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PREPARATION AND PERFORMANCE EVALUATION OF SILVER IMPREGNATED CERAMIC POT FILTERS FOR HOUSE HOLD LEVEL WATER TREATMENT

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October 3, 2017

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A thesis submitted to the school of Research and Graduate Studies of Bahir Dar Institute of Technology, BDU in partial fulfillment of the requirements for the degree of Masters in Process Engineering in the Faculty of Chemical and Food Engineering.

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DECLARATION

I, the undersigned, declare that the thesis comprises my own work. In compliance with internationally accepted practices, I have acknowledged and refereed all materials used in this work. I understand that non-adherence to the principles of academic honesty and integrity, misrepresentation/ fabrication of any idea/data/fact/source will constitute sufficient ground for disciplinary action by the University and can also evoke penal action from the sources which have not been properly cited or acknowledged.

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To my beloved family

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ABSTRACT

About one-fifth of people on earth lack the access to safe drinking water a condition that resulted in the death of many people in developing countries. This research was aimed to prepare silver impregnated ceramic filter from clay and rice husk at different ratios (52C:48RH, 60C:40RH and 70C:30RH) where C denotes clay and RH denotes Rice Husk using three different firing temperatures (800℃ , 900℃ , 950℃) and evaluate the performance of turbidity and total hardness reduction efficiency and bacteