Adola town, Hossana soil from Hadiya zone near Hossana town and Leku soil from Shebedino zone, Sidama wereda in SNNPR. The first goal of this study is to measure the variation of clay properties this different clay samples. The grain size analysis using both sieve and hydrometer analysis was carried out to determine the range in which the representative soil sample falls. After completion of grain size analysis the relative proportion of different size in each sample was determined. The range of the size was especially required for the purpose of soil classification and also to get the relative proportion of clay sized soil out of the total raw soil collected from the study area.

The collected samples were dried in open air (sun dried), after which, the samples were manually crushed into smaller particles using a mortar and pestle From each above mentioned three kind of pulverized and oven dried clay soil, 550gram of each soil sample which passes through the No.14 sieve is collected for particle size distribution analysis (for both sieve and hydrometer analysis) and 200 gram sample of the each soil which passes the No. 40 sieve is collected for Atterberg limit test.

3.1.1 SIEVE ANALYSIS

Mechanical analysis is one of the oldest and most common forms of soil analysis. It provides the Basic information for revealing the uniformity or gradation of the materials (soil) with in established size ranges and for textural classifications.

This test is performed to determine the percentage of different grain sizes contained within a soil. The mechanical or sieve analysis is performed to determine the distribution of the coarser, larger-sized particles, and the hydrometer method is used to determine the distribution of the finer particles. Sieve analysis is carried out by using a set of standard sieves.

3.1.2 HYDROMETER ANALYSIS

Hydrometer analysis is a widely used method of obtaining an estimate of the distribution of soil particle sizes from the No. 200 (0.075 mm) sieve to around 0.01 mm. The data are presented on a semi-log plot of percent finer vs. particle diameters and may be combined with the data from a sieve analysis of the material retained (+) on the No.200 sieve. The principal value of the hydrometer analysis appears to be to obtain the clay fraction (generally accepted as the percent finer than 0.002 mm). The hydrometer analysis may also have value in identifying particle sizes < 0.02 mm in frost susceptibility checks for pavement subgrades. This test is done when more than 20% pass through No.200 sieve and 90% or more passes the No. 4 (4.75 mm) sieve.

The hydrometer analysis is based on Stokes' Law, which gives the relationship among the velocity of fall of spheres in a fluid, the diameter of the sphere, the specific weights of the sphere and of the fluid, and the fluid viscosity. This relation was given by the following formula in equation 3.1[30]:

$$V = \frac{2}{9}\left(\frac{D}{2}\right)^2\left(\frac{G_s - G_f}{\eta}\right) \quad \text{.....(3.1)}$$

Where,

v = velocity of fall of the spheres (cm/s)

G_s = specific gravity of the sphere

G_f = specific gravity of fluid (varies with temperature)

η = absolute, or dynamic, viscosity of the fluid (g /(cm * s))

D = diameter of the sphere (cm)

Solving the equation for D and using the specific gravity of water G_w, we obtain

$$D = \sqrt{\frac{18\eta V}{(G_s - G_w)}} \quad , \quad V = \frac{L}{t} \quad , \quad A = \sqrt{\frac{18\eta}{(G_s - G_w)}}$$

$$D = A\sqrt{\frac{L(cm)}{t(min)}} \qquad \text{.....(3.2)}$$

Where 0.002 mm $\leq$ **D** $\leq$ 0.2 mm

The corrections to hydrometer readings:

- **Zero Correction (F_z):** If the zero reading in the hydrometer (in the control cylinder) is below the water meniscus, it is (+), if above it is (–), if at the meniscus it is zero.

- **Meniscus Correction (F_m):** Difference between upper level of meniscus and water level of control cylinder.

- **Temperature correction (F_t)**: The temperature of the test should be 20°C but the actual temperature may vary. The temperature correction is approximated as

$$F_t = -4.85 + 0.25\ T \text{ (for T between 15°C to 28°C)}$$

3.2 ATTERBERG LIMIT TEST (TEST FOR THE WATER OF PLASTICITY)

To determine the plastic and liquid limits of a fine grained soil. The Swedish soil scientist Albert Attemberg originally defined seven "limits of consistency" to classify fine-grained soils, but in current engineering practice only two of the limits, the liquid and plastic limits, are commonly used. (A third limit, called the shrinkage limit, is used occasionally) The Atterberg limits are based on the moisture content of the soil.

A wide variety of soil engineering properties have been correlated to the liquid and plastic limits, and these Atterberg limits are also used to classify a fine-grained soil according to the Unified Soil Classification system(USCS) or American association state highway and transport official (AASHTO) system. The Atterberg limit were determined according to the

procedure of American standard test for materials (ASTM)- D 4318- 10 [31]. This was a Standard Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils.The Casagrande Cup was used for the Liquid Limit. The Casagrande Cup is a metal cup attached to a device which taps it on a solid surface, disturbing the contents; each tap is counted as a blow. The bottom of the cup is filled with the clay, and a groove of standard size is carved to separate the clay into two sides. The blow count‖ is recorded as the number of blows required to make the clay rejoin along ½‖ of length of the groove. The water content of several clay samples is adjusted to record different blow counts. The liquid limit is the water content at when the blow count is 25. The plastic limit is the water content when a 1/8‖ diameter strand of clay begins to crumble. The plasticity index is the difference between the liquid limit and the plastic limit.

I. **The liquid limit (LL) test:-** is the moisture content that defines where the soil changes from a plastic to a viscous fluid state. The liquid limits of the soils were determined by the Casagrande percussion method. The liquid limit is arbitrarily defined as the water content, in percent, at which a part of soil in a standard cup and cut by a groove of standard dimensions will flow together at the base of the groove for a distance of 13 mm (1/2 in.) when subjected to 25 shocks from the cup being dropped 10 mm in a standard liquid limit apparatus operated at a rate of two shocks per second.

II. **Plastic Limit (PL) test :-**The plastic limit is the moisture content that defines where the soil changes from a semi-solid to a plastic (flexible) state. The plastic limits of the soils were determined by the conventional 3 mm thread rolling method. The plastic limit (PL) is the water content, in percent, at which a soil can no longer be deformed by rolling into 3.2 mm (1/8 in.) diameter threads without crumbling. About 15g of soil, passing through a No.40 sieve, is mixed thoroughly. The soil is rolled on a Glass plate with the hand, until it is about 3mm in diameter. This procedure of mixing and rolling is repeated till the soil shows signs of crumbling. The water content of the crumbled portion of the Thread is determined. This is called the plastic limit.

III. **Plasticity Index**: The PI is a measure of the range of moisture content over which the soil remains plastic [56].It is the numerical difference between the liquid

limit (LL) and the plastic limit (PL) for a particular material. The PI was determined from the following expression:

$$\mathbf{PI = LL- PL} \quad \text{……..(3.3)}$$

Where LL and PL are liquid limit and plastic limit of the three respectively.

Standard test for LL, PL and PI of soils were closely followed as possible (ASTM Standard D4318) [31].

3.3 EVALUATIONS OF OPTIMUM FILTER PROCESSING PARAMETER RANGE

In this section the raw materials physio-mechanical properties were investigated out and this includes water absorption (porosity), plasticity limit, dry, firing and total shrinkage will be determined. This test is according to the clay test protocol of pottery for peace [32] and American standard testing of materials standard for whiteware ceramic products [33]. Around 27 bar samples with different clays to saw dust composition (as shown on figure 3.4 given below) and with two different firing temperatures (800°C and 900°C) were analyzed to evaluate the optimal processing parameters of ceramic pot water filter(CPWF). In this investigation three different clay soil (Hossana,Bambawuha and Leku clay soil) were mixed with saw dust with different mixing composition according to the recommended literature range. The recommended clay to combustible mixing ratio range were 60 wt % to 90wt % of clay to 10 wt % to 50% of combustible [14][15].

Clays with different properties can be combined in order to achieve a clay body that has the desired characteristics. Therefore, the above mentioned three soils are mixed with saw dust with different composition as given on the table $B_1$of appendix B.

The optimal manufacturing process parameters are determined. Evaluating the physical nature of ceramic filter clay body and its reaction to firing are good ways of determining water of plasticity, shrinkage rates (dry, firing & total shrinkage), and the firing temperature (using total shrinkage and percent porosity) [34]. The following section will explain the calculations necessary to analyze the weights and measures thus were obtained on the following test

sample bar preparation procedure. In order to minimize the errors involved, three different test bar samples of the same batch composition were tested and the average values evaluated. The drying, firing and total shrinkage were calculated for each test specimen using standard formula as just given below.

3.3.1 TEST FOR THE WATER OF PLASTICITY

This test determines the amount of water required for clay to become workable, of the desired consistency. Clay with a finer grain structure will require more water and will therefore shrink more during drying [34]. Calculate the amount of water of plasticity using the following formula [32],[33]:

$$\text{Water of plasticity, w (\%)} = \frac{\text{weight of wetting water}(w_w)}{\text{weight of dry powder}(w_d)} \text{ x } 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3.3)$$

3.3.2 SHRINKAGE TESTS

The amount of shrinkage is an important characteristic of any clay and will be partly determined by the amount of non-plastic material in the clay, the particle size, and the water content. Clay with a high shrinkage rate (more than 15% total shrinkage) probably will not be useful because it will warp and crack during drying and firing [14] [15]. Knowing the total shrinkage rate of the filter mixture will be useful for designing molds of the proper dimensions so that after firing the filter element will fit precisely inside the available receptacle. The following Shrinkage tests were carried out according to ASTM C 326-03 [35], Standard test method, which was calculated by using the following formula:

a) Dry or Linear Shrinkage:

$$\text{Linear shrinkage, } S_L \text{ (\%)} = \frac{\text{Plastic bar length } (L_p) - \text{dry bar length}(L_d)}{\text{Plastic bar length } (L_p)} \text{ x } 100 \ldots\ldots\ldots\ldots\ldots\ldots (3.4)$$

b) Firing Shrinkage

$$\text{Firing shrinkage, } S_F \text{ (\%)} = \frac{\text{Dry bar length } (L_d) - \text{fired bar length}(L_f)}{\text{Dry bar length } (L_d)} \text{ x } 100 \ldots\ldots\ldots\ldots\ldots\ldots (3.5)$$

c) Total Shrinkage

Total shrinkage is how much the clay or filter mixture shrinks from its plastic state to its fired state and can be calculated using the formula given below :-

$$\text{Total shrinkage, } S_T\ (\%) = \frac{\text{Plastic bar length } (L_p) - \text{fired bar length} (L_f)}{\text{Plastic bar length } (L_p)} \times 100 \ldots\ldots\ldots\ldots\ldots (3.6)$$

3.3.3 PERCENT ABSORPTION (POROSITY) TEST

The degree of water absorption of the fired clay, or percentage porosity, is also a measure of the maturity of a fired clay body. Earthenware clay, by definition, will have greater than 5% porosity when fired to maturity. Porosity of filters has been measured to range from 30-44% [21],[28]. Calculate the absorption, using the formula given below:

$$\text{Porosity, P } (\%) = \frac{\text{Saturated bar weight } (W_{sat}) - \text{Dry powder weight } (W_d)}{\text{Dry powder weight } (W_d)} \times 100 \ldots\ldots\ldots\ldots\ldots (3.7)$$

3.3.4 WATER ABSORPTION TEST

It was determined using the Archimedes liquid displacement method based on ASTM C373-88 (1988) [see Appendix C].This can be done by boiling the fired test bar samples in distilled water for 2 h and The heating was stopped and the test bar samples were allowed to remain immersed in the water for 24 hrs at ambient temperatu**re**; then the test bar samples were removed from water, dried with a cotton cloth then the test bar samples were again weighted; it was calculated following ASTM C373-88 (1988)[see Appendix C] and UNI 4543 (1986) [36]standards; in these methods, samples are exposed to saturation of water, achieved by Archimedes method by boiling. The test was carried out on three representative test bar samples of the composition.

Materials and equipment: mortar and pestle, mass balance, sieve (30 and 16 mesh), spoon ,syringe , ruler in centimeters with accuracy of 0.5mm / vernier calliper , water cup, wooden mold 4cm x 2cm x 1 cm deep ,pencil , cooking oil ,magic marker, Oven, firing furnace.

1.Clay raw materials were Sun dried for two days, then crush and grinded using mortar and pestle as shown below in the figure 3.1 the grinded clay sieved through a 30 mesh screen and the saw dust is oven dried at 100ºC, and then sieved through 16 mesh Screen sieve.

Figure 3. 1: Sun drying and beneficiation process of Bombowuha, Hosiana (Belessa) and Leku clay (left to the right respectively)

2. For one bar, different weight of mixture of clays and sawdust powder together thoroughly in the bowl. First, dry powder of clay and saw dust mixed for around two minutes and then, water was added to the powder mixture by using water dropper. Sprinkle water from the eyedropper after each layer, leaving the top layer dry.
3. Mix, adding water as necessary until it became sticky. All samples should have a consistent feel. Dry was better than wet, because pressed filters use a dry mix.

Figure 3. 2: Ready powders of Hossaina(the white) , leku clay(grey) and sawdust for dry mixng

4. Record the amount or weight of water used (weight of water used= weight of wet clay-weight of dry clay powder)
5. Oil the wood mold with cooking oil and Pinch and smooth the mixture into the mold. Once the mixture has become a bar in the mold, tap it lightly with the back of the spoon to compact the particles.

Figure 3. 3: Wood mold for forming of sample test bars

6. Eject the slab from the mold. Pinch and smooth the edges to remove cracking. Place the slab back into the mold in reverse. Tap lightly to compact and burnish with the back of the spoon. Eject the bar from the mold. Smooth and compress the edges with the spoon.
7. A clear 1 cm long marking line was Drawn on each green test bars and based on their composition an identification code was given to all test bars.
8. Oven drying of the test bars for two days at 100°C and bars were turned regularly to avoid warping.

Figure 3. 4: Total green test bar samples and oven drying

9. After sufficiently drying of the test bars, they were removed and their linear length and drying weight measured and recorded.
10. From the literature normal firing schedule will last about 8 hours total will be carried out by using firing furnace. Therefore, the rate of firing is 100 °C. Per hour up to 400 °C. Maintain 400 °C for one hour holding time to allow the sawdust to burn out. After one hour, the firing can proceed until the end at the rate of 100°C -150 °C per hour for the remaining four hours till the firing temperature reaches 800 °C ,RDIC,2004[27],[37].

Figure 3. 5: Furnace firing of test bar samples and product of fired test bar samples at 800ºC and 900ºC from the left to right.

11. Water absorption testing of sample test bars by using Archimedes liquid displacement method based on ASTM C373-88 (1988) [see Appendix C]. A sufficient amount of water was boiled to accommodate all the bars, and the bars were submerged in the boiled water and removed one by one just after two hours. Then, the surface of the bars dried by using a damp sponge and their weight were weighed and the results were recorded as suspended weight. Finally, the bars were again immersed and left there in order to saturate for 24 hours then then, the saturated weight was measured and recorded its.

Figure 3. 6: boiling and drying of sample test bars (Archimedes liquid displacement method based on ASTM C373-88 (1988)

Figure 3. 7: Water absorption testing set up

12. Repeating the above listed procedure (step 1-12) for the remaining half bar samples preparation which was fired at 900°C.

3.4 CHARACTERIZATION TECHNIQUE

The materials that were used in the manufacturing of the filters were sampled for characterization. These samples include; three raw soils (Bombowuha, Hossaina and Leku soil) and two combustible materials (sawdust and teff husk). The characterization experiment was used to determine the crystalline phase identification, elemental chemical compositions, and thermal analysis of the raw samples soils and combustible materials. The phase compositions of the samples were obtained using the X-Ray diffraction (XRD) and the elemental chemical compositions of the samples were obtained by using X-Ray Fluorescence (XRF) spectroscopy. While the thermal stability and fraction of volatile components of the raw materials sample were analyzed using Differential Thermo-gravimetric analysis (DTG) device.

3.4.1 POWDER X-RAY DIFFRACTION (XRD) ANALYSIS

X-ray diffraction (XRD) is widely utilized to elucidate the structure of crystalline materials. It is a technique used to confirm the structural characteristics of a synthesized specimen providing with a unique fingerprint of samples under investigation.

In this study, analysis of sample powder of three clay raw materials (Bombowuha clay,Hossaina clay, Leku clay) were analyzed using the X ray powder diffractometer (XRD-7000S ,Dangil shimadzu-south Korean corporation product) operating in Bragg-Brentano geometry with Cu-Kα radiation and Ni filter and it has a wavelength of 1.54056 Å with 2kw or 3kw which is controlled by computer software. The instrument setting for each test at room temperature was: tension = 40 kV, current = 20 mA and a scan rate of 3^o per minute, Data collection will be carried out in the 2θ range 10° - 80°, with a scanning step of 0.02°. Samples for the X-ray analysis were ground before sieving them through the 270 mesh sieve (i.e sieve having 53μm opening diameter). Around0.2-0.5 g of ground/powder samples were then mounted on an aluminum holder before conducting the XRD analysis and the sample holder surface were smoothed off in order to absorb the X-ray beam regularly. The crystalline phase identification were carried out by comparing crystal inter planar distance or d-spacing in the differentiating pattern to their integrated intensity with known standards in the JCPDS (joint committee on powder diffraction standards) standard file. The diffraction pattern was plotted within the XRD machine by generating a scan with continuous scanning mode for the intensity of peak as the Y-axis versus (2θ) as the X-axis.

3.4.2 CHEMICALANALYSIS

X-Ray Fluorescence (XRF) spectroscopy was also used to determine the chemical compositions of the clay samples. Electromagnetic radiations having wavelength in the range of 0.01 to 10 nanometers, corresponding to frequencies in the range 30 petahertz to 30 exahertz (3×1016Hz to 3×1019Hz) and energies in the range 100 eV to 100 keV are known as X-Rays. Meaning there are different kinds of x-rays. When atoms of any chemical element are irradiated with x- or low-energy -rays, they emit energy in the form of fluorescence x-rays; the energy is characteristic of each element involved (Ohrman, 2000). The intensity of each fluorescence line varies according to the quantity of the element present in the investigated sample. The term "fluorescence" is applied to phenomena in which the absorption of radiation of a specific energy results in the re-emission of radiation of a different energy (generally lower).

The XRF data was carried out in mugger cement factory, X-Ray Fluorescence (XRF) spectroscopy laboratory, Ethiopia. The XRF analysis data was collected using a Thermo Fisher ARL9400 XP+ Sequential XRF spectrometer that was equipped with the Win XRF software package (Thermo Fisher Scientific Inc., Ecublens, Switzerland). The Bombowuha and Hossana clay samples were milled in a tungsten-carbide milling pot to achieve particle sizes that were less than 75 microns. They were then dried at 100°C and roasted at 1000°C to determine the Loss On Ignition (LOI) values. A gram of the Bombowuha and Hossana clay samples were mixed with 6g of Lithium Teraborate flux and fused at 1050°C to make a stable fused glass bead. For trace element analyses, the sample was mixed with a PVA binder and pressed into a pellet using a 10 ton press.

3.4.3 DIFFERENTIAL THERMOGRAVIMETRIC (DTG) ANALYSIS

Thermo-gravimetric analysis (TGA) is one of the thermal analysis method in which the effect of heat on the mass of a sample with time is studied to obtain quantitative information. It is an analytical technique used to determine a material's thermal stability and its fraction of volatile components by monitoring the weight change that occurs as a specimen is heated. Elemental chemical composition of clay, oxidative stability and kinetics of the decomposition of clay can be obtained. In addition, the nature of evolving gases can be investigated. A single graph of DTG have two kinds of curves , TGA and DTA curves. The TGA curve tell us about the changes in qualitative and a quantitative information of the weight loss of the samples during

the heating process are related with the emission or absorption of energy and are visualized by endothermic or exothermic peaks of the DTA (differential thermal analysis) graph (curve). Endothermic peaks are related with the emission of energy to the system (for ex. loss of water during heating), while exothermic peaks are related with needing energy from the system (for ex. phase transition).Differential thermal analysis (DTA) is also one of thermal analysis method in which a qualitative analysis and changes in the sample are compared with the reference under the same heating conditions. DTA curve used for examining the degradative pathways of a material as both physical and energetic transformations are detectable. Thermal analysis is an important method for clay identification. The clay composition can be detected from the TGA when percentage weight loss is measured and from the DTA peaks, which are related with different processes during heating. The temperature for changes in the structure of clay and phase transitions will be specified (kinetic of decomposition).

The measurement is normally carried out in air or in an inert controlled atmosphere, such as nitrogen, helium, argon or air, and the weight is recorded as a function of increasing temperature. In this particular study, the differential thermogravimtric analysis (DTG) was performed on three raw soils (Bombowuha ,Hossaina, and Leku soils) and two combustible materials (sawdust and teff husk) were carried out in air atmosphere with a Dangil shimadzu DTG-60 (south Korea) instrument in the temperature range of 50-1500°C and at a heating rate of 20°C/min in air atmosphere by taking sample of 13 to 14 mg weight by using platinum crucible for the three clay samples and aluminum crucible for the combustible materials.

3.5 CERAMICS POT WATER FILTER (CPWF) PREPARATION TECHNIQUE

The ceramic water filters production process follows some common steps regardless of the type of filter being manufactured. The process typically begins with material selection and processing; followed by shaping and pressing the filter element into a mold; firing; drying. The primary materials used in the production of ceramic water filters are clay, water and combustible material. Usually these materials require processing such as grinding and sieving before they can be mixed together into a uniform mixture that is pressed into a filter shape.

Table 3. 1 : Materials and equipment that will be used for the preparation of CPWF element samples and their purpose

No.	Materials and equipment	purpose
1	clay	Main body of the filter element
2	Hard wood Saw dust (eucalyptus tree sawdust)	Combustible material to create required amount of porosity or holes
4	water	As Solvent media for mixing
5	Teff husk	combustible material

Based on the result evaluated for optimum ceramic filter processing range in the previous section on this paper, the CPWF manufacturing condition was used as shown on the table 3.2 given below.

Table 3. 2: The manufacturing variables and variation in optimum range used in this investigation

No.	CPWF manufacturing(processing) variables	Change in manufacturing variables		
1	Firing temperature	900ºC	900ºC	1000ºC
2	Sieve sizes(clay/combustible)	¥¥30/16	60/30	30/16
3	CPWF composition code	(¥¥70H/30S),(80H/20S),(70B/30S),(80B/20S),(25H/55B/20S), and (25B/55H/20S)		
		(70H/30T),(80H/20T),(70B/30T),(80B/20T),(25H/55B/20T), and (25B/55H/20T)		

¥¥30/16 stands for mesh number used to sieve clay and combustible materials respectively.

¥¥70H/30S means seventy weight percent Hosiana kaolinitic clay and thirty weight percent sawdust

The fabrication of ceramic pot water filter element was done according to the following procedure as given below:-

I. Preparation of raw materials : the sun dried clay(Bombowuha and Hosiana kaolinitic clay) and combustible materials(sawdust and teff husk (for two days) were crushed, grinded and sifted by using sieving mesh (30 and 50 mesh number, which has an opening diameter of 600µm and 300µm respectively, was used for sifting of clay raw materials and 16 and 30mesh number, which has opening diameter of 1118µm and 600µm respectively, was used for sifting of combustible materials) as shown the figure 3.1 .(from Bar testing part)

Figure 3. 8: Grinding and sieving of raw materials

II. Mixing of clay to combustible materials:-clays and combustible materials were mixed in an optimal mixing range as just presented on the above section (table 3.2), which was suggested from the previous section. The suggested clay to combustible mixing composition and their particle sizes are given on table given above. The powders were dry mixed until uniform mixture was formed and then mixed with water. The amount of water typically added to the mix was already evaluated as water of plasticity for clay to sawdust mix but this amount a little bit adjusted for clay to teff husk mix. so that the mix was not too wet or not too dry for shaping. This was done periodically to ensure that a homogenous consistent mixture was obtained. When the wet mix was prepared, it became a moist lump of clay. After this step, the clay was wedged to get further work in the moisture and get all of the air out of the mixture. Wedging consists of folding the clay over upon itself repeatedly and applying pressure. After wedging, the mix became a consistent, air free, and lump of moist clay.

III. Construction of aluminum mold with the following dimensions base diameter (D_b) = 3.4cm, top diameter (D_T)= 5.7cm,height (h)=5.4cm, length of the lip(L_{lip}) = 1.5 cm and angle of filter wall inclination(θ) =80° as shown on the figure 3.9 given below.

Figure 3. 9: Aluminum male (with galvanized metal outer cover) and female mold for CPWF forming

IV. Forming stage: The homogenous mixture was then pressed into flower/pot shape by using manually driven hydraulic filter press with a purpose-built metal mold by applying 5kgft/cm^2 bumping pressure per each filter piece sample with two minute holding time as shown on the figure16 given below. Finally, Physical shape quality was checked and Surface finishing by using scrubbing tool also implemented. After Surface finishing, the CPWF were marked with unique codes for filter identification.

Figure 3. 10: Plastic forming of filter element by using semi dry clay to combustible plastic mix and surface finishing

V. After shaping, the filter elements were open air dried for 24 hours and later oven dried for two days as shown on the figure 3.11 given below. The purpose of drying was to remove as much moisture as possible before the filters placed into the furnace. If the filters have excessive moisture, the water evaporates inside the clay when we fire it and cause the filters to explode. In the literature, Drying of pressed filter elements depends on the weather condition, for 7-15 days for dry season (for the first 2 day in dry shady area

covering the surface with plastics and the reaming day sun drying by reversing its position 4-5 hrs. interval) and for wet season 15 – 18 days [37],[21].

Figure 3. 11: Open air and oven drying of sample CPWFs after forming stage

VI. After drying, filters were fired in ceramic firing furnace by using optimal firing temperature which was determined from the previous experiment (but according to RDIC firing temperature ranges from 830°C to 866°C for a 9 hour of total firing time). The firing involved heating in a locally made clay kiln from room-temperature (~25-30°C) to 850°C. During heating, the sawdust was burnt off at a temperature of ~ 500°C[38], as shown in the given figure 3.12 below. The initial heating rate of 45°C per hour was increased to 100°C per hour at temperatures above 500°C. This was done at a rate of 45-100°C /hr. This was then followed by furnace-cooling to room temperature in air for 24 hrs.

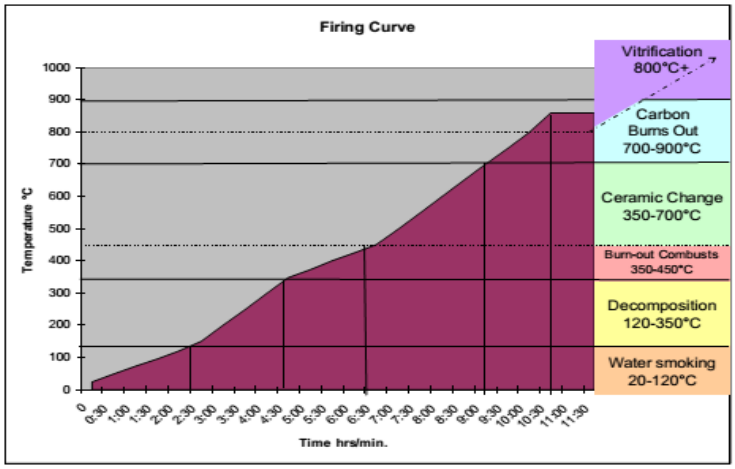


Figure 3. 12: Firing Curve and Stages of Firing [39]

From optimal filter processing range investigation, the firing temperature should be higher than or equal to 900°C.So that, 900°C and 1000°C were selected and used to fire the green

CPWF samples according to the following firing schedule cure as shown on the firing diagram given figure 3.13 below.

Figure 3. 13: Furnace firing of sample CPWFs at 900°C

In order to see the effect of variation of firing on CPWF performance, the CPWF samples were fired at two different optimum firing temperature at 900 ºC and 1000ºC, which were suggested from the previous result on test bars (see section 3.3). They were then allowed to furnace cool down to room temperature.

Seven ceramic water filters with different clay to sawdust volume ratios were intentionally selected and tested for flow rate, turbidity reduction and indicator bacteria removal efficiency from contaminated water sources.

3.6 FILTER PERFORMANCE TESTING METHODS

The objective of this low cost water filter design is to provide safe drinking water to a small family in the third world places. Thus, the product's effectiveness in filtering contaminants is critical. At the same time, the filter flow rate must be optimized to provide clean water in a reasonable amount of time. Two tests had been carried out to justify these factors. A series of water flow rate tests were conducted to find the optimal value. The required materials and procedures utilized in both tests are described in the following sections.

In this project three major filter performance testing methods will be practically implemented. The testing methods are used on the basis of factors that affect filter performance. Therefore, three major filter performance testing methods will be carried out. Thus are filtration rate, physiochemical and microbiological tests. The filtration rate result will be compared and

analyzed according to the standard value of pottery for peace (PFP) [32]. But, the result of both physiochemical and microbiological test result will be analyzed according to WHO [40] and Ethiopian drinking water quality standard guide line [41].

The most commonly used raw ground water sample was collected from Gedemssa and Kelbo, which was found around Wonji town, Ethiopia. The raw ground water sample was collected by using pre-sterlized (120°C) one liter plastic bottle and sealed. The water sample was packed in the ice box containing brushed ice 31 which was at 4°C and\

transported to Oromia self-help organization (OSHO) water quality analysis laboratory, which is found in Mojo town, Ethiopia. It is around 25 km far from Nazret (Adama) town and takes thirty minutes on the main road.

Ceramic water filter performance in terms of flow rate can be described by Darcy's Law for flow across a porous material. The analytical model of the discharge through the filter is based on the Darcy's law [47]. This law describes lamina flow through porous media. The flow of water through the any porous materials can be defined by using Darcy's equation (equ.3.8) which was given below.

$$\boldsymbol{Q} = \frac{\boldsymbol{K}}{\boldsymbol{L}} \frac{\mathrm{A}\Delta\mathbf{P}}{\mu} \qquad \text{……..(3.8)}$$

The overall flow rate of the filter Q_{total}, is given by the summation of flow rate of the base of the filter (Q_b) and the flow rate of the side of the filter (Q_S).

The flow rate in turn can be used as a simple proxy to evaluate filter performance in terms of microbial removal. If the flow rate is very high then it is likely that the filter is too porous to provide proper removal of bacteria and if it is too low then it is simply impractical in terms of supplying enough water to a typical household. It is important to realize that flow rate is not necessarily a measure of pathogens removal, but rather an indicator of water flow-through and possible ease with which bacteria-size particles could flow through the filter.

3.6.1 FILTRATION RATE TEST

The flow rates were measured by taking the volume ratio of water measured in the glass beaker to the time taken for which the volumetric measurement was taken [21]. The flow rate was calculated by using the following equation 3.9, which was given below:

$$\text{Flow Rate} = \frac{\text{Volume of water measured (in ml)}}{\text{Time Taken (in hr)}} \quad \text{.....(3.9)}$$

In this experiment, Two types of combustible additives were considered, sawdust and teff husk and filter elements with clay to combustible ratios of 80% clay and 20% combustible CPWF formulation were tested. In order to control the consistency of the test, all testing water was from the same source. The test was carried out in our ceramic laboratory. The flow rate test was conducted using low turbidity tap water in order to eliminate the effects of the particulate clogging the filter pores and approximately measured by measuring the volume of water that dripped out of the each filter elements into their receptacle glass beaker as shown on the Figure 3.14 given below. The ceramic pot water filters first should be wetted or soaked in pure tap water for 24 hours prior to flow rate test to saturate the filters and also to remove any remaining ashes of the combustible material inside the pores of each filter. They were then set up on a flat raised platform. Each filter had a glass beaker placed directly below the filter element as a receptacle to collect the water flowed through each filter element. The time dependence of flow through the filters was then measured by recording the volume of water discharged from the ceramic water filter after each hour. In this section, eighteen pot (frustum) shaped ceramic water filters of six different clay: sawdust composition were tested. Each time, the flow rate and water level are measured for consecutive five hours. After the water in each filter was completely filtered out, the filters were refilled with water and the whole process was repeated. Each filter was filled five times per a single trial test per day. For each trial, water was feed five times for each filter. Each of the three trial tests was carried out over a period of approximately six hours. Due to shortage of time, the filtration test was carried out for only five days for three filtration rate test trial per a day. The filters were primed overnight with tap water to ensure that they would be saturated at the beginning of the test. The average filtration rate test result was calculated for each trial test for each CPWF element. The average mean flow rates of each filter have been

evaluated. By rearranging Darcy's flow rate equation which was given on equation 3.8, The approximate range of permeability (K) of each filters were evaluated by using flow rate result.

The relationships between filter flow rate and the effect of the three CPWF processing parameters (composition, particle size and firing temperature) on filtration rate were also analyzed. The goal was to find out CPWF formulation that would have optimum filtration rate from a series of water flow rate tests. The filter dimension were scaled up to large scale, which will have a capacity of holding seven or eight liter and evaluate whether this scaled up ceramic pot filters are actually providing safe and sufficient water quantity for a given number of family members. The following materials were required to conduct the flow rate test for each filter prototype:

Materials and equipment: - 18 samples of Ceramic filter element, 700ml glass beaker for soaking of filter element, receptacle glass beakers (each 250 milliliter), distilled water, Stopwatch

The following procedure was carried out to complete a flow rate test.

1. Soaking of the CPWF elements for 24 hour and then the Ceramic filter element Assembled with its receptacle glass beakers as shown on the figure 20 given below.

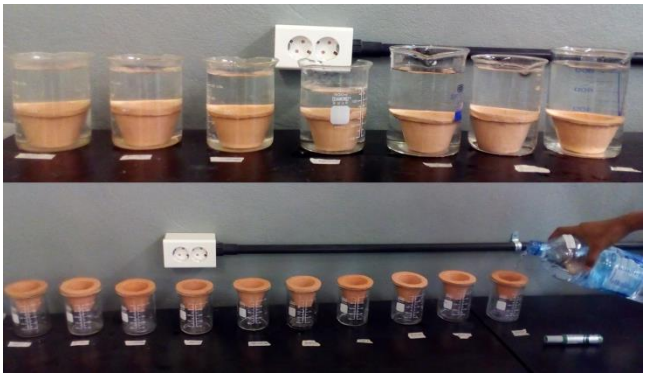


Figure 3. 14: Water soaking of filter elements (top) and pure water filling CPWF assembled on glass beaker receptacles

2. A measuring beaker of 500mL were Used to measure the volume of water received in the volumetric glass beaker. Pour 50mL of water into ceramic filter element.
3. Stop watch was used from starting up to the whole water filtered out. The flow rate was recorded per hour. The recorded flow data was given on the appendix E table E_1.
4. Steps 1-4 were Repeated for each CPWFs.

3.6.2 PHYSIOCHEMICAL REMOVAL EFFICIENCYTEST

Some of the physio-chemical parameters of ground water were analyzed both before and after filtration through seven selected CPWFs (out of eighteen) at the laboratory of Oromia self-help organization (OSHO), which is found in Mojo town, Ethiopia. Which found 25km far from Adama town. Turbidity and Free residual fluoride ion concentration test was analyzed using portable digital Photometer 7100 (wagtech, UK). Similarly, The PH of effluent and fluent ground was analyzed using 704 PH meter (Ω metrohm Germany,2010).Each physiochemical parameter has a unique calibration range which has been generated using reagents tablets. The concentration of the above mentioned physiochemical parameters were evaluated using Photometer 7100 (wagtech, UK) by following the Photometer 7100 operation manual (wagtech, UK). For example, the fluoride ion concentration of the raw or pre filtered ground water was analyzed by preparing and using two fluoride tablets solution , raw ground water and pure distilled water as blank reference solution was analyzed by Photometer 7100 (wagtech, UK) device as shown on the figure 3.15 given below. Similarly, the pH meter was also calibrated just before analysis using two buffer solutions of PH 4.0 and PH 7.0, and it was rinsed with distilled water from one sample to the other following the Ω metrohm 704 pH meter operation manual (Ω- metrohm Germany,2010). The hardness, total dissolved solids and electrical conductivity was analyzed in chemical laboratory of chemical engineering department of Adama science and Technology University. The electrical conductivity was analyzed using portable digital conductivity meter (CC-401, Poland). This instrument was also used to cross check the temperature of the water samples. The water hardness and total dissolved solids (TDS) were tested by titration method.

Figure 3. 15: Analyzing the fluoride concentration in raw ground water by using two kinds of fluorine reagent tablets under Photometer 7100 (wagtech, UK) and its PH value using 704 PH meter (Ω metrohm,Germany).

3.6.3 MICROBIOLOGICAL REMOVAL EFFICIENCY TEST

The microbiological contamination is the most important issue concerning drinking water in Ethiopia. Therefore, microbiological parameters for the drinking water must be tested in order to ensure that the drinking water is free of pathogenic organisms, which causes the waterborne diseases, the leading cause of childhood death in Ethiopia. Two microbial tests were used to determine the performance of the filters in terms of removing microbiological parameters.

With regard to bacteriological parameters, samples were analyzed using membrane filtration (MF) method for water quality to determine the degree of contamination WHO [40] and APHA, [41]. All samples were analyzed for the presence of total coliforms (TC) and faecal coliforms (FC). In addition to this the effects of different processing parameters on total coliform and E. Coli removal efficiency in filtered water were compared by combustible type, size of combustible and firing temperature but not by combustible percentage by mass, .

.The filters were tested for the removal efficiencies of microbiological parameters (total coliform and fecal coliform). Microbial indicators (total coliform and fecal coliform) in influent and effluent water samples were analyzed by 100 mL membrane filtration technique using 0.45µm pore size membrane filters following standard methods [42]. Total coliform was quantified using membrane filtration (MF) techniques followed by incubation at 37°C for a minimum of 14 hours following four hour resuscitation on Membrane Lauryl Sulphate Broth (MLSB) to measure both total coliform and E.coli concentrations in terms of colony forming units (cfu) per 100 mL. For the fecal coliform, the same procedure and materials were used except the incubation temperature, which was at 44°C. In both cases the colony forming unit was counted by the use of low power magnification lenses and reported as colon forming unit (CFU) per 100 ml.

The filtered-water samples were usually diluted one time. Three plates per water sample were thus prepared using the same equipment and materials as for the raw water samples. One plate was used as a blank and the remaining two plates were used for the 1:1 dilution and the 1:10 dilution. The 1:1 dilution plate count was typically used since the resulting microbial concentrations tended to be low (less than 100 cfu/100 mL). The plate with the appropriate number of colony units (i.e.: 20-80 colonies) was used to calculate the final microbial

concentrations. The remaining plates including the blank were used as checks (for example, the 10^{-3} dilution plate should have 10 times as many colonies as the 10^{-4} dilution plate).

Microbial removal efficiency was calculated in terms of percent removal efficiency:

Materials and equipments:-Culture medium, absorbent pad, 0.45µm filter paper, Candle - Lighter,Tweezers,Magnifying glass, and Incubator (Millipore, xx631k230)

Procedure (Millipore, 1992)

1. Sterilization of the portable Millipore MF stainless steel filter holder One must sterilize the filter holder between each water sampling. The procedure is to

- Remove the stainless steel receiver flask from the funnel base assembly
- Soak the ceramic ring around the holder base with one half capful of methanol and subsequently ignite the methanol with a match
- Close the filtering cup over the funnel and the burning ceramic ring
- Leave the filter unit scaled up in place for 15 minutes. Remove cup and rinse funnel thoroughly with approximately 100mL of sterile water.

The steps described above are time consuming when a large number of samples have to be tested. Therefore, to save time, when the author used several dilution of the same water sample, the filter holder was not sterilized. To avoid contamination between dilutions of the same sample, the more dilute (in terms of coliform concentration) sample was filtered followed by the less dilute sample. It is also recommended that a sterile blank be inserted after 10 filtrations of 10 samples to check for potential cross-contaminations.

2. Petri dish label and selective growth medium

- The Petri dish is labelled and absorbent pad is placed aseptically in the dish with the use of sterile tweezers
- The laryl sulphate tryptose broth (Wagtech, England)culture medium pre-packaged in 2mL plastic ampoules is poured into the Petri dish and the excess medium remaining in the Petri dish is decanted

- ❖ When medium is poured, special attention is paid to ensure that every surface of the absorbent pad is uniformly soaked and the excess is poured away, leaving behind about one drop at the bottom

3. Sample volume selection and dilution

   a. The technique for determining maximum sample size to give 20 to 200 colony-forming units (CFU) per filter. The ideal sample volume of non-potable water or wastewater (in our case the raw river water sample) for coliform testing yields 20–80 coliform colonies per filter. Generally, for finished, potable water, the volume to be filtered will be 100 ml.
   b. When possible, 100 mL of the water sample was tested.
      I. However, the high turbidity encountered in many of the samples made it difficult and time consuming to pass 100 mL of the sample through the filtration unit. Therefore, typical sample volumes of the influent (hose) water were 10 mL, 1 mL and 0.1mL.
      II. Typical sample volumes of the effluent (filtered) water were 100 mL, 50 mL and 10 mL, depending on the turbidity, and were measured with a standard sterilized glass graduated cylinder.
   c. In addition, the plate counts of the influent (hose) were often too numerous to count (TNTC). Based on expectations from the experience of previous filtering events (literature result), sample sizes were selected in an attempt to achieve coliform counts within the desired range.

4. Sample pouring and filtration

- ❖ 30mL of boiled, cooled distilled water is then flushed in the assembled filter
- ❖ 0.45µm filter paper are then flushed on the filter to support base using sterile tweezers
- ❖ A total volume of 100mL raw Awash river water sample is poured in the MF setup
- ❖ Filtration is run, pumping water through the filtration unit

5. Funnel rinsing

- ❖ The interior walls of the funnel are rinsed with about 30mL of boiled distilled water three times to avoid carry-over contamination and to ensure even distribution of the sample across the filter paper.

6. Filter removing

- ❖ Filter paper is removed carefully with sterilized tweezers and placed into the labeled Petri dish in a rolling motion to prevent trapping of air bubbles. The air bubbles may prevent the absorbing of media on the top of the filter paper, therefore resulting in the uneven growth of colonies

7. Incubation

- ❖ The Petri dishes are placed in the incubator at 35°C for 24 hours. The Petri dishes are inverted to avoid reading trouble shots due steam formation on the filter
- ❖ After the whole process described above, the petrifilm plates (Petri dishes) were incubated at 35°C ± 1°C for 6 to 24 hours in a horizontal position, to avoid reading trouble shots due steam formation on the filter. The plates were then examined for coliform growth after 24 ± 2 hours of incubation.

7. Colony forming unit (CFU) estimation

- ❖ To be assured of a statistically valid colony count, the number of colonies of TC on plate should be between 20 and 80 CFU for TC, and between 20 and 60 CFU for feacal coliform (FC) or Escherichia coli (EC)

a. The number of CFUs is counted.
   I. Blue CFUs indicate E. coli.
   II. Red and blue CFUs sum to equal total coliforms.

b. The indicator organisms level in water sample are expressed as the number per 100mL

c. The concentration of indicator organisms in the raw awash river water is determined by equation 3.10 which was given below:

$$\text{CFU concentration} = \frac{\text{Number of CFU counted} \times 100}{\text{volume of sample (ml)}} = \frac{CFU}{100ml} \quad \text{.....(3.10)}$$

This process was done once for the raw water(water before filtration) but repeated for each of filtered water samples from each CPWFs were taken.

Microbial removal efficiency is presented in terms of Log Reduction Value and % Removal Efficiency.Log reduction value microbial removal efficiency is calculated by using the following formula given below[14][15]:

$$\text{Log Reduction Value (LRV)} = \log \frac{[\boldsymbol{untreated\ raw\ water}]}{[\boldsymbol{treated\ water}]} \quad \ldots\ldots\ldots\ldots\ldots\ldots(3.11)$$

The removal efficiency can also be calculated by using equation 3.12 which was given below [43]:

$$\text{Removal efficiency} = \frac{(untreated - treated)}{untreated} \times 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3.12)$$

Where,

Untreated: Microbial concentration in the raw water sample (cfu/100 mL)

Treated: Microbial concentration in the filtered water sample (cfu/100 mL)

CHAPTER FOUR

4 RESULT AND DISCUSSION

4.1 PARTICLE SIZE DISTRIBUTION (PSD) ANALYSIS RESULT

After completion of grain size analysis the relative proportion of different size in each sample was determined. The range of the size was especially required for the purpose of soil classification and also to get the relative proportion of clay sized soil in order to determine the plasticity range of the three tested soils. This test is conducted in order to characterize the plasticity nature of each soils. Plastic index was used in classifying fine-grained soils and to the Casagrande plasticity chart. Limits were determined for the soil samples finer than No.200 sieve. Atterberg limit test was conducted in this research for the purpose of obtaining the basic index information and plasticity of the fine grained soils used to identify the soils and to classify them. The Plot of the percent finer versus grain size for both Hydrometer and sieve analysis use arithmetic scale as a vertical axis for percent finer and log scale as horizontal axis for grain size. This curve is called grain size distribution curve. The particle (grain) size distribution (PSD) curve was graphed based on Hydrometer and sieve analysis result of the three soils which was given on appendix A table A_1-A_3.

A. PSD result of Babawuha soil

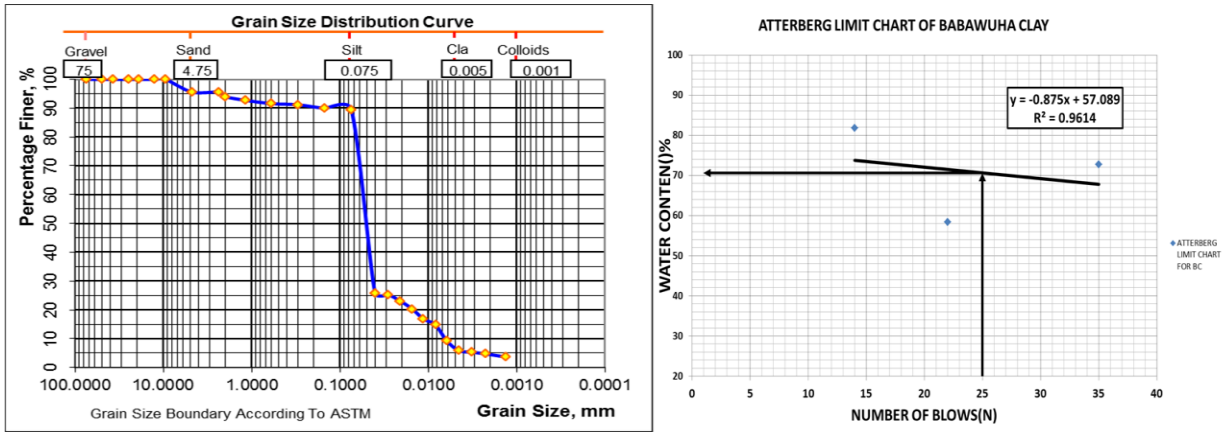


Figure 4. 1: Grain Size Distribution Curve (left) and liquid limit value (right) of Bambowuha clay

From Grain Size Distribution Curve:

% Gravel= 5% D_{10}= 0.007 mm

% Sand= 5% D_{30}= 0.06 mm

% silt+ clay = 90% D_{60}= . 0.003 mm

Where D_{60} stands for 60% of the raw Bombowuha soil has a particle size which is finer than particle size diameter of 0.03mm. That means out 60%

The coefficient of uniformity, Cu, and coefficient of curvature, Cc, were calculated for the clay.

$Cu=\frac{D60}{D10}$ = 1.33, $Cc=\frac{(D30)^2}{D60 \times D10}$=5.643

Table 4. 1: The liquid limit,plastic limit and plastic index of Bambowuha

Liquid Limit (LL or w_L) (%):	**58**
Plastic Limit (PL or w_P) (%):	**25**
Plasticity Index (PI) (%):	**32**

B. PSD result of Hossan soil

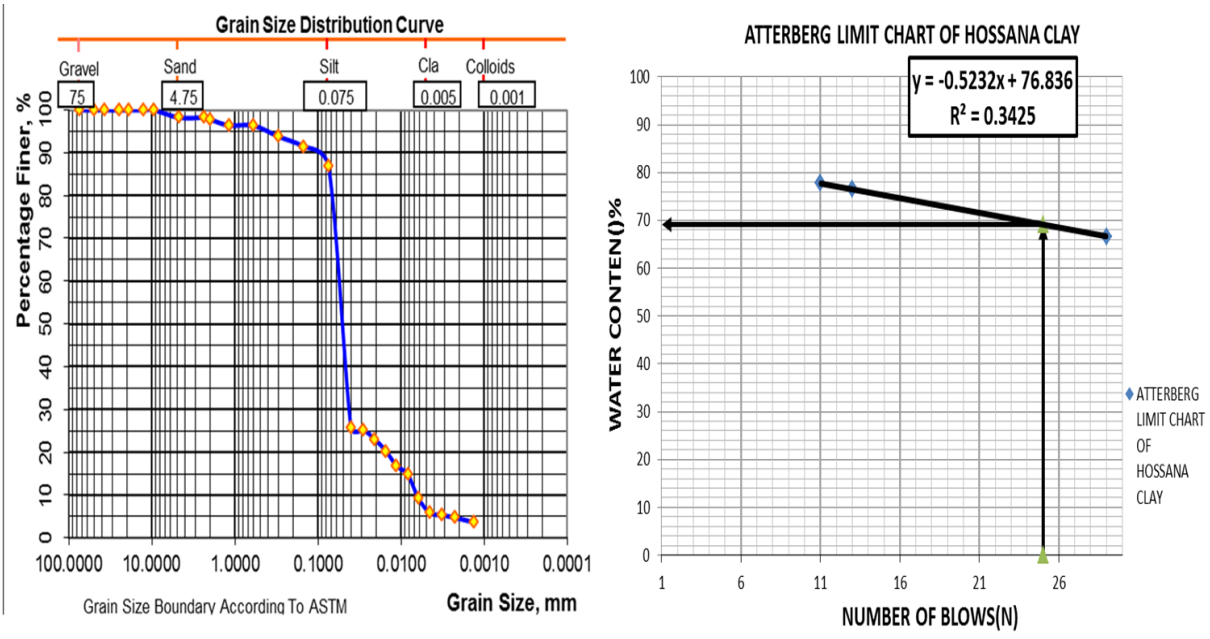


Figure 4. 2: Grain Size Distribution Curve (left) and liquid limit value (right) of Hossana clay

From Grain Size Distribution Curve:

% Gravel= 2.2% D_{10}= 0.007 mm

% Sand= 10.4 D_{30}= 0.04 mm

% Fines = 87.4% D_{60}= .0.05 mm

The coefficient of uniformity, Cu, and coefficient of curvature, Cc, were calculated for the clay.

$$Cu=\frac{D60}{D10}=10, \qquad Cc=\frac{(D30)^2}{D60\times D10}=3.26$$

Table 4. 2: The liquid limit, plastic limit and plastic index of Hossana clay

Liquid Limit (LL or w_L) (%):	**45**
Plastic Limit (PL or w_P) (%):	**20**
Plasticity Index (PI) (%):	**21**

C. PSD result of Leku clay

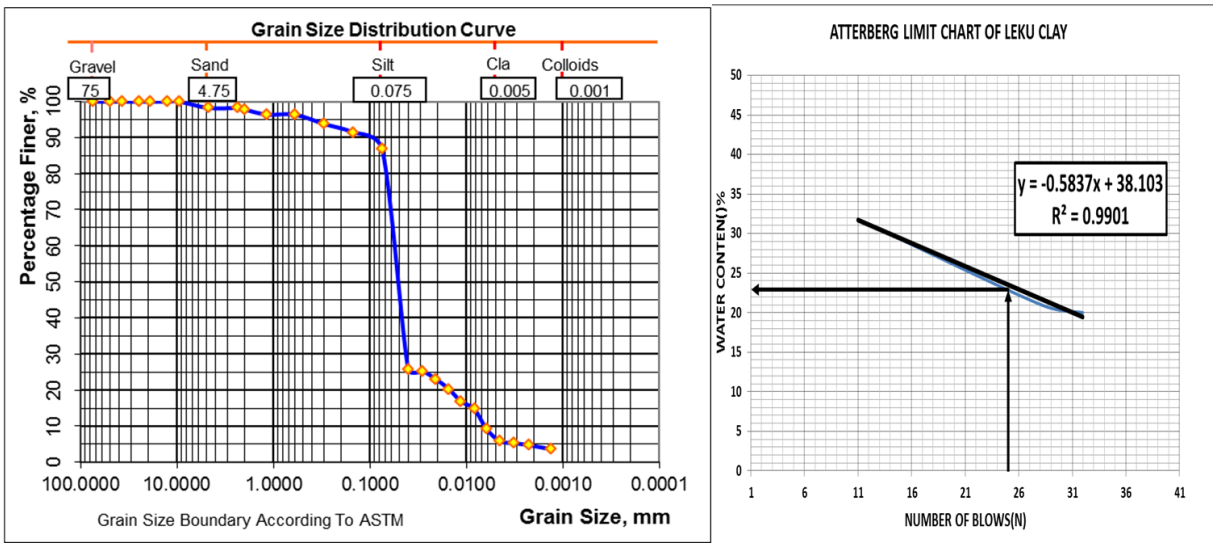


Figure 4. 3: Grain Size Distribution Curve (left) and liquid limit value (right) of Leku soil

From Grain Size Distribution Curve:

% Gravel= 4% D_{10}= 0.005 mm

% Sand= 38% D_{30}= 0.06 mm

% silt + clay = 58% D_{60}= .0.07 mm

The coefficient of uniformity, Cu, and coefficient of curvature, Cc, were calculated for the clay.

$Cu=\frac{D60}{D10}$ = 8, $Cc=\frac{(D30)^2}{D60 \times D10}$=2.4

Table 4. 3: The liquid limit, plastic limit and plastic index of Leku soil

Liquid Limit (LL or w_L) (%):	**23**
Plastic Limit (PL or w_P) (%):	**29**
Plasticity Index (PI) (%):	**-6**

The particle-size distribution by sieve and hydrometer analysis displayed a range of sizes from sand to clay sizes, as shown above given graphical curve results. The primary function of precision particle analysis is to obtain quantitative data about the size and distribution of particles in the raw soil sample. The sieve analysis when performed assists in ensuring that the samples have the required particle sizes needed for the production of ceramic water filters or mouldablity of filter body mixtures (i.e clay to combustible mixture). As for soils without a granular bearing skeleton, the least desirable are the silts that change from a semisolid to liquid state at a small increase in moisture content. The greater the clay content and its water affinity of a soil, the smaller the change of its consistency with an increase in water content. Fine clay has a diameter of particle size <0.002 mm. according to this D_{60}= 0.003 mm for Bombowuha soil (fine clay range), D_{60}= 0.005 mm for Hossana soil (coarse clay range), and D_{60}= 0.07 mm for leku soil (coarse sand range). Bombowuha sample soil has the highest percentage (69% clay) of fine particles than the other soil samples. Hossana sample soil has relatively similar (around 61 % clay) to Bombowuha sample soil particle size. Leku soil has the highest percentage of coarse particles and has the least fine clay content (30% clay). This can be observed clearly on figure 4.5 which was given below. Bombowuha and Hossana sample soil found to be the best for muoldablity (binding) purpose because of their highest percentage of fine particles, which accounts for good strength. By visible inspection, most of these particles were larger than 2mm and could thus be categorized as gravel based on the Wentworth scale. The average amount of gravel in the samples from each site is reported in the figure 4.5 given below (second bar graph).

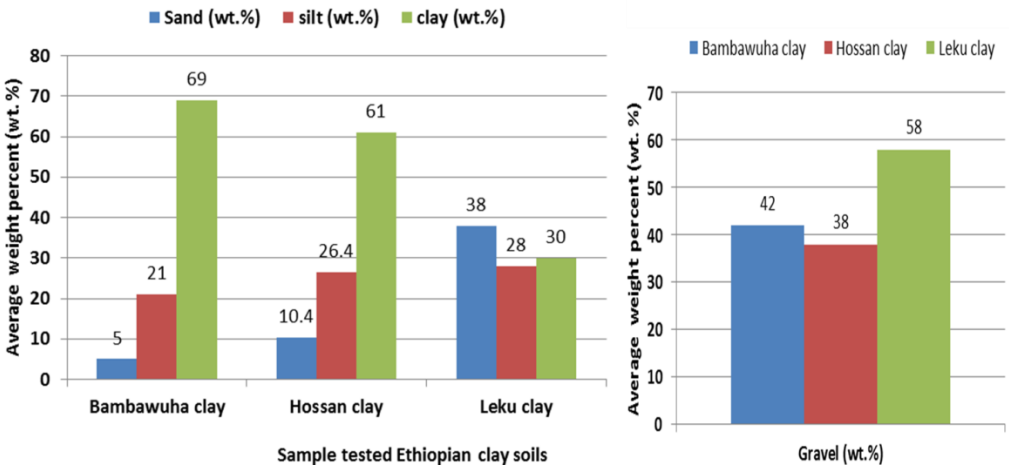


Figure 4. 4: Particle size distribution summary (average percentage by weight) (left) and the average weight percentage of gravel in each kind three tested soils

The results show that the physical properties of the clays are within the specifications for kaolin clays and are suitable for the production of ceramic pot water filter.

Plasticity of the clay bodies is of great importance in the shaping of ceramic materials [58].when the combustible content in the filter formulation increased, the plasticity of the clay to combustible mixture decreased. This was observed during bar and CPWF preparation. Plasticity is an important parameter for the production of ceramic material. Because, during forming stage of every ceramic fabrication the insufficient plasticity creates failures and heterogeneities in the clay body this causes lower mechanical properties [59].The plasticity has an important technological application, since it indicates the minimum percentage of moisture content necessary to reach a plastic condition [60]. With high plasticity, there will be more difficulty in drying the samples and causing the appearance of dimension problem or even cracks.

Clay with higher plasticity, described by the plasticity index (PI) may be useful for filters production [28]. Ideally, clay for a filter would hold together with lower water content, represented by a lower plastic limit, and not slump once pressed due to high water content, represented by higher liquid limit. A high liquid limit is especially useful when attempting to improve the flow rate by increasing the percentage of combustible, because the amount of water added to the mixture must also increase with more combustible. The high amount of combustible requires large amounts of water added, so this made it difficult for the filters to

keep their shape during forming stage of filter fabrication. Plasticity and Liquid limit of the three soil sample was determined three times. it was concluded that the Bambawuha and Hossana soils can be characterized as fine grained clay soil. The specific gravity of Bambawuha and Hossana kaolin clays were 2.56 and 2.45, liquid limit 58% and 45%, plastic limit 25% and 20%, plastic index 32% and 21%.These data enable for classification of Bombowuha and Hossana sample soil by using Casagrande chart.

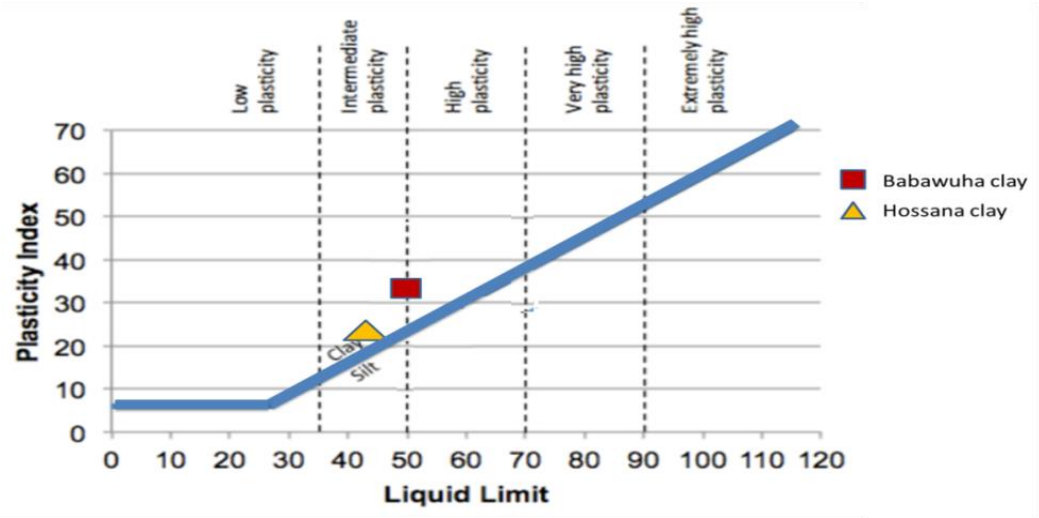


Figure 4. 5: Casagrande Plasticity chart for determination of plastic behavior and classification of sample

The plasticity chart on the figure 4.4 given above, anything above the line is classified as clay and anything below it is classified as silt. Bambowuha and Hossana soils can be classified as clays using the above standard plasticity chart. The result on standard plasticity chart revealed that the Bambawuha soil was found to be more plastic due to its higher clay content with finer average particle size. The particle size distribution analyses indicate that the difference in clay content between samples from Bambawuha and Hosanna is statistically significant, and also that the amount of gravel is a positive indicator of the percentage of clay in the fine portion of that sample.

According to the diagram, plasticity of sample is intermediate (liquid limit between 35 and 50). A-line separates inorganic clay from inorganic silt and organic soil [57]. Consistency limits of Bombowuha and Hossana sample soil correspond to an intermediate plasticity to high degree plasticity medium. Leku soil with low liquid limit and plasticity index,

which could be classified as inorganic clay(mainly quartz with coarse sand grain size range). Soil like Leku cannot be described by using plasticity chart because of its negative value of its plastic index. Bombowuha with high liquid limit and high plasticity inorganic clay (mainly fine kaolinite clay) according to the Unified Soil Classification System [30].

The highest plasticity index (PI) of Bombowuha soil described by the Unified Soil Classification System, ASTM Standard D2487 – 10, is 32 whereas the Leku soil has a PI of -6. Bombowuha and Hossana clay samples have the optimum molding properties, while the leku clays don't have sufficient molding properties. According to the clay workability chart of Bain and Highly, The Bombowuha and Hossana soil samples could be used for filter production [57]. From diffraction result Bombowuha and Hossana soil was found to be kaolin clay soil. The results show that the kaolin belongs to intermediate and upper range degree of plasticity; accordingly it should work satisfactorily in the production of CPWFs. If other clay sources are proven to have a higher plasticity index, they will likely be preferable for filter production than Bombowuha and Hossana clay that currently being used for this project purpose. The plasticity index is the range of water contents over which the clay exhibits plastic behavior and it is calculated by subtracting the plastic limit from the liquid limit. These results reveal that the Bambawuha clay is the most plastic of the three soils analyzed, as indicated by its plasticity index and liquid limit result. Hosanna soil categorized as an intermediate plastic clay soil but the negative plastic index (PI= -6) result of leku soil tell us its non-plastic nature of this kind of soil.

The plastic property of the kaolin, as determined by the Atterberg limit Method, was reported to be of intermediate and high degree of plasticity nature, this also sufficient for ceramic water filter production. It was concluded that the kaolin belongs to intermediate and upper range of plasticity, accordingly it should work satisfactorily in the production of CPWFs. However, the shrinkage problem was solved by blending of the two kinds of kaolin clay. The experimental detail result of sieve analysis, hydrometer analysis and Atterberg limit results of each kinds of soil was given in appendix-A table A_1 to A_3.

4.2 OPTIMUM FILTER PROCESSING PARAMETERSRESULT

4.2.1 WATER OF PLASTICITY TEST RESULT

From the literature, for most of clay soil minerals water of plasticity ranges between 20 to 30% [44]. The water of plasticity is increased when the amount of the combustible materials incorporated in the test bar formulation increased. But the plasticity (workablity) nature of the clay used decreased and this leads to the weaker green body consistency of the test bars during forming stage. The average water of plasticity for the test bar samples ranges from 54 to107 % which is very high and unexpected one. This mainly due to incorporation of higher proportion of the combustible in test bar formulation in order to maintain test bars workability. Some test bars showed water of plasticity practically meaningless, thus includes test bars formulated by 50B/50S and 15H/30B/15L/40S showed there water of plasticity was 101 and 107 % (given on the average test bar water of plasticity table A_1 of appendix A).Bars made from Bombowuha kaolin clay has higher water of plasticity than the same composition bars made from Hossana (Belessa) kaolin clay which was observed from comparison of water of plasticity result of three trial each test bars with bar formulation of 50H/50S and 50B/50S and the other one was test bars with bar formulation of 25H/45B/30S and 25H/45L/30S. This mainly due to the relative finer particle size of Bombowuha kaolin clay enables higher water adsorption capacity than Hossana (Belessa) kaolin clay. Most bars which has been made up of with higher leku clay, which was found to be refractory clay with highest silica content (described in detail in section 3 of raw material characterization part), showed lower water of plasticity than bars with same formulation of Hossana (Belessa) and Bambawha kaolin clay. This was mainly due its coarser particles grain size with lower surface energy for interaction to the water molecules, so that its water of plasticity becomes much lower.

The water of plasticity and linear dry shrinkage were expected to have a direct relation according to many earthen ware and white ware ceramic processing literature. The result of tested bars also agreed to the literature, this can be observed on figure 4.6 given below.

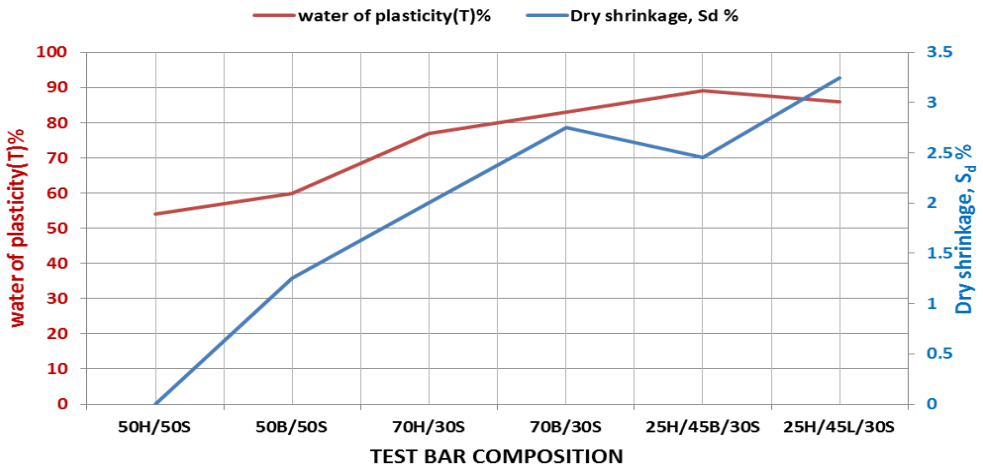


Figure 4. 6: Dry shrinkage and water of plasticity of different composition of test bars

According to literature, the recommended water plasticity range for ceramic water filter production was from 20 to 30 % .this was much lower than water plasticity of all tested bars.it can be said that the plasticity of the clay decreased with increasing percentage of sawdust in the mixture. The application of sawdust to the clay makes the sawdust get clung around its clay minerals and absorbs water from them - thereby reducing their moisture holding capacity and their ability to freely interact with themselves and become aggregated together. Consequently, the plasticity of the clay decreases as its sawdust content increases. In the case our investigation, this mainly due to the moderate plasticity nature kaolinite clay (i.e Hossana (Belessa) and Bombowuha kaolinitic clay) and increase in combustible materials proposition in the bar formulation. This forced to use higher amount of water to maintain the bars workability due to moderate plasticity nature the clay used, caused fragility during plastic bar forming stage.

Therefore, In order to get easier workability and maintain the green body consistency, the test bars with higher Bombowuha and Hosiana (Belessa) kaolinitic clay formulation was selected for ceramic pot water filter (CPWF) production. In order to get waters of plasticity on the literature recommended range for ceramic water filter fabrication process, the amount of clay has to be higher than 70 wt% and the amount of saw dust or any combustible material has to be lower than 30wt%.

4.2.2 SHRINKAGE TEST RESULT

The Linear Drying and Fired Shrinkages of the three randomly selected clays were tested [33]. Due to the smaller size of our furnace the test bar samples were made smaller in size In order to accommodate enough test bar samples within a single batch firing process, this leads to a challenge to identify the linear shrinkage. As a result, some of the test bars showed all most negligible linear shrinkage difference. This was clearly evidenced by most test bar specially test bar 50H/50S showed zero linear shrinkage but not the reality because there has to be change dimension due dehydration.

The Average Values of Linear Drying and Fired Shrinkages of Selected Clays are presented in Tables 4.4 .An average linear shrinkage value of 10% or more, qualifies a clay as suitable for the manufacture of earthenware, sanitaryware, white and coloured tile, and also for electrical insulator. The drying shrinkage indicates to some degree the plasticity of the mixture. A large drying shrinkage means that test bars formulation mixture could absorb much water, which in turn indicates the finer mixture particles size. The firing shrinkage indicates how fusible the mixture is. The total shrinkage of test bar sample bodies tells how much bigger we should have to make our moulds.

From Table 14, the average linear drying shrinkage of clay sample bars which are fired at 800ºC and 900 ºC varies from 0 % to 3.75 % and from 1.5 % to 3.5% respectively, while the average fired shrinkage varies from 0.5 % to 3.89% and from 1.6% to 3.8 % for test bars which were fired at 800ºC and 900ºC respectively. The recommended total shrinkage range of ceramic water filter was less than 15% [15]. Even though, almost all the sample tested bars have suitable shrinkage value for ceramic water filter production due to their total shrinkage values fall within acceptable limits for ceramic water filter production, but some of the test bars were mechanically very weak ,which makes such test bars un suitable for filter production. This was mainly due to the lower of firing temperature.

Table 4. 4: Average percentage Values of Linear, dry and fired Shrinkages of test bar samples fired at 800ºC

Sample test bar code	Dry shrinkage, S_d %	Fired shrinkage, S_f %	Total shrinkage, S_T %
50H/50S	0	0.5	0.5
60B/40S	1.25	0.50633	1.75
50L/50S	1.25	3.8	5
25H/45B/30S	1.25	3.75	5.75
25B/35L/40S	3.25	5.68475	8.75
25H/45L/30S	2.5	2,75	4.75
17H/17B/17L/49S	3.75	3.8961	7.5
15H/30B/15L/40S	2.5	2.5641	5

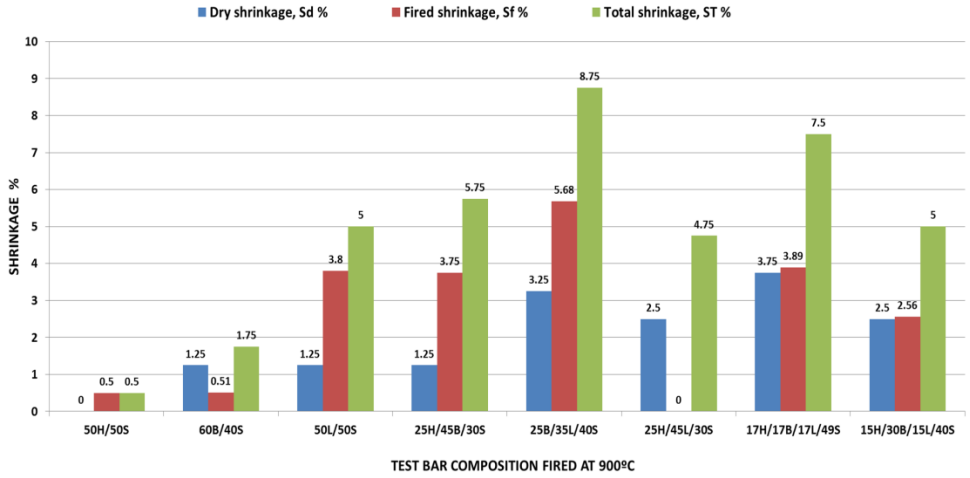


Figure 4. 7: The effect of composition variation on a test bars fired at 800ºC.

Table 4. 5: Average percentage Values of Linear, dry and fired Shrinkages of test bar samples fired at 900ºC

Sample test bar code	Dry shrinkage, S_d %	Fired shrinkage, S_f %	Total shrinkage, S_T %
70H/30S	2	3.1	5
70B/30S	1.75	2	3.75
70B/30S	1.25	2.5	3.75
50L/50S	1.25	3.8	5
60L/40S	3.5	1.6	5
70L/30S	2	1.8	3.75
25H/45B/30S	1.25	4.5	6.5
25H/45L/30S	3.25	3.3	5.5

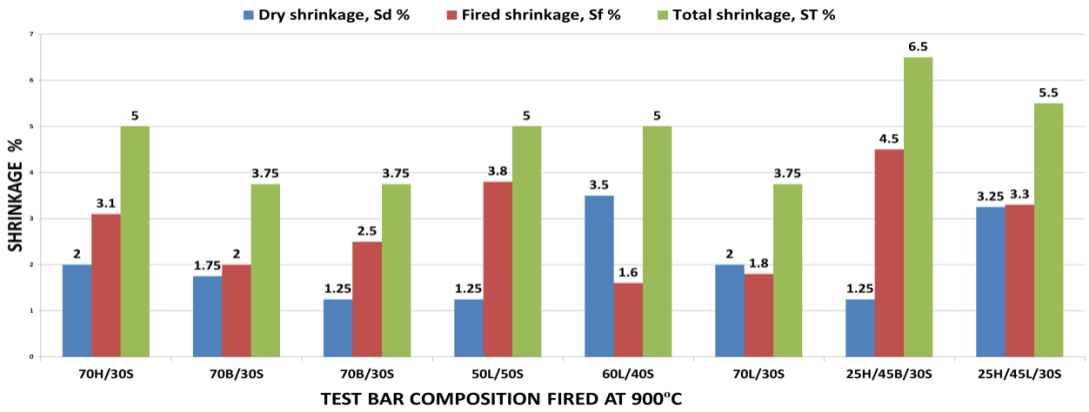


Figure 4. 8: Shows the effect variation of test bar composition and firing temperature on the average percentage of linear, dry and total shrinkage test bar samples fired at 900ºC.

From figure 4.8, A highly linear relation occurred between volume shrinkage and percentage of combustible composition of the bar formulation. The percentage firing and total shrinkage of the test bar samples generally increases as percentage composition of the combustible composition (sawdust) of the bar formulation increased for both firing temperature(i.e 800ºC and 900ºC).this can be confirmed by 60H/40S to 70H/30S and 50L/50S to 70L/30S test bars fired at 900ºC and But, The percentage total shrinkage of the test bar samples generally decreases as percentage composition of test bars with high amount of Bambawha and hossanna kaolin clay was increased except test bars formulation made from leku clay. The total shrinkage varies from 0.5 % to 8.75 % and 3.75 % to 5 % for the bar samples fired at 800ºC and 900 ºC respectively. It was evident from the above two stacked bar graphs that the test bars composed of leku refractory clay generally has lower firing and total shrinkage values and high both apparent porosity and water adsorption at both firing temperature . This is because of the high quartz component of Leku refractory clay inhibits shrinkage and the reason could be attributed to the vitrification level and the subsequent formation of strengthened network microstructure formation, which helped to resist further contraction.

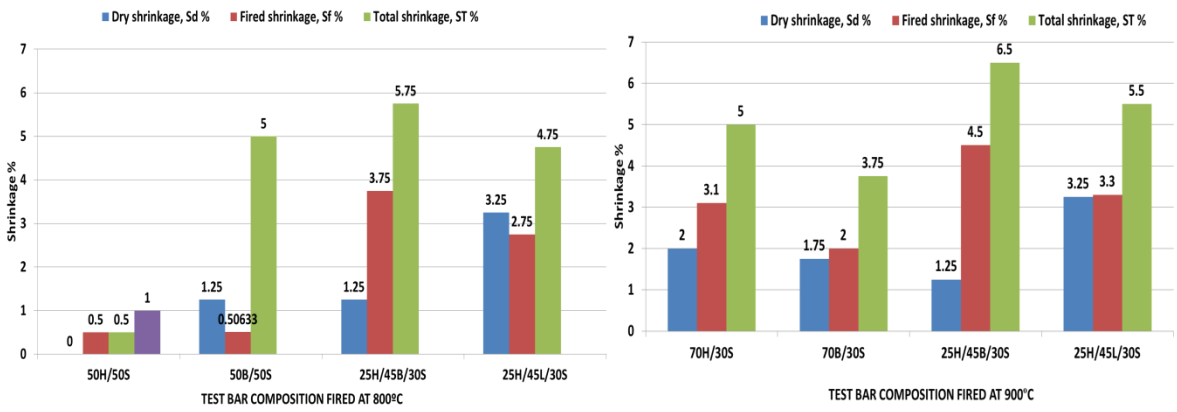


Figure 4. 9: The effect variation of firing temperature and bar composition on linear (dry) and firing shrinkage of test bars

Test bars with higher weight percentage of combustible material (i.e sawdust) and Leku clay showed lower mechanical integrity. This was mainly due to their coarser particle grain size, lower plasticity nature of the clay used and the lower firing temperature. Some of them completely failed at all during experimentation, this was observed on the test bars25H/25B/50S, 25B/25L/50S,25H/25L/50S, 50L/50S and 50H/50S. Most of the test bars which were fired at 800ºC have lower mechanical integrity due to the moderate plasticity nature of Bombowuha and Hosiana (Belessa) kaolinitic clay and even much lower plasticity nature of leku refractory clay, the coarser particles grain size and the lower firing temperature. The immiscibility (non-blending nature) of the three clay soil with higher weight percentage of combustible material caused also lower mechanical strength and leading to a complete failure which was observed on the test bars formulation of 17H/17B/17L/49S and 15H/30B/15L/40S.

Shrinkage is an indicator of the firing efficiency of the clay samples. The recommended total shrinkage value was less than 15% [14] [15] were more desirable in order that the clay will be less susceptible to volume change. Even though, almost all the tested bars satisfied this condition, but mechanically weak and failed. However, test bars which were composed of higher weight percentage of Bombowuha and Hosiana (Belessa) kaolinitic clay showed good mechanical strength and total shrinkage falls within the recommended value range is selected for ceramic water filter construction. The recommended linear shrinkage range was 7 -10% for clays used for the fabrication of ceramic water filter [15]; therefore, from linear and firing

shrinkage result Bombowuha and Hosiana (Belessa) kaolinitic clay classified on this range also. Thus test bars includes: 70H/30S, 70B/30S, and 25H/45B/30S were selected for CWF construction.

The average water absorption and apparent porosity determined by boiling for 2 hours and submersion of the test bars in water for 24 hours must be in the range between 30% to 44% [15]. In this study water absorption for some of the samples produced at 1000ºC met the criteria specified by the pottery for peace [32].Water absorption results of samples with varying composition are listed in table B_1 (see appendix B). Figure 4.10 presents the result of water absorption, apparent porosity and total shrinkage of the test bars fired at 800ºC and 900ºCwith various compositions (bar formulation).

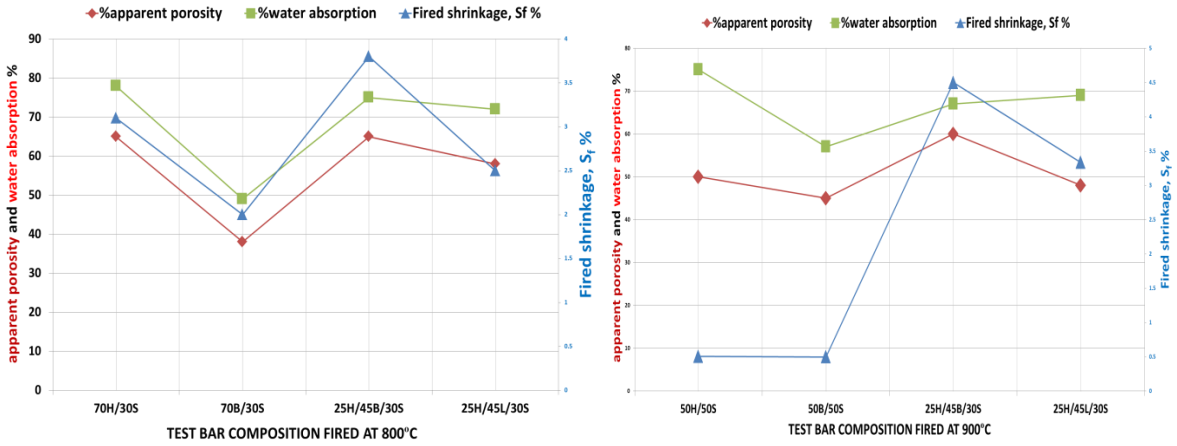


Figure 4. 10: The effect of firing temperature and bar composition on firing shrinkage, apparent porosity and water absorption

The average water absorption percentage of the test bars was governed by the particles size and amount and type of both the combustible materials and the clay used for bar preparation and the firing temperature. Since, water absorption percentage is an indicator of test bars density (which also responsible for the test bars mechanical strength) and which intern indicates the degree of vitrification of fired test bars body, which were evaluated from the relative weight difference of test bars saturated in boiled water and its fired weight according to the formula given on section 3.3.

There are a number of factors that are known to affect the porosity of tested bars include the clay composition, particle size and ramming (manual or hand consolidation / forming)

pressure, and the reaction occurring on firing. The apparent porosity is a measure of the effective open pores spaces in a tested bar samples. But, Water absorption percentage is a measure of maturity of fired clay test bars body. The recommended values ranges for apparent porosity of ceramic water filter is 30-44%. The apparent porosity level in some test bars meets these observations. The result obtained in this study (Fig.4.10) show that most of the samples have high percentage porosity because of combustible materials in their composition which usually burn off on firing. Manual ramming method used in this investigation which reduces densification also contributes to high porosity recorded. The presence of pores in clay affects the strength by reducing the cross-sectional area expose to an applied load. This also the other responsible factor for the failed test bars that already mentioned on the above section.

Figure 4.10 depicts the water absorption and apparent porosity of the test bars, which ranged from 49to 78% and 38 to 65% for test bars fired at 800ºC, and 57 to 75% and 45-60% for test bars fired at 900ºC ,respectively. An in-depth assessment of the test result, the water absorption and apparent porosity decreased with the increase in the sintering temperature, as a result of the vitrification and densification processes that occur during sintering. The least apparent porosity of 70B/300S test bar formulation is attributable to its high grain fineness number (smaller particles) couple with a relatively low loss-on-ignition (LOI) clay which implies that it consists of the lowest amount of combustible materials.

Water absorption is generally dependent up on the apparent porosity, which in turn is controlled by firing temperature. As expected (based on the information from previous literature sources found the least water absorption and apparent porosity values were observed for the test bars fired at the highier temperature. Comparing the water absorption and apparent porosity for the two firing temperatures, the results are broadly linear (see Figure 4.10), in which water absorption and apparent porosity decrease from 75 to 67% and 65 to 60% for the test bar of 25H/45B/30Sas the temperature increases from 800°C to 900°C.similar phenomena also observed for test bar of25H/45L/30S.

The graph depicted by figure 4.10 was the result for water absorption, apparent porosity and total shrinkage with variation of bar composition and firing temperature. Averagely Bombowuha and Hosiana (Belessa) kaolinitic clay based test bars absorbed more water than

leku refractory clay based test bar composition. This was due to the less plastic nature of the composition of leku refractory clay as compared to Bombowuha and Hosiana (Belessa) kaolinitic clay based test bars,by virtue of that more water was probably needed to bind the Bombowuha and Hosiana (Belessa) kaolinitic clay based test bars together. As porosity increased the rate of water absorption also increased. As temperature increased, percentage water absorption decreased.This was goes to buttress the argument that the increasing of temperature leads to shrinkage of pores, which subsequently leads to the disappearing of many pores, the result of this was less water absorbed by the samples. The lesser the plasticity of the clay material used In the bar formulation, lowered its total shrinkage.

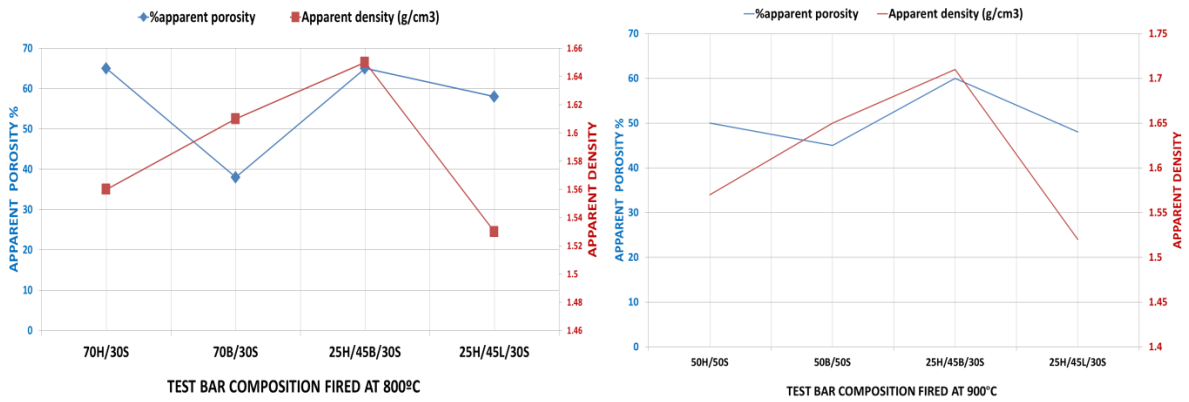


Figure 4. 11: The effect of apparent porosity on the Bulk density as function of test bar composition.

The graph depicted by fig. 4.11 was the effect of apparent porosity on the Bulk density as function of test bar composition. It was observed there was an inverse relation between mechanical strength and apparent porosity. As the temperature of test bars increases, densification occurs. This implies reduction in pore sizes and also percentage of pores; increase in cohesive forces between inter-particles and also intra-particles of the test bar compositions are expected. The absorption of water is mainly through the pores and reduction in pore size apparently corresponds to decrease in water of absorption. This is demonstrated in Figure 4.10 and 4.11. As the firing temperature rises, test bars generally undergo de-hydroxylation and therefore bulk density increases. From the figure 4.11 test bar formulation 25H/45B/30S had the highest Bulk density of 1.71 g/cm3 and 25H/45L/30S had the lowest g/cm3 as compared to other test bars fired at the two temperature.

For mechanical strength within tolerable limits for CPWF fabrication, the combustible proportion in the filter mixture formulation must be between 10% to 30%.

The optimum ceramic water filter fabrication processing parameter range was investigated. Test bars were made from batch mixes of kaolinite clay with intermediate plasticity nature and high combustible material (i.e saw dust) in varying test bar formulation. The physico-mechanical properties considered for different test bars are water of plasticity, shrinkage (i.e drying, firng and total shrinkage), apparent porosity, water of absorption, and bulk density at firing temperatures of 800ºC and 900ºC. The following conclusions can be drawn based on the results obtained from this investigation: Apparent porosity and water of absorption reduced while the mechanical strength (by physical inspection) and the bulk densities increased at higher firing temperature. 70-80% of kaolinite clay and 10-30% of Combustible materials were selected as a formulation range for the proceedings CPWF preparation part of this paper. This was a comparative approach of some important sample test bar properties compared to each other in order to get the best combination of properties of the samples in order to meet standards in CPWF product fabrication. The test bar formulation, which was 70-80% of kaolinite clay and 20 - 30% of Combustible materials, gave the best combination of properties such as optimum apparent porosity, good mechanical strength and total shrinkage. Therefore, from those bar formulation discussed in the above section, test bars with bar formulation of 70H/30S, 70B/30S, 80H/20S, 80B/20S, 25H/45B/30S And 25H/55B/20S was selected for CPWF preparation.

Other test bar formulations were also within tolerable limits of apparent porosity (30-44%),total shrinkage (<15%)and with good mechanical strength would be employed with slight processing parameter adjustment for CPWF fabrication process. This was supported by results in the literature which employed firing temperatures within 900 ºC -1000ºC range for better performance ceramic water filter fabrication.

Therefore, from this investigation it is possible to produce CPWF with apparent porosities higher than 30% and lower than 44%, by increasing the firing temperature 900ºC to 1000,by lowering the particle size of both the clay and combustible materials in to 300 to 600µm and 600 to 1200 µm respectively. Thus, the correct choice of raw materials mixing proportion, particle size and firing temperature are very important processing parameter to produce

CPWF with in an acceptable and optimum filter performance range (i.e with optimum microbial removal efficiency and filtration rate).

4.3 CHARACTERIZATION RESULTS AND DISCUSSION

4.3.1 XRD ANALYSIS RESULT BOMBOWUHA

X-ray diffraction scans for the raw Bombowuha and Hosiana(Belessa) clays were illustrated in Figure 33 and 34 which was given below respectively. The X-ray scan for the raw Bombowuha clay shows that the mineral is predominantly composed of kaolinite with some muscovite and halloysite while the raw Hosiana clay is mainly composed of quartz with some kaolinite and microcline.

The Bombowuha clay is contains three major minerals, kaolinite with a chemical formula of $Al_2(Si_2O_5)(OH)_4$ (ICDD 01-079-1570) and quartz- SiO_2(ICDD 00-046-1045). Other minerals such as microcline(orthoclase or k-feldspar) $KAlSi_3O_8$(ICDD 01-084-0709) and muscovite(sub group of mica) $KAl_2(AlSi_3O_{10})$-$(OH)_2$ (ICDD 00-040-0020) were detected. The clay contained less than 3 wt% fluxing agent mineral components (K_2O, Na_2O and CaO). Figure 4.12 which was give below represents the XRD patterns of Bombowuha clays.

The mineralogical composition of Bombowuha clayrevealed that kaolinite as adominant mineral. The deposits also showed traces quantities of illite/muscovite, feldspar and quartz as a common characteristics. The Bombowoha clay typically contains Gibbsite and Halloysite as Other secondary minerals phases (minor constituents). The XRD result curve for Bombowoha clay shows a distinctive peaks of kaolinite. Kaoline minerals classified under Phyllosilicate Structural Groups having 1:1 Layered Silicates with Dioctahedral sheet. From the result Bambawuha clay contain kaolinite mineral in the form of four different polymorphs. The classification of Kaolin minerals type based on Structural Varieties classified in to Halloysite ,Kaolinite, Dickite, Nacrite. Thus are Kaolinite-1A(ICDD reference pattern: 00-058-2030 and 00-058-2030),Dickite-2M1(ICDD reference pattern: 00-058-2002),Nacrite-1Md(ICDD reference pattern: 00-029-1488),and Halloysite-1and Halloysite-7(ICDD reference pattern: 00-058-2006 and 00-029-1487 respectively).

Based on the results, quartz SiO_2 (ICDD 00-046-1045), potassium aluminum silicate $KAl_3Si_3O_{11}$ (ICDD 00-046-0741),orthoclase $KAlSi_3O_8$ (ICDD 01-075-1592), and

mullite,($Al_{1.272}$ Si $_{0.728}$ O $_{4.864}$) (ICDD 01-083-1881) were detected. The nature of the impurities was determined by studying the crude samples (Figure 33); quartz is the dominant impurity (101 reflection at 3.34 Å), the bulk Bombowuha Clay sample with a small amount of feldspar. This Clay sample contains quartz and calcite ($CaCO_3$) (reflection at 3.03 Å).

Table 4. 6: The quantitative Phase Identified from the result of X-ray diffraction pattern analysis for bulk Bombowuha clay soil sample

Phase Identified	In Weight %
Kaolinite[$Al_2Si_2O_5(OH_4$]	65
Gibbsite/ Halloysite [$KAl_2(AlSi_3)O_{10}(OH)2$]	5
Quartz[SiO_2]	22
Orthoclase (k-feldspar)([$KAlSi_3O_8$)]	2.5
Plagioclase(ca/Na- feldspar)	2.5
Other impurities phases	< 3

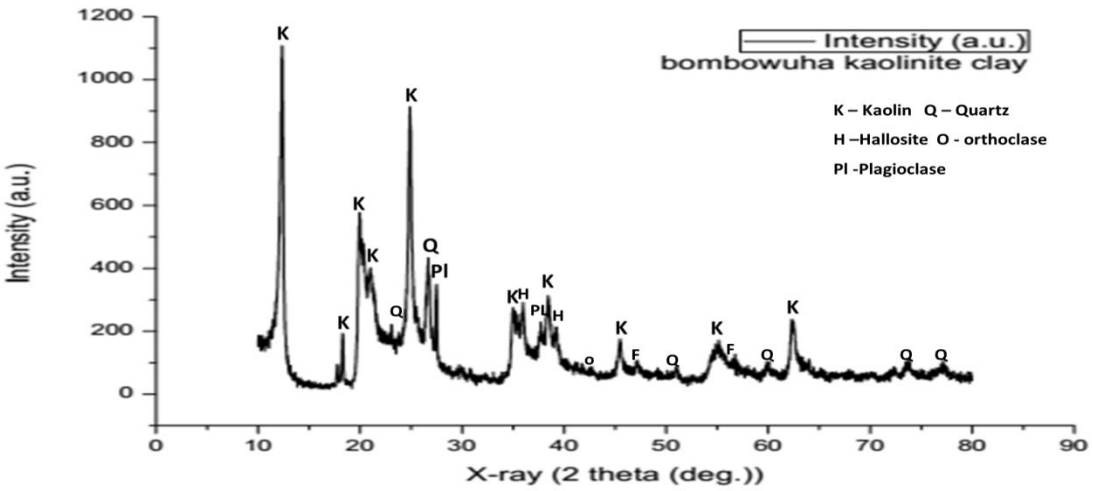


Figure 4. 12: X-ray diffraction pattern of bulk Bombowuha clay soil

The XRD analysis revealed that, the clay showed strong peaks of a sodium aluminum silicate compound known as Albite (plagioclase albite), which is a common feldspar and has the chemical formula of $NaAlSi_3O_8$.

4.3.2 XRD CHARACTERIZATION RESULT OF HOSSANA CLAY

In this section, the qualitative and quantitative mineralogical determination performed for the bulk Hossana Clay three soil samples will be examined. The XRD results (qualitative and quantitative) of samples collected from Hossana (Belessa) Clay deposits are given in table 4.7 and figure 4.13.These results showed clear resemblances and differences. Qualitative measurements by XRD revealed that kaolinite is the only clay mineral which occurs in the ores. As a component of "universal impurity", quartz is also found associated with the kaolinites in all kaolin samples (except in pure standard kaolinite clay powder). The mineralogical result showing the presence of quartz is also supported by the slightly higher ratio of SiO_2/Al_2O_3 (>1.2) which indicates the presence of other silicate phases beside the kaolinite. The amount of these minerals varies from slightly kaolinized to completely kaolinized samples. Thus, kaolinite and quartz value show a ranges of (53.2 – 100 %) and (0- 46.8 %) respectively (Fig. 4.13).

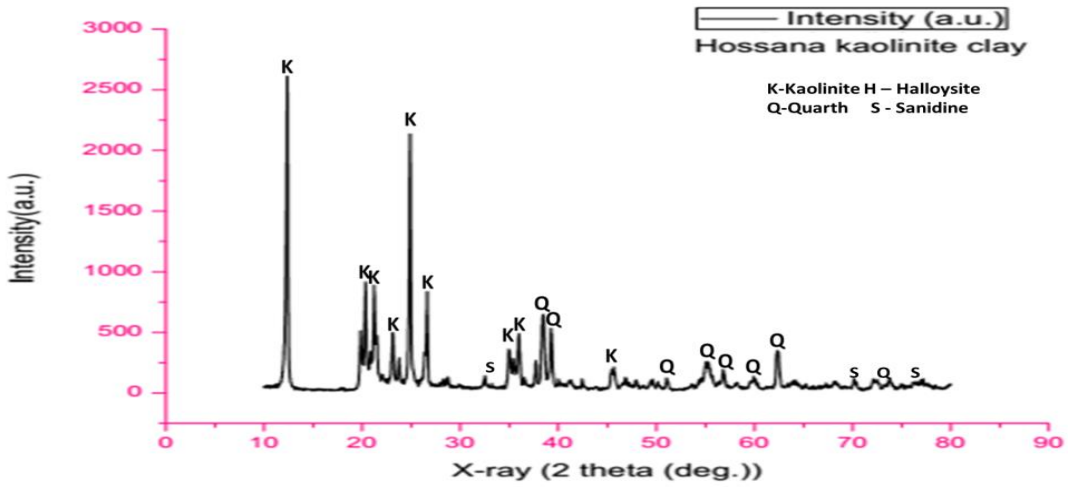


Figure 4. 13: X-ray diffraction pattern (pahse analysis) of bulk Hossana clay

A slight mineralogical difference the hosanna samples which consists of halloysite, quartz and sanidine as the main identified phases. The XRD results in figure show differently changing patterns. Moreover, the kaolinites show a series of strong X-ray diffractions peaks mainly at about 7Å (~ 13º2θ) and 3.5 Å (~ 26º 2θ). In figure , the broad peaks, especially on the high theta side, are typically for highly disordered halloysites. The phases with sharp peaks are quartz and

sanidine. The quartz in all samples are part of the parent rock.While, Sanidine is the high temperature polymorph of K-feldspar, which is typical for rhyolites.

Table 4. 7: Xrd result of bulk Hossana clay soil sample showing the quantity of different phases

PHASE IDENTIFIED	WEIGHT %
kaolinite[$Al_2Si_2O_5(OH_4$]	70
halloysite[$KAl_2(AlSi_3)O_{10}(OH)2$]	2.5
quartz[SiO_2]	25
Sanidine(K-feldspar) [$KAlSi_3O_8$)]	2.5

4.3.3 XRD RESULTS OF LEKU SOIL

Leku soil identified to be 100 wt% of pure quartz which is shown the figure below. Quart is one of a filleric component material that have been introduced to enhance the mechanical strength and to reduce shirinkage at the vitrification temperature. The two kaolin that has been discussed on the above section has sufficient amount of quartz as component mineral. Therefore, the author decided not to use leku soil for the formulation of CPWFs during fabrication.

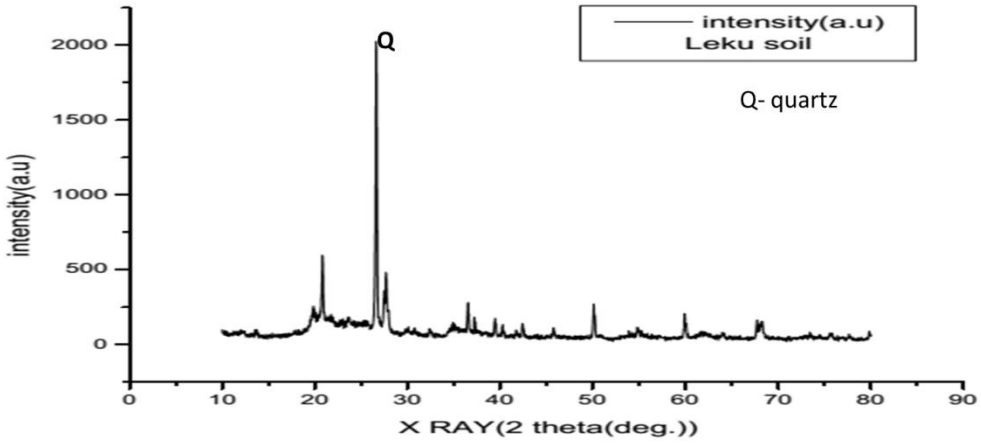


Figure 4. 14: X-ray diffraction patern of bulk Leku soil

Table 4. 8: Xrd result of leku soil sample showing the quantity of different phases

Phase Identified	WEIGHT %
Quartz	100

The resultant structural formula for the two kaolin clay samples was deduced to be $KA_{l2}(AlSi_3)O_{10}(OH)_2$ and it account for crude kaolinite containing quartz and microcline. And according to Ekosse G (2001), pure kaolinite has a theoretical chemical composition of 46.55 wt. % SiO_2, 39.49 wt. % $Al_2O_3$and 13.96 wt.% H_2O, and in nature it is hardly found in pure form. It is always associated with two types of impurities resulting from accessory minerals that adhere to the surface of kaolinite, and those resulting from isomorphous substitution of an element into the kaolinite structure.

X ray diffraction and x ray fluorescence result of Bombowha kaolin revealed that presence of large quantities of iron, alkali and alkaline earths as components of clay minerals, as absorbed ions, or as non-clay mineral, there may be little development of distinct high temperature crystalline phases [44]. Kaolin which was relatively high in alkali and iron develop high shrinkage and low porosity at lower temperatures. The presence of such fluxing agent in the clay material may cause vitrification and fusion at as low temperatures as 900ºC. This phenomena results a sharp increase in porosity and decrease in bulk density values for the bar samples fired at 900ºC. The increase in porosity and decrease in the bulk density values in the temperature range of 950–1050ºC manifested by the Bombowha kaolin might be ascribed to structural adjustment caused by the transformation of meta-kaolinite to gamma alumina.

The mechanical inspection of the CPWFs showed that a sharp increase at 1000ºC for both kinds of kaolin clays from both source areas mainly due to the formation of a high temperature. crystalline phase mullite . The specific gravity values of such samples also correspond to their mineralogy with the highest values for samples containing.

The result of the chemical analysis of the two kaolinite clay have almost equivalent amount of silca and alumna. The only difference between Bombowha and Hosanna kaolin was found to be in their impurity trace amount of alkali oxide contents. On the particle size distribution section of this paper, Bombowha kaolin has a much finer particles size distribution than Hossahna kaolin. That was the reason why Bombowuha kaolin was much more plastic than hosanna kaolin. Hence, the mixing of the two kaolin clays produced composite clay with intermediate plasticity and strength for the fabrication of CPWFs.

4.4 CHEMICAL ANALYSIS RESULT AND DISCUSSION

4.4.1 XRF OR CHEMICAL ANALYSIS RESULT OF BOMBOWHA CLAY

Table 4. 9: Chemical analyses of Bombowha kaolin

DEBTH (in m)	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	H_2O	LOI	MnO_2	TiO_2	P_2O_3	Bao
1.5–2.0	46.7	37.5	0.14	0.09	0.01	<LD	0.01	0.525	14.6	<LD	0.57	0.01	<LD

Tables 19 shows the chemical analysis of the kaolinitic clays from the Bombowha area collected from two pits. Alumina is generally above 35% for the Bombowha kaolin with. impurity elements such as iron -1% , total alkali and titanium accounting for less than 3%. The XRD also showed some weak peaks of other elements, which were revealed on the XRF result as Potassium (K), carbon (C), Fluorine (F), Calcium (Ca), Iron (Fe), Titanium (Ti) and Magnesium (Mg).

4.4.2 XRF OR CHEMICAL ANALYSIS RESULT OF HOSSANA CLAY

Table 4. 10: Chemical analyses of hosanna kaolin

DEBTH (in m)	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	H_2O	LOI	MnO_2	TiO_2	P_2O_3	Bao
1.5–2.0	46.7	37.5	0.14	0.09	0.01	<LD	0.01	0.525	14.6	<LD	0.57	0.01	<LD

Tables 2**0** shows the chemical analysis of hosanna kaolin displayed a range of concentrations (73.36 -81.1 wt. % SiO_2), (11.91 -17.75 wt. % Al_2O_3), (0.9 - 4.68 wt.% Fe_2O_3) and (3.15 – 9.24 wt. % Na_2O+ K_2O). It also shows relatively the lowest LOI (3.66- 7.27 %).There were a few weak peaks that were not identified in the XRD scan. The XRF analysis of hosanna kaolin revealed for the presence of the trace elements which includes Ni, Li, Sb, Ge, Re, Tl, Cd, Co and Cu are below the detection limits in the kaolinized samples.

Moreover, the feldspar minerals observed in table 4.10 (i.e, microcline and plagioclase) explain the source of the oxides of potassium, sodium and calcium as depicted in Table 1 and Figure 1. It has equally been reported that the common impurities in feldspar are iron and titanium [15]; this explains the source of the titania and hematite depicted in Figure 1 and Table 1. The presence of magnesium in the clay is explained by the presence of muscovite/illite (mica mineral) in the clay. This clay is observed to contain high percentage of feldspar minerals.

Admittedly, the beneficiated kaolin was not used in the fabrication of CPWFs in this work because of in most previous literatures and ceramic filter producing factories don't undergo the beneficiation process due its cost for bulk production. Similarly, on this paper work the purification of the raw materials was not done.

4.5 DIFFERENTIAL THERMO-GRAVIMETICANALYSIS (DTG) RESULT

Upon heating in air and under inert condition kaolin starts to lose water at approximately 400˚C, and the dehydration approaches completeness at approximately 525˚C [45]. The dehydration depends on the particle size and crystallinity. Loss of absorbed water begins at 100˚C to 200˚C. Loss of structural water (hydroxyls) 450˚Cto 500˚C and complete at 600˚C to 750˚C. At 800˚C to 900˚C disintegration of crystal lattice and produces a variety of phases, such as mullite, cristobalite and cordinerite. This result is ideal for Kaolinite because its loss in weight from literature is 14% [48] and [46].

The moisture content has a strong influence on the engineering behavior of clays. Temperatures above dehydration but below dehydroxylation: when the temperature is raised from ambient to that of the onset of dehydroxylation, clays lose adsorbed and hydration water. As a result, the interlayer spaces collapse, while pore space is changed, and the acidity of the clay mineral surfaces and interlayer's is substantially altered. Loss of adsorbed water alters the macro and micro porosity of the clay mineral as well as its plasticity. Temperatures above dehydroxylation, but below those leading to complete destruction of the structure: the changes occurring in this temperature range vary for different clay mineral groups. Dehydroxylation destroys the layer structure of trioctahedral, 2:1 type (T-O-T) minerals, whereas that of their di-octahedral counterparts is preserved. Kaolinite group minerals become amorphous to X-rays although some features of the structural framework are preserved [49].

The differential thermal analysis (DTA) and thermo-gravimetry (TG) measurements of the bambowuha and Hossana kaolin clay are given in Fig.4.15 and 4.16 respectively. As can be observed on the DTA curves of bambowuha, two consecutive endothermic peaks appeared and one exothermic peak for the bambowuha sample at 950 °C. These first two endothermic peaks were at a temperature lower than 250 °C, proving the removal of weakly-bound water. While the

endothermic peak found at about 488 °C indicates the dehydroxylation of the kaolinite. The decarbonation reaction of calcite (686 °C) was detected in the structure as well as the formation of quasi-amorphous materials in the two clay sample. The total mass loss of the bambowuha and Hossana kaolin clay samples was 9.2% and 14.6% respectively (Fig.4.15 and 4.16). Exothermic peak on the DTA curve with maximum at 1000°C is attributed with the transformation of the heated kaolinite to mullite and recrystallization.

4.5.1 DTG ANALYSIS RESULTS OF BOMBOWHA AND HOSSANA CLAY

The DTG curves of all the Bombowha kaolin clay exhibited characteristic peaks of kaolinite fig.4.15**.** The temperature of the main endothermic peak is the same about 587ºC , The exothermic peak temperature 950ºC is also the same for both samples. A sharp endothermic peak at about 95ºC for can be due to hygroscopic water and or halloysite. A small endothermic peak at about 320ºC probably suggests the presence of gibbsite fig.4.15.Only 13.408 wt% of mass loss was recorded for Bombowha kaolin clay just before crystalline phase transformation temperature at 1000 ºC.

The differential thermo-gravimetry (DTG) measurements of the Bombowuha bulk clay was given in fig.4.15.As can be observed in the DTA curves, two consecutive endothermic peaks and one exothermic peak for the sample at 950 °C. These first endothermic peaks were at a temperature lower than 250 °C, proving the removal of weakly-bound water. The endothermic peak of the Bombowuha bulk clay found at about 488 °C indicates the dehydroxylation of the kaolinite.

From Fig. 4.15, the first stage of firing clay is a completion of drying pore water. From the TG curve, it can be seen that the initial weight of the sample was reduced by 0.62% when the temperature was increased up to 289.8^{o}C. At the temperature of 350^{o}C, the chemical combination water of the clay started to be driven off. This chemically combined water is not to be confused with pore water and water of plasticity, which escapes during early stages of drying. This chemically combined water is part of the molecular structure of the clay and is only affected by temperatures above 350^{o}C. The weight of the sample was reduced by 1.43% when the temperature increased to 658.8^{o}C where the dehydroxylation of clay minerals occurs. The effect of flux components such as K2O, Na2O and CaO can be seen when the clay started to have a reaction at around 900 ^{o}C. This also marks the beginning of the sintering process for the clay.

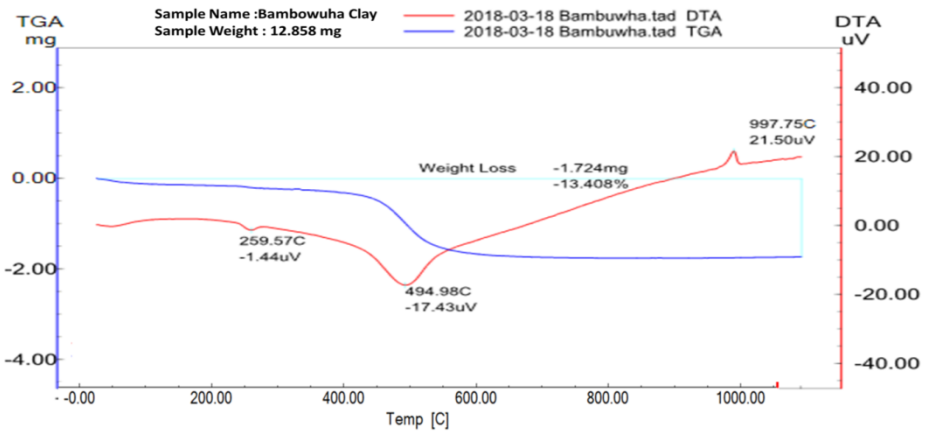


Figure 4. 15: Differential Thermo-gravimetric analyses (DTG)of the raw Bombowuha clay :

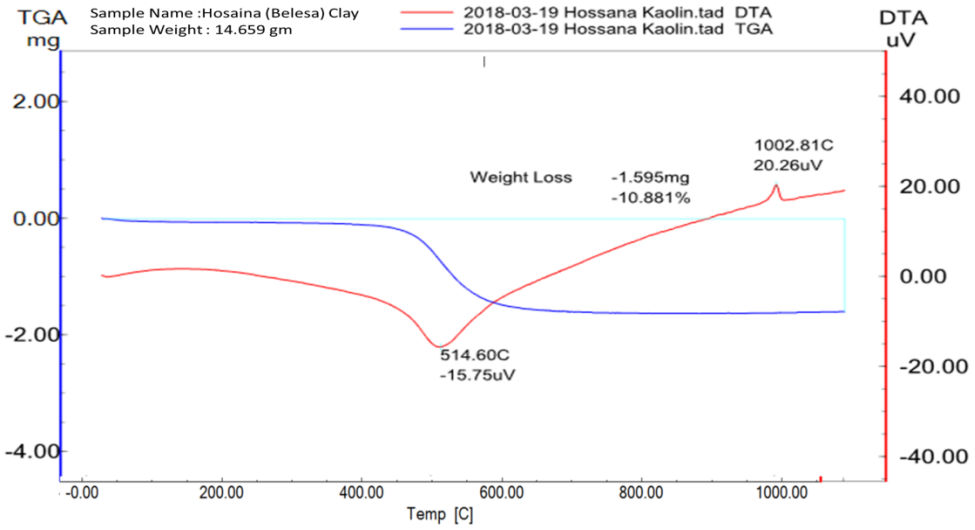


Figure 4. 16: Differential Thermo-gravimetric analyses(DTG)of the raw Hossana clay

The differential thermo-gravimetry (DTG) measurements of the Hossana bulk clay was given in Fig.4.16. As can be observed in the DTA curves, two endothermic peak at 520°C and 250 °C, and one exothermic peak for the sample at 950 °C. These first endothermic peaks were at a temperature lower than 250 °C, proving the removal of weakly-bound water. The endothermic peak of the Hossana kaolin clay found at about 514°C indicates the dehydroxylation of the kaolinite.

As can be seen in Figure 4.16, the first and second weight loss varied with temperature. Thermo-gravimetric analysis (TG) studies indicated that kaolinite specimens seem to lose 9 wt. % at temperatures between 400°C and 600°C.

Bambowuha kaolinite clay have weaker bonds between hydroxyl groups in its structure due to higher halloysites than Hossana kaolin clay this leads to its decomposition or phase transformation temperature was at low temperatures goes through a more rapid loss of weight compared to hossana kaolinite.

4.5.1 DTG ANALYSIS RESULT OF HARD WOOD SAW DUST AND RED TEFF HUSK

The major objective of differential analysis of the combustible materials was to know their complete decomposition temperature range. Knowing their decomposition temperature range means knowing the their holding temperature and holding duration during firing stage of CPWF fabrication process.

Pyrolysis is essentially the thermal decomposition of organic matter under inert atmospheric conditions or in a limited supply of air, leading to the release of volatiles and formation of char. Pyrolysis in wood is typically initiated at 200^{o}C and lasts till 450-500^{o}C, depending on the species of wood dust or teff husk used. The major constituents of most combustible materials are organic hydrocarbons. For example, most wood dust composed of cellulose (a polymer glucosan), hemicellulose (a polysaccharide producing wood sugars), and lignin (a multi-ring organic compound).

Thermal decomposition characteristics of wood components are different because of differences in their chemical structure. Hemicellulose, cellulose, and lignin decompose in distinctive temperature range. Hemicellulose decomposes easily with respect to other components of wood. It decomposes at temperature between 200-280°C. In temperature range between 250-300°C, the other main components of the wood products (lignin and cellulose) degrade. It was reported that the wooden materials generally separate into three stages during the pyrolysis. First stage is removal of volatile parts below 200°C; second stage is degradation of hemicelluloses, celluloses, and lignin between 200-378°C; and third stage is conversion of nonvolatile and noncombustible part into tar and char, up to 600°C.

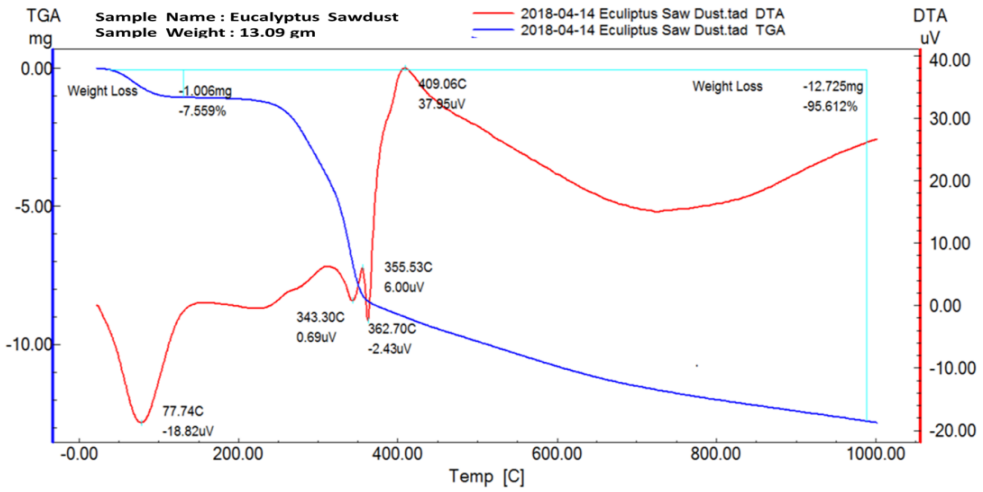


Figure 4. 17: Differential Thermo-gravimetric analyses(DTG)result of eucalyptus hard wood saw dust

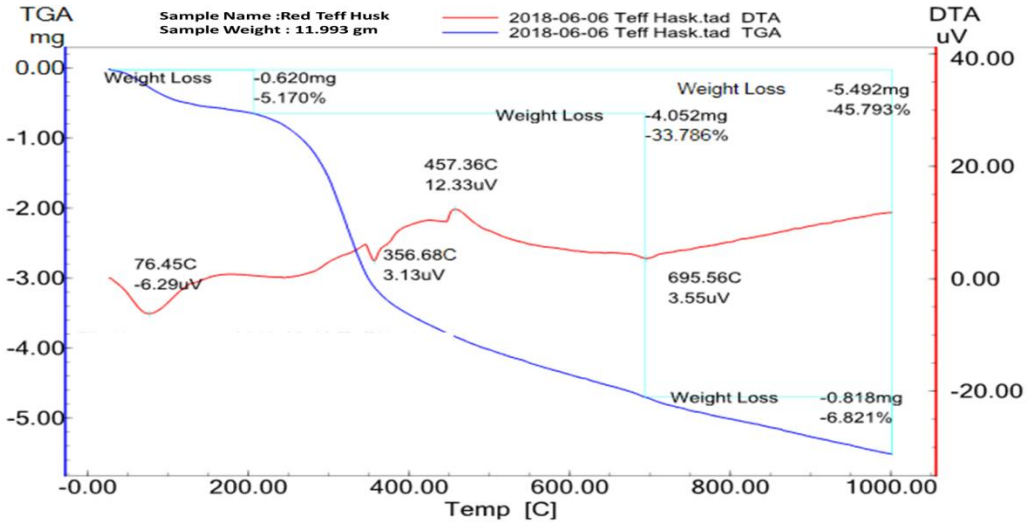


Figure 4. 18: Differential Thermo-gravimetric analyses (DTG) result of teff husk

From the above figure 4.17 and 4.18, like most combustible materials the decomposition temperature of saw dust and teff husk occurred at 362.7°C and 356.68°C.but their decomposition temperature onset from 250°C and ends at 600°C for both combustible materials. Therefore, the holding firng temperature was decided to be fall between 250°C and 600°C but in project case the holding temperature was decided to be 400°C for two hours during firing stage of CPWF fabrication process.

To summarize the overall characterization result, the data obtained from chemical analysis correlates with the mineralogical composition of kaolinite. Thus, the values of concentration for the contents of silica and alumina obtained agree with those of kaolinite and quartz with traces of microcline of the diffraction result. Therefore, the percentage weights of the metal oxides were calculated from 2.4403g of for both kaolin clays used in this paper. The total percentage weight of the oxides fell outside the expected range of 99.01 to 100.05% probably because of the lost water. Pure kaolinite has a theoretical chemical composition of 46.55 wt.% SiO2, 39.49 wt.% Al2O3 and 13.96 wt.% H2O, and in nature it is hardly found in pure form [50]. It is always associated with two types of impurities resulting from accessory minerals that adhere to the surface of kaolinite, and those resulting from isomorphous substitution of an element into the kaolinite structure. From the DTG graph, the TGA curve showed that the Bambawuha and Hossana kaolin sample decomposed from 100% to 86.59wt% and 89.22wt % and, which corresponds to a loss of 13.408 wt% and 10.88wt % and of the total weight. This is ideal for kaolinite because its loss in weight from the literature is 14% [51]. The difference in the experimental loss in weight compared to that in the literature may be due to the fact that the analyzed clay is not solely kaolinite but contains microcline and quartz as revealed by chemical analysis. From the DTA curve, two sharp exothermic peaks were observed at 59.06°C and 463.77°C corresponding to loss of physisorbed water and dehydroxylation of kaolinite respectively. This is whereby the structural OH is lost as water, as kaolinite is transformed to metakaolinite expressed as below:-

$$Al_2Si_2O_5(OH) \longrightarrow Al_2Si_2O_7 + 2H_2O$$

Dehydroxylation of kaolinite occurs in normal atmospheres at temperatures above 400°C [51]. The experimental dehydroxylation of Bambawuha and Hossana kaolinite occurred at 658.8 ^{o}C and 514°C, which is in reasonable agreement with the literature. Kaolinite is known to have water molecule intercalated between the layers. Thus, it contains structural water and in the DTA curve, loss of this water was observed between 100°C and 400°C and resulted in small endothermic peaks within that temperature range.

4.6 FILTER PERFORMANCE RESULT

4.6.1 FILTRATION RATE TEST RESULTS

During filtration, water seeps out from the sides and the bottom of the filter. Therefore as the filter is full, larger area of the filter is covered meaning, more water gets filtered out. Also from the Darcy's equation, it is seen that the flow rate of the liquid through a porous media is directly proportional to the hydrostatic pressure difference across the specimen (ΔP). Therefore at higher levels of pressure difference, that is when the level of water in the filter is high, the flow rate will be high and likewise when the pressure difference is low, the flow rate will also reduce. Hence for the filters to work effectively in terms of the amount of water filtered, the user will have to make sure that the level of water in the filter is high all the time.

The quantity of water filtered was measured for the developed ceramic pot water filters and the effect of the three CPWF processing parameters (composition, particle size and firing temperature) on filtration rate were also analyzed by using this flow rate result which was given on table E_1(appendix E).

The Effect of variation in firing temperature on Flow rate of CPWFs analyzed based on flow rate data result. The flow rate experiment revealed that except CPWFs with formulation of 80B/20S and 80B/20T, the filtration rate of most of CPWFs becomes decreased as the firing temperature increased. This can understood easily from fig.4.22 given below. This was mainly due to the process of vitrification at higher temperature above 900ºC, this leads to the flow of particles in the form of vitrified viscous fluid to fill the remaining porous portion of filters body, and this was resulted in the reduction of pore sizes, which intern affect or reduce filtration rate of the filters. Therefore, CPWFs fired at 900 ºC have higher filtration rate than filters fired at 1000ºC.CPWFs produced with the same other processing parameters but different firing temperature showed variation in filtration rate. CPWFs with formulation of 80B/20S and 25H/55B/20T showed the highest and the least filtration rate respectively than any other filters fired at both firing temperature. CPWFs with formulation of 80H/20S and 25H/55B/20T have moderate filtration rate from all filters fired at a temperature of 1000 ºC and 900 ºC respectively.

Results have shown that the teff husk ingredient based filters did not have a noticeable variation on the filter flow rate even though the firing temperature varied. From this result, sawdust is a more sensitive filters composition ingredient for increasing flow rates through varying processing temperature.

Within the same processing parameters (firing temperature, sieving mesh and clay to combustible formulation ratio), Bambawuha kaolinite clay and sawdust (i.e 80B/20S) based filter showed the highest filtration rate. Followed by Bambawuha and Hosaina kaolinite blended clay and sawdust based filter (i.e 25H/55B/20S) .teff husk based filters showed the least filtration rate performance than in any other formulated filters at both firing temperature.

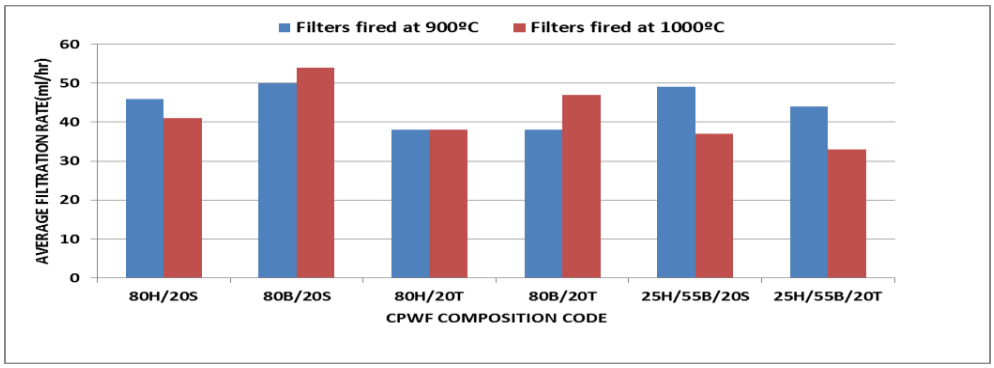


Figure 4. 19: The Effect of variation in firing temperature on Flow rate of CPWFs

The Effect of variation in particle size of both clay and combustible materials on Flow rate of filters fired at 900ºC was analyzed on Fig. 4.20 shown below. One of the most common approaches to increase the flow rate was to increase the number of pores in the filter by raising the proportion of combustibles to clay. In addition to this, the flow rate can be increased by increasing the particle size of the combustibles and lowering the firing temperature. If there are more pores in the filter, then water should flow through the filter faster. The study results revealed that when the particle size of the combustibles increased from 600 µm (sieved through 600 mesh number) to 1150 µm (sieved through 30 mesh number) the flow rate also increased as just shown on figure 41 shown below. The flow rate of the ceramic silver impregnated clay filter is basically dependant on the nature of the pores in the filter [27]. As the pores become bigger and more connected, the water finds it easy to flow through, therefore causing the flow rate of the filter to increase.

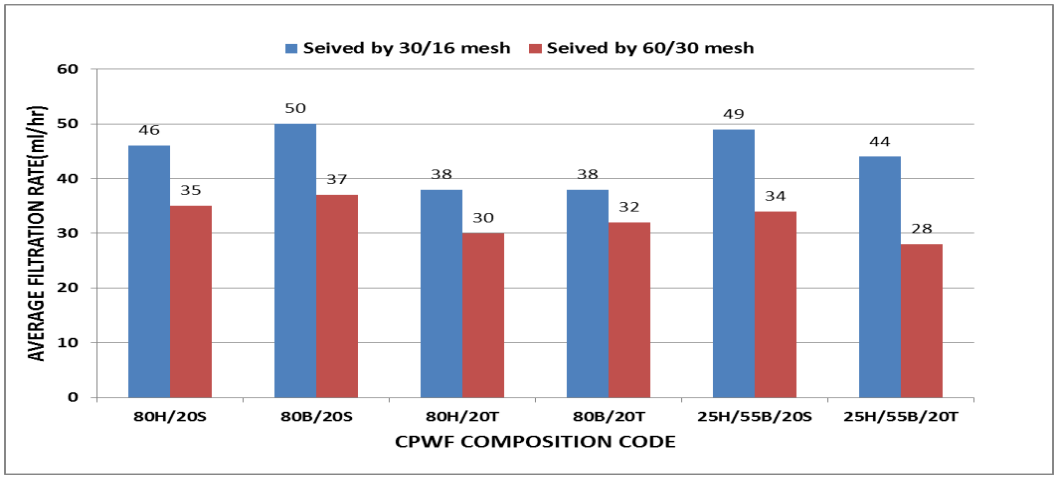


Figure 4. 20: The Effect of variation in particle size of both clay and combustible materials on Flow rate of filters fired at 900ºC and 1000ºC

Comparison of filtration rate of the same batch processed Filters was given on the Fig. 4.21 given below. By filling the filters with water to the top (maximum height) the quantity of water filtered from each eighteen CPWFs was given on the table E_1 (appendix E).The filtration rate of all filters was higher for the first one hour and decreased with number of trials runs. Among the developed eighteen ceramic pot water filters, the quantity of water filtered was highest for the filter developed from 80B/20S while it is the lowest for the filter developed from 25H/55B/20T.

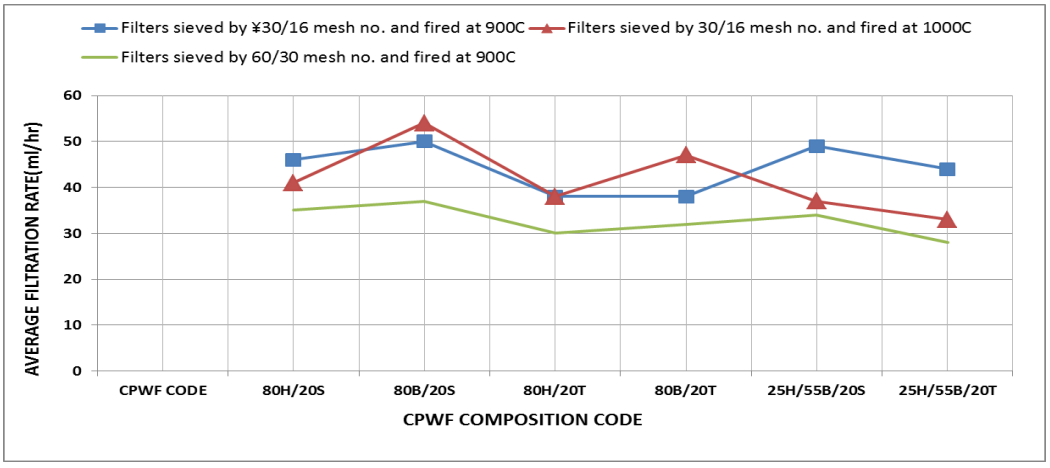


Figure 4. 21: Comparison of filtration rate of the same batch processed Filters

During filtration, water seeps out from the sides and the bottom of the filter. Therefore as the filter is full, larger area of the filter is covered meaning, more water gets filtered out. Also from the Darcy's equation, it is seen that the flow rate of the liquid through a porous

media is directly proportional to the hydrostatic pressure difference across the specimen (ΔP). Therefore at higher levels of pressure difference, that is when the level of water in the filter is high, the flow rate will be high and likewise when the pressure difference is low, the flow rate will also reduce. All the filters had their highest flow rate at the beginning of the flow rate experiment and subsequently reduced with increasing time as the level of the water in the filter reduced. It can also be observed from the graphs that, the flow characteristics of the filters followed a similar trend. All the filters had their highest flow rate at the beginning of the flow rate experiment and subsequently reduced with increasing time as the level of the water in the filter reduced. Fig.4.22 shown below is the average flow rate results of three Filters sieved by 30/16 mesh no. and fired at 900ºC.Hence for the filters to work effectively in terms of the amount of water filtered water for use, the user will have to make sure that the level of water in the filter is high all the time.

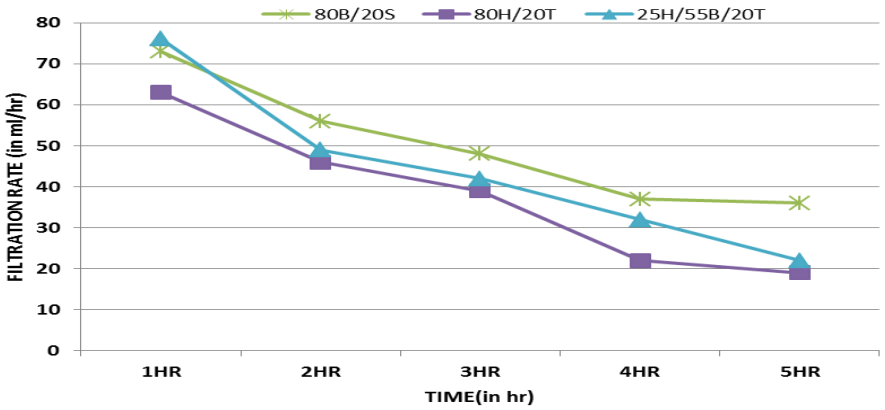


Figure 4. 22: The decrease in average flow rate results of three Filters sieved by 30/16 mesh no. and fired at 900ºC.

The mean flow rates obtained for the three runs for each ceramic water filter of eighteen ceramic water filters that were tested are presented in Figures 43. The average individual flow rate each filters were found to be between ~ 54 and ~ 33 ml/hr during the first five hours of the flow.when this value However, the flow rates decreased with increasing time. This was due to the decrease in the hydraulic pressure and possibly clogging or unclogging for increasing flow durations [21],[38]. the variations in the flow rates would be expected to result in variations in the permeability extracted from the overall flow data,[38],[28],[21].

The mean flow rate of water discharge for the six filters was 2.3 L/hr during the first hour of discharge. The effective permeability of each ceramic filter was also obtained by fitting the measured flow rate data to the Darcy's flow rate equation. The permeability values for the six filters were found to be between ~ 0.44 x 10^{-14} $m^2$and ~ 2.54 x 10^{-14} m^2, with an average value of 1.19 x $10^{-14}m^2$ (hydraulic conductivity, k is 1.46 x 10^{-7}m/s). The average effective permeability value is found to be very comparable to permeability values found for ceramic water filters from Cambodia (1.37 x 10^{-7}m/s) and Ghana (1.3 x 10^{-7}m/s) from previous work [21]. Also the average effective permeability computed from literature was well within the hydraulic conductivity range (1.15 x 10^{-7}m/s to 5.01 x 10^{-7} m/s) for three ceramic water filters [28]. Furthermore, the permeability values also found between ~ 0.1 x $10^{-14}m^2$ to 5.0 x 10 $^{-14}m^2$[52]. There exists a linear dependence of the flow on the permeability which therefore suggests that the effective permeability approach captures the trends in the flow rate data.

Not only the need to improve access to safe drinking water is recognized, but also the problem of a lack of sufficient quantities of safe drinking water needs attention. If a family or community decides to invest their resources into a water treatment system, it is important that they not only get water that is free of harmful bacteria and disease causing pathogens but also available in sufficient quantities to meet their needs. A water treatment system that provides safe drinking water is virtually useless if there is not enough quantity of it and if cannot be afford to be bought by the majority of the peoples which low income like peoples in most developing countries. It is difficult to make accurate estimates regarding daily fluid intakes because the requirement is highly dependent on body physiology, activity level, and local climate. The Recommended amount of daily water consumption can be shown on table 21 given below.

Table 4. 11: The Recommended amount of daily water consumption

		Volume(L/day)	
		Average Conditions	Manual Labour in High Temperatures
Adults	Male	2.9	4.4
	Female	2.2	4.4
Children		1.0	4.4

An average estimate based on a review of the literature for adult males is 2.9 L/person/day, adult females is 2.2 L/person/day and children is 1.0 L/person/day [53].

If this lab scale filters properly scaled up and manufactured, the developed ceramic pot water filters to large scale (top diameter= 30 cm, water head height= 23cm and 22cm filter base diameter) are capable of producing 2 up to 2.5 liter/hr having a capacity of providing 25.5 – 36 liters per a day which was sufficient safe drinking water for an average five-member household. This is not assuming the situation where the filter is consistently refilled throughout the day (to maintain the maximum level of hydraulic head).This was evaluated with by considering non refilling free time (like family sleeping and recreation time). According to the Potters for Peace (PFP) filter design standards, filters that have a flow rate of between one and two (1-2) liters per hour are the best and filters that have flow rate within this range have their pores sizes determined as 1 μm [11]. The results obtained for the flow rate experiment, shows that all the eighteen filters that were used in the experiment met the pore requirement of the PFP filter standards, since they all had their flow rate between 2-2.5 liters per hour (L/h). It can also be observed from the graphs that, the flow characteristics of the filters followed a similar trend.

This finding is consistent with the results of the majority of previous researches conducted in many countries. Further work is needed to explore the clogging mechanism and the effects of turbidity on the long term flow characteristics. Mean of the saw dust based filters' flow rates are greater than the mean of the teff husk based filters' flow rates by 1.31 to 1.96 L/ hour.Out of the two tested combustible materials, sawdust did not have significant influence on the flow rate but it was the more reliable CPWFs preparing ingredient than teff husk. The teff husk mix had lower workability or consistency at the processing stage is a setback; this would become an issue at production. Its workability had improvements on the finer particle size range than the coarser one.

The CPWFs average flow rate meets WHO minimum necessary volume of water needs at a small household level (three persons could benefit from it for drinking, food preparation and basic personal hygiene).According to WHO, the minimum necessary volume of water required per person for drinking, food preparation and basic personal hygiene is 7.5L. If regularly filled, the CPWFs would effectively produce 25.5 – 36 L of potable water per day. The filtration rate

result of CPWFs, compared to the previous literature filtration result, high flow rate performance is achieved without sacrifice of the microbial removal.

4.6.2 PHSIOCHEMICAL REMOVAL EFFICIENCY TEST RESULT

Turbidity is a water quality parameter which quantifies the degree to which light traveling through a water column is scattered by the suspended organic (including algae) and inorganic particles.The scattering of light increases as the suspended load increases. Turbidity is commonly measured in Nephelometric Turbidity Units (NTU), but may also be measured in Jackson Turbidity Units (JTU). Organic constituents in water may harbor microorganisms, and thus water with high turbidity generally has a higher concentration of pathogens and a higher possibility of transmitting waterborne diseases. The WHO standard for the turbidity level in drinking water is set at 5 NTU. The aesthetics of the water is an important factor for many people, especially people from the third world places. Water samples used for the experiments were from the ground water supplied from the OSHO Laboratory, which was collected from the same source, where the communities use this water as a source for domestic purposes. Influent and effluent water samples were tested for turbidity. The water was tested for turbidity before and its reduction by the developed filters after filtration.

The test results showed that the turbidity of the ground water supplied from the OSHO Laboratory was found to have turbidity levels varying between 12 and 14 NTU. The average turbidity level of the raw ground water was 13NTU. After filtration, the turbidity of the ground water was reduced to less than 5 NTU for the all seven tested filters. This level is well within the acceptable value range according to drinking water quality standards of 5NTU as set by WHO [40] and Ethiopian drinking water quality standard guide line. CPWF with 80B/20T (fired at 1000ºC) formulation was observed to remove turbidity with the highest efficiency, followed by 80B/20S (fired at 1000ºC) formulation CPWF and then 80H/20S (fired at 1000ºC) and 25H/55B/20T. However, the differences in performance of these filters were negligible. The reduction of the turbidity level of ground water was one indication of the homogenous distribution of micro size pores throughout the filters body. The average turbidities of the raw water and the filtered water using various filter systems are shown in on the Table 4.12 given below.

Turbidity is a water quality parameter which quantifies the degree to which light traveling through a water column is scattered by the suspended organic and inorganic particles. The scattering of light increase as the suspended load increases. Turbidity is commonly measured in Nephelometric Turbidity Units(NTU).Organic constituents in water may harbor microorganisms, and thus water with high turbidity generally has a higher concentration of pathogens and a higher possibility of transmitting waterborne diseases. Studies have shown that there is a strong relationship between reduction of turbidity and removal of pathogens in water filtration process. Additional parameters tested to characterize source water included conductivity, temperature and pH. Results of the analysis of pre- and post-filtration water samples collected showed some interesting indication. Both pH and conductivity of the filtered ground water were decreased. These may be due to the entrapment of some ions within the filter element by clay.

The results were analyzed as compared to the concentration in raw water based on the permissible value of both Ethiopian and WHO standard specification for drinking water 2013 and 2006/7 respectively[40],[41].

The average result of Turbidity, free residual fluoride and other physical parameters test results before filtration and after filtration of the ground water samples filtration through seven CPWFs was summarized on the table 4.12 given below.

Table 4. 12: Turbidity Measured over Time

Filters composition code	Average Turbidity (in NTU/100ml) before filtration	TURBIDITY (in NTU/100ml) after filtration									
		Week-1			Week-2			Week-3			Average Turbidity
		†T-1	T-2	T-3	T-1	T-2	T-3	T-1	T-2	T-3	
80B/20S (fired at 1000C)	13	0.6	0.8	1	0.8	0.9	1	1	1.2	0.9	0.9
80H/20S (fired at 1000C)	13	1.2	0.8	1.2	1	1	0.8	0.9	1	1.1	1
80B/20T (fired at 900C)	13	2.3	2.7	2.5	2	2.4	2.6	3	2.5	2.5	2.5
25H/55B/20S(fired at 1000C)	13	1.4	1.6	1.2	1.4	1.7	1	1.4	1.1	1.8	1.4
25H/55B/20S(fired at 900C)	13	1.2	1	1	0.9	1.3	1.3	0.8	0.9	1	1
80H/20T(fired at 1000C)	13	0.4	0.45	0.48	0.47	0.45	0.45	0.46	0.46	0.43	0.45
80B/20T (fired at 1000C)	13	0.8	0.6	0.8	1	1.1	0.7	0.8	0.7	0.7	0.8

† T-1 stands for test trial one

Table 4. 13: The average result of Some physiochemical parameters of the ground water before and after filtration through seven CPWFs

Tested physiochemical Parameters	Before filtration	Maximum permissible level for drinking water (ETH,WHO)	Post filtration						
			80B/20T	80H/20S	80B/20T	25H/55B/20S	25H/55B/20T	80H/20T	80B/2OS
Turbidity(NTU)	13	5	0.9	1	2.5	1.4	1	0.45	0.8
PH	8.4	(6.5 – 8.5,)	8.4	8.5	8.3	8.6	8.5	8.2	8.4
Temperature(°C)	25	25	22	24	23	26	25	23	24
Electrical Conductivity($\mu s \cdot cm^{-1}$)	1200	330 – 1005	330	350	350	340	400	360	300
Total dissolved solids(TDS)(mg/lit)	1245	(1000, 200 to 600)	7	8	6.8	7.5	7	6.8	6.8
Water hardness (as CaCO3 in mg/lit)	160	(300,60 to 120)	40	40	44	48	45	60	60
Free residual Fluoride (as F^{-1} in mg/lit)	3.4	(1.5, <1)	0.04	0.06	0.05	0.056	0.045	0.062	0.06

Following filtration, turbidity of the filtered water sample was reduced to less than 5 NTU for all the developed seven CPWFs tested. This level is within the acceptable drinking water quality standards of 5NTU as set by World Health Organization. The influent water from the ground water source was found to have turbidity levels varying between 12 and 14 NTU with an average of 13 NTU. Even when raw ground water with higher turbidity levels was used, the turbidity of filtered water sample was found to be below 5 NTU. The developed ceramic water filters have the capability of reducing turbidity to less than 5 NTU.

Among seven tested CPWFs for chemical contaminants removal efficiency , CPWFs with 80B/20T and 80B/20S (fired at 1000ºC) formulation were observed to remove most chemical contaminants with the highest efficiency, followed by (fired at 1000ºC) formulation CPWF and then 80H/20S (fired at 1000ºC) and 25H/55B/20T.

The average reduction result of different physiochemical parameters filtered water as compared to the raw ground water, this includes the reduction of turbidity from 13 to 1.15 NTU(i.e 91.15% removal efficiency),free residual fluoride ion from 3.4 to 0.053mg/100ml(i.e 99.81% removal efficiency), total dissolved solids from 1245mg/l to 7.4 mg/l (i.e 99.4% removal efficiency) and pH from 8.9 to 8.4 which was within acceptable range. From this

research result, it was possible to fabricate ceramic water filter in Ethiopia and to use it as one of a promising future house hold water treatment technology for microbial removal and DE fluoridation of contaminated drinking water sources. One of the most successful achievements in this project was 99.81% fluoride ion removal efficiency of CPWFs. The laboratory test result was approved by legal certificate paper given for the author from Oromia self-help organization. This organization was one most well-known organization, which play a major role on fluorosis mitigation in Ethiopia especially on central rift valley regions. The certificate was given on appendix 6 just at the end this paper.

4.6.3 MICROBIOLOGICAL REMOVAL EFFICIENCY TEST RESULT

Total coliform removal was found according to methods described in Section 4.4.3. In order to calculate the Log Removal Values (LRVs) of total coliform performed by the filters, it was necessary to make a conservative adjustment to the data. Results from membrane filtration testing Too Numerous To Count (26 events, 8%) were adjusted by assuming the count was the maximum in the acceptable counting range, 200. Results from membrane filtration testing that were zero (184 events, 58%) were adjusted to be equal to one.

The coliform group of organisms is the most widely used indicator organisms for water quality testing. Fecal coliform, a subset of the total coliform group are associated with the intestinal tract, whose presence in water indicates that the water has received contamination of an intestinal origin. In testing the microbial quality of water, indicator organisms were used to test the microbial removal efficiency of the filters. Total coliform and fecal coliform indicator organisms are typically microbes that do not cause disease by themselves, but are found in harmony with waterborne pathogens in higher concentrations.

These common indicator organisms are so numerous in feacal matter and testing them is carried out more easily with less expensive equipment. The presence of coliform organisms has health significance for consumers. Due to this both World Health Organization and Ethiopia Guidelines set a guideline value of zero CFU/100mL.

Table 4. 14: Water Quality Risk Levels (Rayner, 2009)

Number of Thermotolerant (faecal) coliforms or E. coli per 100 ml water sample	
0	Conforms to WHO guidelines
1-10	Low Risk
10-100	Intermediate Risk
100-1000	High Risk
1000+	Very High Risk

The results from the E.coli test are presented in Figures 4.23and 4.24.

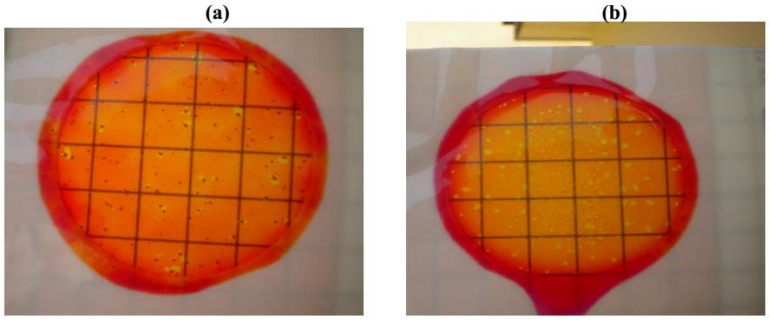


Figure 4. 23: Image of E.coli test(a) 1ml pre filtered and (b) 1ml of filtered ground water showing the colony forming unit(CFU)

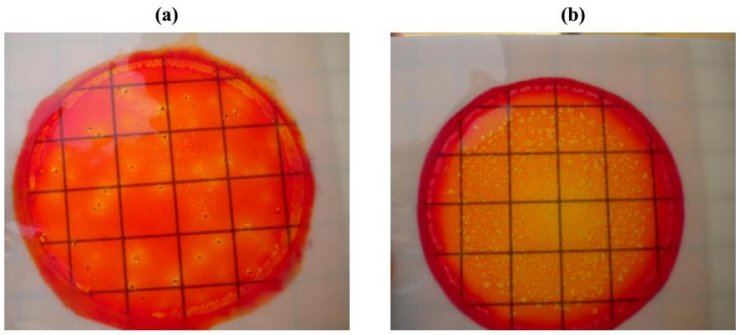


Figure 4. 24: Image of E.coli test(a) 0.5ml pre filtered and (b) 0.5ml of filtered ground water showing the colony forming unit(CFU)

The results show that there was no colony formation in the filtered water of 1 ml and 0.5 ml. However, colony formation was observed in the case of the pre-filtered water . The number of colony forming units was essentially doubled for the case of the 1 ml sample of water, compared to the 0.5 ml sample of water. Table 4.15 presents the number of

count obtained for the three trial petridish plates, and computation of the average colony forming units.

Table 4. 15: Colony Forming Unit (CFU) count of the Five Plates used for the Pre-filtered Water of 0.5 ml

Petridish -1	Petridish -2	Petridish -3
8 CFU/ml	9CFU/ml	7 CFU/ml

Table 4. 16: Colony Forming Unit (CFU) count of the Five Plates used for the Pre-filtered Water of 1.0 ml

Petridish -1	Petridish -2	Petridish -3
8 CFU/ml	9CFU/ml	7 CFU/ml

The average colony forming unit is obtained from the formula (P1 + P2 + P3)/3. This is calculated as (8 + 9 + 7/3= 8.33. Now to obtain the results in CFU/ml, the value obtained above is multiplied by two, since half a milliliter was used. Therefore we obtain, 8.33x 2 = 16.6 CFU/ml. Since the volume of the sample water in this test is 1 ml, the average value obtained above is the colony forming unit count in CFU/ml (8.33~8.4 CFU/ml) when it is scaled up it gives 840cfu/100ml.

The results obtained for the E.coli test confirms that, during the filtration of the water, all disease causing bacteria and microorganisms were removed through the mechanical screening process, since no colony forming unit was record for the filtered water (for 0.5 ml and 1 ml sample water). It can, therefore, be concluded here that, the pores that were present in the filters are significantly small to occlude disease causing bacteria and microorganisms. Furthermore, the results presented in tables 4.15 and 4.16 show that, the total colony forming unit per milliliter in the 1 ml sample water used, was approximately twice that obtained for the sample water of 0.5 ml. This therefore implies that, the amount of the disease causing bacteria and microorganisms is directly proportional to the volume of the pre-filtered water. Therefore,

the more the pre-filtered water ingested, the more disease causing bacteria and microorganisms introduced into the system.

Table 4. 17: Total Average coliform and fecal coliform in source and filtered water samples filtered through CPWFs fired at 1000ºC

Mixed ratio OR filter code	Risk Level	Log reduction value (LRV)	Before filtration		After filtration		Removal Efficiency	
			TC(cfu/100mL)	FC(cfu/100mL)	TC(cfu/100mL)	FC(cfu/100mL)	TC(cfu/100mL)	FC(cfu/100mL)
80B/ 20S(fired at 900ºC)	Low	2.15	840	132	6	0	99.3	100
80B/20S(fired at 1000ºC)	Conformity	2.92	840	132	1	0	99.9	100
25H/55B/20T (fired at 1000ºC)	Conformity	3	840	132	0	0	100	100
25H/55B/20T (fired at 1000ºC)	Conformity	3	840	132	0	0	100	100

Key: according to WHO 1997 Risk Levels Conformity <1,Low 1-10 ,Intermediate 10-100,High 100-1000 andThe Categories for microbial removal efficacy are <1 $\log_{10}$ (<90%) is low, 1to 2 $\log_{10}$ (90-99%) is moderate and >2 $\log_{10}$ (>99% is high).

As it can be seen from Table 4.17, laboratory test results indicated that the developed ceramic water filters are capable of removing more than 99.3to 100 % of the total coliform bacteria and 100% of the fecal coliform from influent water samples. Many studies assessing the performance of ceramic water filters have found them to be highly effective in removing total and fecal coliforms from bacterially contaminated water sources. The ceramic water filter technology should remove 99.98% of total coliform and E.coli under laboratory conditions [32]. Some other studies revealed that the effectiveness of ceramic water filters at removing bacteria, viruses, and protozoa depends on the production quality of the ceramic filter. Most ceramic water filters are effective at removing most of the larger protozoan and bacterial organisms, but not at removing the smaller viral organisms [54].

Studies have also shown that pathogenic bacteria are removed from contaminated water sources by filtering the water through high quality locally produced ceramic water filters in developing countries [55].

Total coliform removal is a measure of a water treatment technology's microbial removal performance. In comparison to other studies, the filters in this study, whose results are in Section 5.3, performed similarly. The range of conservative total coliform log removal values found in this study was from 0.19 LRV to 4.30 LRV. Total coliform log removal values (LRVs) for filters manufactured in the Dominican Republic in the range of 0.5 LRV to 3.8 LRV, with influent total coliform counts of 535 CFU/100mL to 11,567 CFU/100mL [26].

In the literature filters from Ghana, Nicaragua and Cambodia had total coliform log removal values in the range of 1 LRV to 4 LRV using canal water, with influent total coliform counts of 7 CFU/100mL and 2100 CFU/100Ml [26]. In this paper case, total coliform log removal values for tested CPWFs ranges from 2 LRV to 3 LRV.

Although as a group filters with teff husk were not found to have statistically better in total coliform log removal than filters with sawdust, It could be implied that the teff husk produces pores that are better able to screen coliform from the filtered water. Perhaps the angular nature of the larger sawdust pieces which were present in all of the sawdust types created opportunistic flow pathways that permitted more coliform to pass through than pathways created in teff husk filters.

CHAPTER FIVE

5 FILTER COST ANALYSIS

The gross national income per capita in Ethiopia is only $660 USD [61]. The proposed target sale price for the ceramic pot water filter is $3 USD. An economic analysis was conducted to estimate the production cost of the filter. The manufacturing line for making the ceramic filters consist of a hydraulic press, ceramic kiln, clay mixer, and other tools. Further, a total of four workers are to be hired to work at each station. The following assumptions apply for calculating an estimated cost of making the ceramic filter level.

- Manufacturing line operates at 8 hours a day, 5 days a week, 50 weeks a year
- A total of 100 ceramic filter elements will be produced each day
- A total of 125,000 filters will be produced in 5 years of operation

Tables 5.1, 5.2, and 5. 3 illustrate the material, equipment, and operating costs required to operate a production line to manufacture the ceramic filters over five years.

Table 5. 1: Material Costs for Running the Ceramic Production Line for Five Years

Materials	Cost ($ USD)	Remarks
Clay	7,500.00	Purchased locally
Water	0.00	Surface water
Sawdust + teff husk	500.00	Purchased locally
Total Material Cost	8,000.00	

Table 5. 2: Start-up Equipment Costs for Running the Ceramic Production Line

Equipment	Qty	Cost ($ USD)	Model
Clay Crusher	1	1 10.00	Custom made hand tool
Hammer Mill	1	1 1,680.00	Meadows #5 Hammer Mill

			[62]
Clay Mixer	1	1 4,082.00	Bailey: C-119-200 [63]
Misc. Tools (Shelves, Buckets, Brushes)	1	1 200.00	Tools with basic functionality
Hydraulic Press with Mold	1	1 542.85	Draper HBP/10 [64]
Kiln	1	1 5,950.00	L&L Kilns: TB3418-D [65]
Total Equipment Cost		12,464.85	

Power required for the hammer mill, clay mixer, and the kiln are 10 kW, 4.584kW and 19.935kW respectively [62], [63], [64]. Referring to the assumptions made earlier, the manufacturing line would run for 2,000 hours a year. The cost of electricity in Ethiopia is $0.012 USD/kWh as of june 28, 2018 [68]. Therefore, the total energy cost is $828.46. This is summarized in Tables 5.3 and 5.4 for the calculation of operating costs.

Table 5. 3 : Electricity Costs for Running the Ceramic Production Line for Five Years

Machine	Power (kWh)
Hammer mill	20,000
Clay mixer	9,168
Kiln	39,870
Total Power	69,038
Total Electricity Costs	$828.46

Table 5. 4 : Operating Cost for Running the Ceramic Production Line for One Year

	Qty	Cost ($ USD)
Workers	4	$2,640.00
Power Consumption	-	828.46
Total Operating Cost		$3,468.46

Table 5. 5 : Unit Cost Summary for Production of Ceramic Filters

Number of Operating Years	5
Number of Production Lines	1
Number of Filters to be Produced	125,000
Total Production Cost	$117,166.85
Unit Cost	$0.94

The total production cost of making 125,000 filters in 5 years is $99,650.95. This yields a cost of $0.94 USD per ceramic filter and the proposed target sale price for the ceramic water filter is $3 USD per ceramic filter. Detail cost analysis was given on appendix G.

CHAPTER SIX

6 CONCLUSION AND RECOMMENDATIONS FOR FUTURE WORK

6.1 CONCLUSION

Based on the results obtained from the particle size distribution analysis result, Bambowuha and Hossana soils can be characterized as fine grained clay soils and their plasticity was found to be intermediate and high degree of plasticity nature. This also approved by drawing their plasticity result on the cassagrande plasticity chart. However, leku soil were found to be coarse sandy soil range particle size and non-plastic clay soil (due its high quartz content, said to be refractory clay soil). These gave them high flexibility or mouldablity nature during forming stage of filter production. This physical properties leku soil made it unsuitable for filter production because non plstic nature makes it fragile during forming stage and the high silca (quarz) content needed high firing temperature for vitrificatin to occur. Therefore, the soil was not selected for CPWF production. The characterization result revealed that, these two soils were found to be kaolinite clay mineral soils. Kaolin has a problem of shrinkage during fabrication process. This was due to the lage grain size inhibit the close packing of particles this leads to formation of void spaces which was responsible for high shrinkage during firing stage of production. However, the finer grain size and good plasticity nature made Bambowuha and Hossana soils suitable for ceramic water filter fabrication.In addition to this the shrinkage problem was solved by blending of the two kinds of kaolin clay soils (during Bambowuha and Hossana soils) during fabrication of lab scale filters.

From sample bar experimental result, it was easily understood that the correct choice of raw materials mixing proportion, particle size and firing temperature are very important processing parameter to produce CPWF with in an acceptable and optimum filter performance range. it was found that kaolin based filters (because from characterization result Bambowuha and Hossana found to be kaolinite clay) can be fabricated by setting the filter processing parameter range the clay and combustible materials particle size in to 300 to 600µm and 600 to 1200 µm respectively and firing temperature 950ºC to 1000 ºC. This processing was able to produce CPWF with

apparent porosities between 30% to 44% and filter total shrinkage less than 15%,which was agreed to the literature result. Out of the two tested combustible materials, sawdust did not have significant influence on the flow rate but it was the more reliable CPWFs preparing ingredient than teff husk. This mainly because of its good workability nature during mixing with clay and it lowered the plasticity of the clay lower than teff husk. The teff husk mix had lower workability or consistency at the processing stage is a setback; this would become an issue at production. Its workability had improvements on the finer particle size range than the coarser one.

The filtration rate of the lab scale developed filters having the following dimensions, base diameter (D_b) = 3.4cm, top diameter (D_T)= 5.7cm,height (h)=5.4cm, length of the lip(L_{lip}) = 1.5 cm and angle of filter wall inclination(θ) =80º, has a capacity of producing 2 up to 2.5 liter/hr. But if this dimension scaled up to filter element with ten liter water holding capacity in to large scale (having the following dimensions top diameter= 30 cm, water head height= 23cm and 22cm filter base diameter), it was calculated using Darcy flow rate equation and found to have a capacity of providing 25.5 – 36 liters per a day which was sufficient safe drinking water for an average five-member household. According to the Potters for Peace (PFP) filter design standards, filters that have a flow rate of between one and two (1-2) liters per hour are the best and filters The results obtained for the flow rate experiment, shows that all the eighteen filters that were used in the experiment met the pore requirement of the PFP filter standards, since they all had their flow rate between 2-2.5 liters per hour (L/h). The flow rate experiment revealed that except CPWFs with formulation of 80B/20S and 80B/20T, the filtration rate of most of CPWFs becomes decreased as the firing temperature increased from 900ºC to 1000ºC. This was mainly due the reduction of the filter pores through mobility of particles at vitrification temperature. Among the developed eighteen ceramic pot water filters, CPWFs with formulation of 80B/20S and 25H/55B/20T, which fired at 1000ºC and 25H/55B/20T 900ºC showed the highest(fastest) and the lowest(slowest)filtration rate respectively. Within the same processing parameters (firing temperature, sieving mesh and clay to combustible formulation ratio), Bambawuha kaolinite clay and sawdust (i.e 80B/20S) based filter showed the highest filtration rate. the flow rate was increased when the particle size increased from 600 µm to 1150 µm, when the combustibles amount of increased from 20 to 30 wt.% and the firing temperature lowered 1000ºC to 900ºC . This finding is consistent with the results of the majority of previous researches conducted in many countries. If regularly filled, the CPWFs would effectively produce 25.5 – 36 L of potable

water per day. According to this result, average flow rate CPWFs were also meets WHO minimum necessary volume of water needs for drinking, food preparation and basic personal hygiene, which was 7.5L. The filtration rate result of CPWFs,compared to the previous literature filtration result, high flow rate performance were achieved without sacrifice of their microbial removal efficiency.

Among seven tested CPWFs for chemical contaminants removal efficiency,CPWFs with 80B/20T and 80B/20S (fired at 1000ºC) formulation were observed to remove most chemical contaminants with the highest efficiency, followed by (fired at 1000ºC) formulation CPWF and then 80H/20S (fired at 1000ºC) and 25H/55B/20T.includes the reduction of turbidity from 13 to 1.15 NTU(i.e 91.15% removal efficiency),free residual fluoride ion from 3.4 to 0.053mg/100ml(i.e 99.81% removal efficiency), total dissolved solids from 1245mg/l to 7.4 mg/l (i.e 99.4% removal efficiency) and pH from 8.9 to 8.4 which was within acceptable range. From this research result, it was possible to fabricate ceramic water filter in Ethiopia and to use it as one of a promising future house hold water treatment technology for microbial removal and DE fluoridation of contaminated drinking water sources. One of the most successful achievements in this project was 99.81% fluoride ion removal efficiency of CPWFs.

From microbiological laboratory test results by using membrane filtration method indicated that the developed ceramic water filters are capable of removing more than 99.3 to 100 % of the total coliform bacteria and 100% of the fecal coliform from influent water samples. The removal efficiency result in log removal values expression for tested CPWFs for the removal of total coliform from tested ground water ranges from 2 LRV to 3 LRV. The results obtained for the E.coli test confirms that, during the filtration of the water, all disease causing bacteria and microorganisms were removed through the mechanical screening process, since no colony forming unit was record for the filtered raw ground water (for 0.5 ml and 1 ml sample water).

Ceramic water filters are one of household water treatment and safe storage (HWTS) technology, that have a capacity to supply sufficient and safe drinking water for around 43 % of our people who are in need for safe drinking water. In addition to these, compared to other water filters available on the market(bone char and bio sand water filters ,ceramic water filters will be the most socially accepted, cheap in price, highly efficient and multifunctional (i.e for both microbial and chemical contaminant removal).

Finally, from this project, it was possible to fabricate ceramic water filter in Ethiopia and to use it as one of a promising future house hold water treatment technology for microbial removal and DE fluoridation of contaminated drinking water sources

6.2 SUGGESTIONS FOR FUTURE WORK

Even though the ceramic filters are known to remove about 99.9% of disease causing bacteria and organisms without silver impregnation, it is also known not to be effective at the removal of viruses from filtered water. It is therefore proposed that, ceramic filters should be designed such that they will be good both at the removal of disease causing bacteria and viruses. In the larger picture, filters should be made such that, they will be able to remove toxic elements such as arsenic, zinc, and lead. These elements most often find their way into drinking water sources through leaching, erosion and bad farming practices which causes a lot of health problems.

One other issue that should be considered for future work concerning the ceramic filters has to do with their fragility. Since these filters are highly brittle, during transportation they develop hair-like cracks that affect their performance in terms of bacterial and microorganism removal. Some of them even break in the process and can no longer be used. Therefore, materials used in the making of these filters should be toughened to increase their resistance to cracking. Lastly, there is a need to study the effect of hydroxyapatite doping on the removal of fluoride from water. There is also the need to determine the lifetime of such filters.

Further work is needed to explore the clogging mechanism and the effects of turbidity on the long term flow characteristics. Mean of the saw dust based filters' flow rates are greater than the mean of the teff husk based filters' flow rates by 1.31 to 1.96 L/ hour.

In order to extend the study in this thesis, the following possible suggestions are given:

1. In this study, six ceramic water filters were tested over 12hours consecutive period. The flow rate and the effective permeability values are computed via Darcy Equation. However, to minimize variation in flow rate values and establish reliance on other flow parameters, there is a need to study ceramic water filters flow rates and permeability values over 1-2 year periods in which most the ceramic water filters are expected to provide filtered water.

2. It was also realized that, these filters can have a longer life span as long as the water being filtered is less turbid. Since the clogging of the pores is reduced to a minimal level and cleaning would not be very frequent, so keeping the filter intact for a long while.
3. Future research on theoretical flow models analysis on different geometrical shapes like paraboloid, disk and candle shape ceramic water filters should work to improve the quality of the models with further refinement, including manufacturing variable terms.
4. This research study is limited in that the flow rates were ascertained only during first use, not during use over time. This time period was chosen as the most relevant time for manufacturing quality control, but our results provide no information on normal use (including user cleaning recommendations) or end-of-life conditions. **Future research should consider above mentioned limitations of this study.**
5. The particle size distribution analysis part is not well covered for different kinds of Ethiopian soil specially monthimoreillonite and semectite clay for ceramic filter production. It is important that the clay used to make CWFPs does not shrink or expand excessively to the point that stress is created in the final product. Montmorillonite – which is highly plastic and seems ideal for forming CWFPs – can swell and shrink, resulting in cracking and breakage (Potters for Peace, 2011). Smectiteis generally sticky with high plasticity and strength in both dry and wet state.it is recommended that in making ceramic pots and water filters, clay comprising of high percentage of smectite. CPWFs with silver impregnation and hydroxyaphatite doped ceramic water filters may give also fruitful for future research.
6. Finally,such kinds of project should be an integral part of any water treatment and sanitation strategy. This research as it is of the first attempt to develop ceramic water filter in Ethiopia and provides clues to the manufacturing and production understanding of CPWF. Preliminary development and laboratory test results of the ceramic water filters showed promising results, but more research is required to make the filters applicable at large scale.

7 REFERENCE

1. Bekele T. and Leta S.(2016).Review: Water Supply and Health: Drinking water and Sanitation Coverage in Ethiopia 1990–2015. International Journal of Environment, Agriculture and Biotechnology (IJEAB),[Vol-1, Issue-1 , ISSN: XXXX-XXXX]
2. Gurría A. (2017). Putting water at the center of the global agenda. OECD Secretary-General, New York.
3. CSA and ICF International. (2012). Ethiopia Demographic and Health Survey 2011. Addis Ababa, Ethiopia and Calverton, Maryland, USA: Central Statistical Agency (CSA) and ICF International.
4. UNICEF and World Health Organization (2015). Progress on sanitation and drinking water – 2015 update and MDG assessment. World Health Organization, Geneva.
5. CSA and ICF International. (2012). Ethiopia Demographic and Health Survey 2011. Addis Ababa, Ethiopia and Calverton, Maryland, USA: Central Statistical Agency (CSA) and ICF International.
6. Onda, K., LoBuglio, J., & Bartram, J. (2012). Global Access to Safe Water: Accounting for Water Quality and the Resulting Impact on MDG Progress. International Journal of Environmental Research and Public Health, 9(12), 880–894.
7. WHO and UNICEF, "Global Water Supply and Sanitation Assessment 2000 Report" http://www.who.int/water_sanitation_health/Globassessment/GlobalTOC.htm
8. Brown, J., Sobsey, M. and Proum, S. (2007) Use of Ceramic Water Filters in Cambodia. Water and Sanitation Program/UNICEF: Cambodia.
9. Mwabi, J. K., Adeyemo, F. E., Mahlangu, T. O., Mamba, B. B., Brouckaert, B. M., Swartz, C. D., … Momba, M. N. B. (2011). Household water treatment systems: A solution to the production of safe drinking water by the low-income communities of Southern Africa. Physics and Chemistry of the Earth, 36(14–15), 1120–1128.
10. Sobsey, M. D., Stauber, C. E., Casanova, L. M., Brown, J. M., & Elliott, M. a. (2008). Point of use household drinking water filtration: A practical, effective solution for providing sustained access to safe drinking water in the developing world. Environmental Science and Technology, 42(12), 4261 –4267.
11. Lantagne, D.S. (2001a) Investigation of the Potters for Peace Colloidal Silver Impregnated Ceramic Filter Report 1: Intrinsic Effectiveness. Alethia Environmental: Allston, MA, USA

12. Van Halem, D., Heijman, S.G.J., Soppe, A.I.A., van Dijk, J.C., Amy, G.L., 2007. Ceramic silver-impregnated pot filters for household drinking water treatment in developing countries: material characterization and performance study. Water Sci. Technol. Water Supply 7 (5e6), 9e17
13. Amenu D. (2014). Bacteriological and Physicochemical Quality of Well Water Sources .Res. J. Chem. Env. Sci. Vol 2 [5]. 13-27, ISSN 2321 -1040, CODEN: RJCEA2 [USA].
14. Rayner, J. (2009). Current Practices in Manufacturing of Ceramic Pot Filters for Water Treatment. Loughborough University.
15. Rayner, J., Skinner, B., Lantagne, D., 2013. Current practices in manufacturing locally-made ceramic pot filters for water treatment in developing countries. J. Water, Sanit.Hygiene Dev 3 (2), 252e261.
16. Gebrekidan M, Samuel Z (2011). Concentration of heavy metals in drinking water from urban areas of the Tigray Region, Northern Ethiopia. Coll Nat Comput Sci Mekelle Uni 3(1):105–121
17. WHO (2004).Guidelines for drinking water quality,3rd edition Vol.1.World Health Organizations, Switzerland, Geneva.
18. Alemu Z. A., Kirubel T. T., Tsigereda A. A., Kifl H. B. and Sisay D. M. (2015). Physicochemical quality of drinking water sources in Ethiopia and its health impact: a retrospective study. Environ Syst Res 4:22, DOI 10.1186/s40068-015-0049-7.
19. WHO, & UNICEF. (2014). Progress on sanitation and drinking-water 2014 update.95 Monitoring Program for water supply and sanitation. World Economic Forum. (2015). Global Risks 2015 10th Edition. World Economic Forum.
20. Dies W.R.,(2003). "Development of a ceramic water filter for Nepal", Masters of Engineering Thesis.(Massachusetts Institute of Technology(MIT), Department of Civil and Environmental Engineering, Cambridge, MA
21. van Halem, D. (2006) Ceramic silver impregnated pot filters for household drinking water treatment in developing countries. Unpublished Thesis, Delft University of Technology, Delft.

22. Xiaolong, L., and M.S.C. Yi (2005)‘The method to define the pore diameter and its distribution for porous membrane’,Tianjin Montian Company, Tianjin Polytechnic University, Tianjin.
23. Van der Laan, H.,van Halem, D.,Smeets, P. W. M. H., Soppe, a. I. a, Kroesbergen, J.,Wubbels, G.Heijman, S. G. J. (2014). Bacteria and virus removal effectiveness of ceramic pot filters with different silver applications in a long term experiment. Water Research, 51, 47–54.
24. Brown, J., Sobsey, M. and Proum, S. (2007) Use of Ceramic Water Filters in Cambodia.Water and Sanitation Program/UNICEF: Cambodia.
25. Simons s. (2011) comparative Investigation of Ceramic Pot Filter performance . M Sc. thesis. Emory University. Pp.1-38.
26. Klarman, M. (2009) Investigation of Ceramic Pot Filter Design Variables. Unpublished Thesis, Emory University, Rollins School of Public Health, USA.
27. Hagan, J.M., Harley, N., Pointing, D., Sampson, M., Smith, K. and Soam, V. (2009) Resource Development International - Cambodia Ceramic Water Filter Handbook-, Version 1.1. Phnom Penh, Cambodia.
28. Oyanedel-Craver, V.A. and Smith, J.A. (2008) Sustainable colloidal-silver-impregnated ceramic filter for point-of-use water treatment. Environmental science & technology 42(3): 927-933.
29. Bielefeldt, A.R., Kowalski, K., Schilling, S., Schreier, S., Kohler, A., Summers, R.S., 2010. Removal of virus to protozoan sized particles in point-of-use ceramic water filters. Water Res. 44,1482e1488
30. ASTM International, 2003. Standard test method for particle-size analysis of soils (Standard D422-63[2002]). In Annual Book of ASTM Standards (Vol. 04.08): Soil and Rock (I): West Conshohocken, PA (Am. Soc. Testing and Mater.), 10–17.
31. ASTM. 2010. ASTM Standard D4318, 2010, “Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils,”. ASTM International. www.astm.org.
32. Potters for Peace. (2011). Best Practice Recommendations for Local Manufacturing of Ceramic Pot Filters for Household Water Treatment. The Ceramics Manufacturing Group, 1(1), 187.

33. ASTM (2001): Standard Test Method for Drying and Fired Shrinkages of Ceramic Whiteware Clays (Designation: C 326), 15:02
34. Rhodes, D. (1973) Clay and Glazes for the Potter. Krause Publications: Iola Wisconsin.
35. ASTM C 326-03, Standard test method for drying and firing shrinkages of ceramic whiteware clays, Volume 15 – 02, Glass and Ceramic.
36. UNI 4543-2:1986, "Ceramic Sanitary Appliances - Tests On Ceramic Materials", ICS [91.140.70], UNI,
37. Rayner, J., Skinner, B., Lantagne, D., 2013. Current practices in manufacturing locally-made ceramic pot filters for water treatment in developing countries. J. Water, Sanit.Hygiene Dev3 (2), 252e261 .
38. Yakub, I., Du, J. and Soboyejo, W.O. (2012). "Mechanical Properties, modeling and design of porous clay ceramics." Mat. Sci. & Eng. A 558, 21-29
39. Hamer, F. and Hamer, J. (2004) The Potter's Dictionary of Materials and Techniques. A&C Black Publishers Ltd: London.
40. WHO (2006).Guidelines for drinking water quality, 1st Addendum to the 3rd edition Vol. Recommendations. World Health Organizations. Switzerland, Geneva
41. Girma,A.,Bamboro,S.,Shimselis,B.,Tadesse,C.,Mokonnen,M.,Gossa,T.,(2011).National Drinking Water Quality Monitoring and Surveillance Strategy. Addis Ababa:
42. APHA, 1999. Standard methods for the examination of water and wastewater, 20th Ed., American Public Health Association, Washington DC, USA,.
43. Millipore.1992.Water Microbiology: Laboratory and Field Procedures. Millipore corp., Bedford, MA. pge.35-39.
44. Grim, R.E. (1968) Clay Mineralogy. McGraw-Hill Book Co., New York, 596.
45. Bramao, L. et al., 1952. Characterization of kaolin minerals. Soil Sci. 73, 273–287.
46. Velde, B. (1992) Introduction to clay minerals; First edition; Chapman and Hall; UK.
47. Bear, J. (1972)."Dynamics of Fluids in Porous Media", New York, USA: American Elsevier Publication Company.
48. Bontle, M. and Nadiye-Tabbiruka, M.S. (2007) Chemical and Thermal Characterization of a Clay Material Found Near Gaborone Dam. Journal of Applied Sciences and Environmental Management, 11, 77-80.

49. Heller-Kallai L (2006).Handbook of Clay Science, Chapter 7.2, Edited by F.Bergaya, B.K.G.Theng and G.Lagaly, Developments in Clay Science, Elsevier Ltd.1.
50. Ekosse, G.; (2001); Provenance of the Kgakgwe kaolin deposit in southeastern Botswana and its possible utilization; Applied Clay Science; 20:137-152.
51. Newman, A.D.C; (1987). Chemistry of clays and clay minerals; Longman scientific and technical; USA.
52. Yakub, I. and Soboyejo W.O.(2013). 'Adsorption of Fluoride from Water Using Sintered Clay-Hydroxyapatite Composites', J. Environ. Eng., 2013 vol.139: 995-1003
53. Molly, K.(2009). Investigation of Ceramic Pot Filter Design Variables. M Sc. thesis. Emory University. Pp.1-38.
54. Center for Disease Control (CDC).Household Water Treatment Options in Developing Countries: Ceramic Filtration [online]. http://www.cdc.gov..
55. Clasen, T., Cairncross, S., Haller, L., Bartram, J. (2007). "Walker, D. Cost effectiveness of water quality interventions for preventing diarrheal disease in developing countries. Journal of Water and Health Vol.5 No.4 pp. 599–608.
56. Andrade, F. A., Al-Qureshi H. A., and Hotza D. (2011). "Measuring the plasticity of clays: A review." Applied Clay 51, 1-7.
57. Bain, J.A., Highly, D.E., 1978.Regional appraisal of clay resources challenge to the clay mineralogist. In: Mortland, M.M., Faxmer, V.C. (Eds.), Proc. Int. Clay. Conf. Elsevier, Amsterdam, pp. 437–446
58. Morachevskii, Chernogorenko, V.B., 1961. The effect of density deformation on the structural strength and electrical conductivity of clay bodies. Steklo i Keramika 18 (1), 33–36.
59. Demir, Ismail, Serhat Baspinar, M., Orhan, Mehmet, 2005. Utilization of Kraft pulp production residues in clay brick production. Build.Environ. 40, 1533–1537.
60. Baccour, H., Medhioub, M., Jamoussi, F., Mhiri, T., Daoud, A., 2008.Mineralogical evaluation and industrial applications of the Triassicclay deposits, Southern Tunisia. Mater. Charact. 59, 1613–1667
61. International Finance Corporation, "Explore Economics – Ethiopia," doingbusiness.org, 2016.[Online].Available:http://www.doingbusiness.org/ExploreEconomies/?economyid=101

62. Meadows Mills, “New and Used Hammer Mills and Related Equipments,” meadowmills.com, 2001. [Online]. Available:http://www.meadowsmills.com/forsalehm.htm
63. Bailey Ceramics Supply, “Bailey Clay Mixers – Soldner Clay Mixers & Bailey Dust Hoods,”baileypotter.com,2009.[Online].Available:http://www.baileypottery.com/pugmillsmixers/soldnerclaymixers.htm
64. Justoffbase, “Hydraulic Presses,” justoffbase.co.uk, 2009. [Online]. Available: http://www.justoffbase.co.uk/10-Tonne-Hydraulic-Bench-Press-58157-Draper HBP10
65. “2008 Price List for L&L Kilns,” October 6, 2008. [Online]. Available: http://www.hotkilns.com/price
66. XE, “Currency Converter,” xe.com, June 28, 2018. [Online]. Available: www.xe.com

8 APPENDIX

APPENDIX -A

Particle size distribution analysis result of Bambowuha clay, Hossan clay and Leku clay

Table A_1: sieve and hydrometer analysis of Babawuha soil

sample kind: Babawuha clay **Sample Depth, m :** 0.60

Sieve Analysis Total mass of sample, g 500

Sieve No	Sieve Opening (mm)	Mass of Sieve (g)	Mass of sieve + Retained soil (g)	Mass of Retained soil (g)	Percentage Retained (%)	Cum. Percentage Retained (%)	Perc. Passing (%)
3''	75.0	1057.0	1057.0	0.0	0.0	0.0	100.0
2''	50.0	1199.0	1199.0	0.0	0.0	0.0	100.0
1.5"	37.5	1084.0	1084.0	0.0	0.0	0.0	100.0
1"	25.0	1187.0	1187.0	0.0	0.0	0.0	100.0
3/4''	19.0	716.0	716.0	0.0	0.0	0.0	100.0
1/2"	12.5	584.0	584.0	0.0	0.0	0.0	100.0
3.8"	9.5	586.0	586.0	0.0	0.0	0.0	100.0
No 4	4.75	441.0	643.0	202.0	4.4	4.4	95.6
No 8	2.36	530.0	530.0	0.0	0.0	4.4	95.6
No 10	2	467.0	540.0	73.0	1.6	6.0	94.0
No 16	1.18	434.0	492.0	58.0	1.3	7.3	92.7
No 30	0.6	407.0	459.0	52.0	1.1	8.4	91.6
No 50	0.3	372.0	391.0	19.0	0.4	8.8	91.2
No 100	0.15	343.0	399.0	56.0	1.2	10.1	89.9
No 200	0.075	335.0	354.0	19.0	0.4	10.5	89.5
pan	-------	252.0	279.0	27.0	0.6	11.1	-------

Hydrometer Analysis

Specific Gravity of soil 2.79 Test Temperature, deg.c 20

Elapsed Time (min)	Actual Hydrometer Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Coefficient K	Grain Size (mm)	Perc. Finer (%)	Perc. Finer Combined (%)
3/4	1.0260	-0.0027	1.0233	9.42	0.01312	0.0403	72.63	25.82
1	1.0255	-0.0027	1.0228	9.55	0.01312	0.0287	71.07	25.27
2	1.0235	-0.0027	1.0208	10.08	0.01312	0.0208	64.84	23.05
4	1.0210	-0.0027	1.0183	10.75	0.01312	0.0152	57.05	20.28
8	1.0180	-0.0027	1.0153	11.54	0.01312	0.0115	47.69	16.96
15	1.0160	-0.0027	1.0133	12.07	0.01312	0.0083	41.46	14.74
30	1.0135	-0.0027	1.0108	12.73	0.01312	0.0060	33.67	11.97
60	1.0110	-0.0027	1.0083	13.39	0.01312	0.0062	25.87	9.20
120	1.0080	-0.0027	1.0053	14.18	0.01312	0.0045	16.52	5.87
240	1.0075	-0.0027	1.0048	14.32	0.01312	0.0032	14.96	5.32
480	1.0070	-0.0027	1.0043	14.45	0.01312	0.0023	13.40	4.77
1440	1.0060	-0.0027	1.0033	14.71	0.01312	0.0013	10.29	3.66

TEST			LIQUID LIMIT			PLASTIC LIMIT		
Variable	NO							
	Var.	Units	1	2	3	1	2	3
Number of Blows	N	blows	35	22	14			
Can Number	---	---						
Mass of Empty Can	M_C	(g)	60	60	60	60	60	60
Mass Can & Soil (Wet)	M_{CMS}	(g)	79	79	80	70	71	70
Mass Can & Soil (Dry)	M_{CDS}	(g)	71	72	71	66	67	68
Mass of Soil	M_S	(g)	11	12	11	6	7	8
Mass of Water	M_W	(g)	8	7	9	4	4	2
Water Content	*w*	(%)	72.72727	58.33333	81.81818	66.66667	57.14286	25

Table A_2: sieve and hydrometer analysis of Hossan soil

Sample No : TP1 **Sample Depth, m :** 0.90

Sieve Analysis Total mass of sample, g 500

Sieve No	Sieve Opening (mm)	Mass of Sieve (g)	Mass of sieve + Retained soil (g)	Mass of Retained soil (g)	Percentage Retained (%)	Cum. Percentage Retained (%)	Perc. Passing (%)
3''	75.0	1057.0	1057.0	0.0	0.0	0.0	100.0
2''	50.0	1199.0	1199.0	0.0	0.0	0.0	100.0
1.5"	37.5	1084.0	1084.0	0.0	0.0	0.0	100.0
1"	25.0	1187.0	1187.0	0.0	0.0	0.0	100.0
3/4''	19.0	716.0	716.0	0.0	0.0	0.0	100.0
1/2"	12.5	584.0	584.0	0.0	0.0	0.0	100.0
3.8"	9.5	586.0	586.0	0.0	0.0	0.0	100.0
No 4	4.75	441.0	523.0	82.0	1.8	1.8	98.2
No 8	2.36	530.0	530.0	0.0	0.0	1.8	98.2
No 10	2	467.0	486.0	19.0	0.4	2.2	97.8
No 16	1.18	434.0	498.0	64.0	1.4	3.6	96.4
No 30	0.6	407.0	409.0	2.0	0.0	3.6	96.4
No 50	0.3	372.0	489.0	117.0	2.6	6.2	93.8
No 100	0.15	343.0	450.0	107.0	2.3	8.5	91.5
No 200	0.075	335.0	550.0	215.0	4.7	13.2	86.8
pan	-------	252.0	306.0	54.0	1.2	14.4	-------

Hydrometer Analysis

Specific Gravity of soil 2.79 Test Temperature, deg.c 20

Elapsed Time (min)	Actual Hydrometer Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Coefficient K	Grain Size (mm)	Perc. Finer (%)	Perc. Finer Combined (%)
3/4	1.0260	-0.0027	1.0233	9.42	0.01312	0.0403	72.63	25.82
1	1.0255	-0.0027	1.0228	9.55	0.01312	0.0287	71.07	25.27
2	1.0235	-0.0027	1.0208	10.08	0.01312	0.0208	64.84	23.05
4	1.0210	-0.0027	1.0183	10.75	0.01312	0.0152	57.05	20.28
8	1.0180	-0.0027	1.0153	11.54	0.01312	0.0115	47.69	16.96
15	1.0160	-0.0027	1.0133	12.07	0.01312	0.0083	41.46	14.74
30	1.0135	-0.0027	1.0108	12.73	0.01312	0.0060	33.67	11.97
60	1.0110	-0.0027	1.0083	13.39	0.01312	0.0062	25.87	9.20
120	1.0080	-0.0027	1.0053	14.18	0.01312	0.0045	16.52	5.87
240	1.0075	-0.0027	1.0048	14.32	0.01312	0.0032	14.96	5.32
480	1.0070	-0.0027	1.0043	14.45	0.01312	0.0023	13.40	4.77
1440	1.0060	-0.0027	1.0033	14.71	0.01312	0.0013	10.29	3.66

TEST			LIQUID LIMIT			PLASTIC LIMIT		
Variable	NO							
	Var.	Units	1	2	3	1	2	3
Number of Blows	N	blows	29	13	11			
Can Number	---	---						
Mass of Empty Can	M_C	(g)	61	60	61	60	60	61
Mass Can & Soil (Wet)	M_{CMS}	(g)	91	90	93	69	70	71
Mass Can & Soil (Dry)	M_{CDS}	(g)	79	77	79	65	68	68
Mass of Soil	M_S	(g)	18	17	18	5	8	7
Mass of Water	M_W	(g)	12	13	14	4	2	3
Water Content	*w*	(%)	66.66667	76.47059	77.77778	80	25	42.85714

Table A_3: sieve and hydrometer analysis of Leku soil

Sample kind: LEKU CLAY(LC) **Sample Depth, m :** 0.90

Sieve Analysis Total mass of sample, g 500

Sieve No	Sieve Opening (mm)	Mass of Sieve (g)	Mass of sieve + Retained soil (g)	Mass of Retained soil (g)	Percentage Retained (%)	Cum. Percentage Retained (%)	Perc. Passing (%)
3''	75.0	1057.0	1057.0	0.0	0.0	0.0	100.0
2''	50.0	1199.0	1199.0	0.0	0.0	0.0	100.0
1.5"	37.5	1084.0	1084.0	0.0	0.0	0.0	100.0
1"	25.0	1187.0	1187.0	0.0	0.0	0.0	100.0
3/4''	19.0	716.0	716.0	0.0	0.0	0.0	100.0
1/2"	12.5	584.0	584.0	0.0	0.0	0.0	100.0
3.8"	9.5	586.0	586.0	0.0	0.0	0.0	100.0
No 4	4.75	441.0	523.0	82.0	1.8	1.8	98.2
No 8	2.36	530.0	530.0	0.0	0.0	1.8	98.2
No 10	2	467.0	486.0	19.0	0.4	2.2	97.8
No 16	1.18	434.0	498.0	64.0	1.4	3.6	96.4
No 30	0.6	407.0	409.0	2.0	0.0	3.6	96.4
No 50	0.3	372.0	489.0	117.0	2.6	6.2	93.8
No 100	0.15	343.0	450.0	107.0	2.3	8.5	91.5
No 200	0.075	335.0	550.0	215.0	4.7	13.2	86.8
pan	-------	252.0	306.0	54.0	1.2	14.4	-------

Hydrometer Analysis

Specific Gravity of soil 2.79 Test Temperature, deg.c 20

Elapsed Time (min)	Actual Hydrometer Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Coefficient K	Grain Size (mm)	Perc. Finer (%)	Perc. Finer Combined (%)
3/4	1.0260	-0.0027	1.0233	9.42	0.01312	0.0403	72.63	25.82
1	1.0255	-0.0027	1.0228	9.55	0.01312	0.0287	71.07	25.27
2	1.0235	-0.0027	1.0208	10.08	0.01312	0.0208	64.84	23.05
4	1.0210	-0.0027	1.0183	10.75	0.01312	0.0152	57.05	20.28
8	1.0180	-0.0027	1.0153	11.54	0.01312	0.0115	47.69	16.96
15	1.0160	-0.0027	1.0133	12.07	0.01312	0.0083	41.46	14.74
30	1.0135	-0.0027	1.0108	12.73	0.01312	0.0060	33.67	11.97
60	1.0110	-0.0027	1.0083	13.39	0.01312	0.0062	25.87	9.20
120	1.0080	-0.0027	1.0053	14.18	0.01312	0.0045	16.52	5.87

Appendix B

Table B_1: all survived test bar result fired at 800ºC and 900ºC

Sample test bar code	weiht of plastic bar, W_p(in gm)	Weight of oven dried bar, W_d (in gm)	Weight of fired bar, W_f (in gm)	Weight in air ,Wair (g)	Soaked weight, Ws(g)	Water saturated, Wsat (g)	water of plasticity(T)%	%apparent porosity	%water absorption	Apparent density (g/cm3)	Bulk density (g/cm3)	% Loss of ignition (LOI)
50H/50S	12.3	8	6.76	6.76	2.45	11.98	54	55	77	1.57	0.71	16
60H/40S	13.13	7.4	4.2	4.2	1.5	12.11	77	75	188	1.56	0.4	43
70H/30S	16.07	8.8	6.73	6.73	2.54	10.66	83	48	59	1.61	0.83	24
50B/50S	12	5.96	5.7	5.96	2.19	11.61	101	60	95	1.58	0.63	4
70B/30S	16.93	8.68	6.82	6.82	2.67	12.73	95	59	87	1.64	0.68	21
60L/40S	14.3	7.67	5.21	5.2	1.79	10.9	86	63	110	1.53	0.57	32
70L/30S	15.83	8.62	6.94	6.34	2.6	12.78	84	63	102	1.7	0.62	20
25H/45B/30S	17.03	9.02	5.68	5.68	2.36	10.64	89	60	87	1.71	0.69	37
25B/35L/40S	15.1	9	4.93	4.93	1.55	11.14	68	65	126	1.46	0.51	45
25H/45L/30S	17.37	9.35	5.75	5.75	1.97	10.88	86	58	89	1.52	0.65	39
15H/30B/15L/40S	18.3	8.86	4.18	4.18	1.42	9.12	107	64	118	1.51	0.54	53

APPENDEX C

ASTM On Water Absorption,Bulk Density And Apparent Porosity Test

Designation: C 373 – 88 (Reapproved 2006)

Standard Test Method for Water Absorption, Bulk Density, Apparent Porosity, and Apparent Specific Gravity of Fired Whiteware Products[1]

This standard is issued under the fixed designation C 373; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers procedures for determining water absorption, bulk density, apparent porosity, and apparent specific gravity of fired unglazed whiteware products.

1.2 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Significance and Use

2.1 Measurements of density, porosity, and specific gravity is a tool for determining the degree of maturation of a ceramic body, or for determining structural properties that may be required for a given application.

3. Apparatus and Materials

3.1 *Balance*, of adequate capacity, suitable to weigh accurately to 0.01 g.

3.2 *Oven*, capable of maintaining a temperature of 150 ± 5°C (302 ± 9°F).

3.3 *Wire Loop, Halter, or Basket*, capable of supporting specimens under water for making suspended mass measurements.

3.4 *Container*—A glass beaker or similar container of such size and shape that the sample, when suspended from the balance by the wire loop, specified in 3.3, is completely immersed in water with the sample and the wire loop being completely free of contact with any part of the container.

3.5 *Pan*, in which the specimens may be boiled.

3.6 *Distilled Water*.

4. Test Specimens

4.1 At least five representative test specimens shall be selected. The specimens shall be unglazed and shall have as much of the surface freshly fractured as is practical. Sharp edges or corners shall be removed. The specimens shall contain no cracks. The individual test specimens shall weigh at least 50 g.

5. Procedure

5.1 Dry the test specimens to constant mass (Note 1) by heating in an oven at 150°C (302°F), followed by cooling in a desiccator. Determine the dry mass, *D*, to the nearest 0.01 g.

NOTE 1—The drying of the specimens to constant mass and the determination of their masses may be done either before or after the specimens have been impregnated with water. Usually the dry mass is determined before impregnation. However, if the specimens are friable or evidence indicates that particles have broken loose during the impregnation, the specimens shall be dried and weighed after the suspended mass and the saturated mass have been determined, in accordance with 5.3 and 5.4. In this case, the second dry mass shall be used in all appropriate calculations.

5.2 Place the specimens in a pan of distilled water and boil for 5 h, taking care that the specimens are covered with water at all times. Use setter pins or some similar device to separate the specimens from the bottom and sides of the pan and from each other. After the 5-h boil, allow the specimens to soak for an additional 24 h.

5.3 After impregnation of the test specimens, determine to the nearest 0.01 g the mass, *S*, of each specimen while suspended in water. Perform the weighing by placing the specimen in a wire loop, halter, or basket that is suspended from one arm of the balance. Before actually weighing, counterbalance the scale with the loop, halter, or basket in place and immerse in water to the same depth as is used when the specimens are in place. If it is desired to determine only the percentage of water absorption, omit the suspended mass operation.

5.4 After the determination of the suspended mass or after impregnation, if the suspended mass is not determined, blot each specimen lightly with a moistened, lint-free linen or cotton cloth to remove all excess water from the surface, and determine the saturated mass, *M*, to the nearest 0.01 g. Perform the blotting operation by rolling the specimen lightly on the wet cloth, which shall previously have been saturated with water and then pressed only enough to remove such water as will drip from the cloth. Excessive blotting will introduce error by withdrawing water from the pores of the specimen. Make the weighing immediately after blotting, the whole operation being completed as quickly as possible to minimize errors caused by evaporation of water from the specimen.

6. Calculation

6.1 In the following calculations, the assumption is made that 1 cm^3 of water weighs 1 g. This is true within about 3 parts in 1000 for water at room temperature.

6.1.1 Calculate the exterior volume, *V*, in cubic centimetres, as follows:

$$V = M - S \quad (1)$$

6.1.2 Calculate the volumes of open pores V_{op} and impervious portions V_p in cubic centimetres as follows:

$$V_{op} = M - D \quad (2)$$

$$V_p = D - S \quad (3)$$

6.1.3 The apparent porosity, *P*, expressed as a percent, the relationship of the volume of the open pores of the specimen to its exterior volume. Calculate the apparent porosity as follows:

$$P = [(M - D)/V] \times 100 \quad (4)$$

6.1.4 The water absorption, *A*, expressed as a percent, the relationship of the mass of water absorbed to the mass of the dry specimen. Calculate the water absorption as follows:

$$A = [(M - D)/D] \times 100 \quad (5)$$

6.1.5 Calculate the apparent specific gravity, *T*, of that portion of the test specimen that is impervious to water, as follows:

$$T = D/(D - S) \quad (6)$$

6.1.6 The bulk density, *B*, in grams per cubic centimetre, of a specimen is the quotient of its dry mass divided by the exterior volume, including pores. Calculate the bulk density as follows:

$$B = D/V \quad (7)$$

7. Report

7.1 For each property, report the average of the values obtained with at least five specimens, and also the individual values. Where there are pronounced differences among the individual values, test another lot of five specimens and, in addition to individual values, report the average of all ten determinations.

8. Precision and Bias

8.1 This test method is accurate to ±0.2 % water absorption in interlaboratory testing when the average value recorded by all laboratories is assumed to be the true water absorption. The precision is approximately ±0.1 % water absorption on measurements made by a single experienced operator.

9. Keywords

9.1 apparent porosity; apparent specific gravity; bulk density; fired whiteware products; water absorption

[1] This test method is under the jurisdiction of ASTM Committee C21 on Ceramic Whitewares and Related Products and is the direct responsibility of Subcommittee C21.01 on Methods for Whitewares and Environmental Ceramics.

Current edition approved Feb. 15, 2006. Published February 2006. Originally approved in 1925. Last previous edition approved in 1999 as C 373 – 88 (1994).

APPENDEX D

Table 5 : Table on different composition of sample test bars for evaluating filter processing parameter

Test Bar samples code	Raw materials for filter production			
	Hossana clay (in wt. %)	Babawuha clay (in wt. %)	Leku clay (in wt. %)	Saw dust (in wt. %)
50H/50S	50	0	0	50
60H/40S	60	0	0	40
70H/30S	70	0	0	30
50B/50S	0	50	0	50
60B/40S	0	60	0	40
70B/30S	0	70	0	30
50L/50S	0	0	50	50
60L/40S	0	0	60	40
70L/30S	0	0	70	30
25H/25B/50S	25	25	0	50
35H/25B/40S	35	25	0	40
25H/45B/30S	25	45	0	30
25B/25L/50S	0	25	25	50
35B/25L/40S	0	35	25	40
25B/35L/40S	0	25	35	40
25H/25L/50S	25	0	25	50
35H/25L/40S	35	0	25	40

APPENDIX E

Table E_1 Quantity of water filtered in ml from each of the filters for each time interval

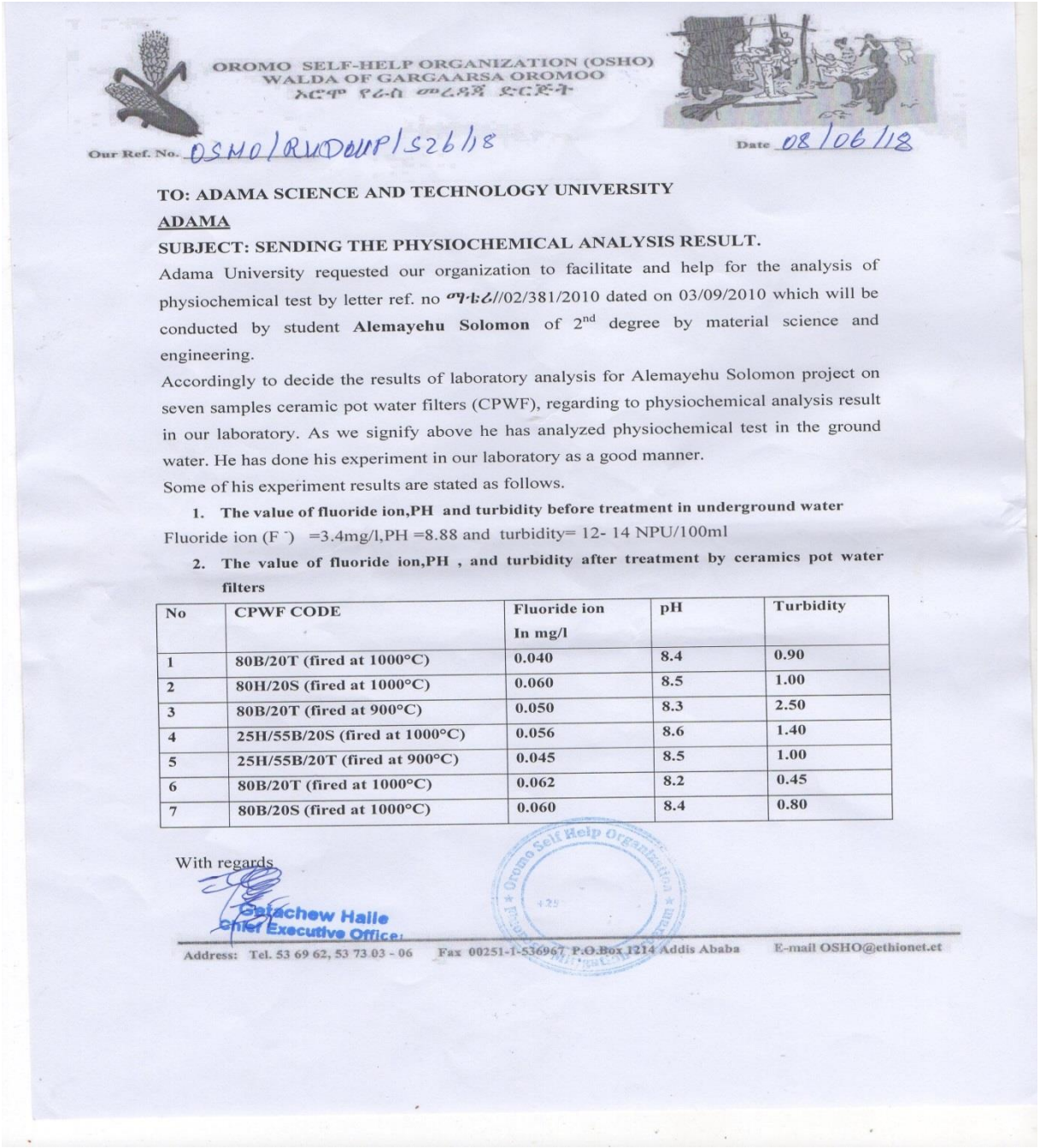
Filter processing condition	Mixed ratio OR filter code	water filtered in ml																			
		1HR				2HR				3HR				4HR				5HR			
		¥T-1	T-2	T-3	¥A	T-1	T-2	T-3	A	T-1	T-2	T-3	A	T-1	T-2	T-3	A	T-1	T-2	T-3	A
Filters sieved by ¥30/16 mesh no. and fired at 900ºC	80H/20S	75	72	70	72	57	54	52	54	48	47	45	47	38	36	34	36	23	20	21	21
	80B/20S	75	73	70	73	57	55	57	56	48	48	47	48	38	37	37	37	35	36	36	36
	80H/20T	61	65	63	63	46	48	44	46	41	40	36	39	23	20	22	22	20	20	18	19
	80B/20T	71	69	72	71	44	45	44	44	32	30	29	30	24	24	21	23	23	25	24	24
	25H/55B/20S	76	78	75	76	50	49	50	50	48	48	47	48	37	40	39	39	31	33	30	31
	25H/55B/20T	79	75	74	76	51	48	49	49	44	40	42	42	33	32	30	32	25	22	20	22
Filters sieved by 30/16 mesh no. and fired at 1000ºC	80H/20S	50	52	49	50	47	45	42	45	44	45	44	44	38	37	36	37	31	33	30	31
	80B/20S	69	67	70	69	5 9	54	56	56	53	50	51	51	48	49	47	48	48	46	46	47
	80H/20T	50	46	48	48	48	52	49	50	44	52	40	45	28	24	26	26	25	20	22	22
	80B/20T	74	72	69	72	51	50	48	50	48	45	46	46	44	42	41	42	29	25	26	27
	25H/55B/20S	47	48	48	48	44	45	44	44	31	33	30	31	30	32	30	31	30	33	31	31
	25H/55B/20T	49	52	46	49	44	42	40	42	29	27	24	27	27	28	24	26	23	22	23	23
Filters sieved by 60/30 mesh no. and fired at 900ºC	80H/20S	48	47	45	47	42	40	41	41	40	36	38	38	30	27	28	28	21	23	20	21
	80B/20S	48	48	47	48	45	43	45	44	41	41	38	40	33	30	29	31	23	22	20	22
	80H/20T	41	40	36	39	38	35	32	35	36	39	35	37	25	22	20	22	20	18	18	19
	80B/20T	38	36	35	36	35	37	34	35	38	32	30	33	34	35	30	33	25	22	23	23
	25H/55B/20S	50	48	47	48	45	46	44	45	28	30	30	29	27	25	26	26	24	24	22	23
	25H/55B/20T	44	40	42	38	40	39	39	39	26	25	25	25	20	22	21	21	18	20	20	19

¥30/16 mesh no is the sieving mesh stands for sieving clay (i.e 30 mesh no. is equivalent to 600µm) and the second sieve (i.e 16 mesh no. is equivalent to 1180µm).similarly, to 30/60 mesh no. and 60 mesh no. is equivalent to 300 µm.

¥T-1 and ¥Astands for the first trial flow rate test and the average first trial flow rate test result. Similarly to other filtration trial tests and average result.

APPENDIX F

A legal certificate for de-fluoridation, turbidity removal and PH result ground water filtered through CPWF



OROMO SELF-HELP ORGANIZATION (OSHO)
WALDA OF GARGAARSA OROMOO
ኦሮሞ የራስ መረዳጃ ድርጅት

Our Ref. No. OSHO/RWDOWP/526/18 Date 08/06/18

TO: ADAMA SCIENCE AND TECHNOLOGY UNIVERSITY
ADAMA
SUBJECT: SENDING THE PHYSIOCHEMICAL ANALYSIS RESULT.

Adama University requested our organization to facilitate and help for the analysis of physiochemical test by letter ref. no ማ·ቴ/ሪ//02/381/2010 dated on 03/09/2010 which will be conducted by student **Alemayehu Solomon** of 2nd degree by material science and engineering.

Accordingly to decide the results of laboratory analysis for Alemayehu Solomon project on seven samples ceramic pot water filters (CPWF), regarding to physiochemical analysis result in our laboratory. As we signify above he has analyzed physiochemical test in the ground water. He has done his experiment in our laboratory as a good manner.

Some of his experiment results are stated as follows.

1. **The value of fluoride ion,PH and turbidity before treatment in underground water**

Fluoride ion (F^-) =3.4mg/l,PH =8.88 and turbidity= 12- 14 NPU/100ml

2. **The value of fluoride ion,PH , and turbidity after treatment by ceramics pot water filters**

No	CPWF CODE	Fluoride ion In mg/l	pH	Turbidity
1	80B/20T (fired at 1000°C)	0.040	8.4	0.90
2	80H/20S (fired at 1000°C)	0.060	8.5	1.00
3	80B/20T (fired at 900°C)	0.050	8.3	2.50
4	25H/55B/20S (fired at 1000°C)	0.056	8.6	1.40
5	25H/55B/20T (fired at 900°C)	0.045	8.5	1.00
6	80B/20T (fired at 1000°C)	0.062	8.2	0.45
7	80B/20S (fired at 1000°C)	0.060	8.4	0.80

With regards

Gutachow Halle
Chief Executive Office

Address: Tel. 53 69 62, 53 73 03 - 06 Fax 00251-1-536967 P.O.Box 1214 Addis Ababa E-mail OSHO@ethionet.et

APPENDIX G

Cost Analysis Calculations Ceramic Filter

I. **Materials Cost**

- Clay to be purchased locally at approximately $0.06 USD/single used brick
- 125,000 bricks required to produce 125,000 ceramic filters in 5 years
- Saw dust(rice husk) and teff husk would be purchased locally at approximately $0.01 USD for sufficient supplies to produce 125,000 filters

The materials cost needed to manufacture 125,000 ceramic filters are estimated as below.

Cost of materials = 125,000 × $0.06 + $0.01 = $7,500.06

II. Equipment cost

- Clay crusher $10.00
- Meadow #5 hammer mill $1,680.00
- Bailey clay mixer $4,082
- Misc. Tools $200.00
- Draper hydraulic press with mould $542.85
- L&L kiln $5,950

Cost of equipment = $10 + $1680 + $4082 + $200 + $542.85 + $5950 = $12,464.85

III. Operating Costs

$$Cost_{operating} = cost_{labour} + cost_{power}$$

a) Labour cost in one year

- 4 workers working for the ceramic filters
- Gross national income per capita in Ethiopia : $660 USD/year

Total Labour cost for four years

$$Cost_{labour} = 4 \times \$660 = \$2,640.00$$

b) Power cost

- Hammer mill: 10kW
- Clay mixer: 4.584kW

- Kiln: 19.935kW
- Operating hours in one year: 2000

Cost of electricity in Ethiopia : $0.012 USD/kWh

$P_{hammer\ mill} = 10 \times 2000 = 20000$ kwh

$P_{clay\ mixer} = 4.584 \times 2000 = 9168$ kwh

$P_{kiln} = 19.935 \times 2000 = 39870$kwh

$P_{electricity} = 3 \times P_{hammer\ mill} = 69038$kwh

Cost power = $$0.012 × 69,038 = $828.46

cost $_{operating}$ =cost $_{labour}$ + cost $_{electricity}$ = $2,640.00 + $828.46= $3,468.46

IV. Production cost

- 5 operating years
- Number of filters to produce: 125,000
- Number of production line: 1

Cost $_{production}$ = (cost $_{materials}$ + cost $_{equipment}$ + cost $_{operating}$) × operating years

cost $_{production}$ = ($7,500.06+ $12,464.85+ $3,468.46) × 5 years = $117,166.85

unit cost of ceramic filter = $\frac{\text{cost production}}{\text{number of filters}} = \frac{\$117{,}166.85}{125000} =$ $0.94

I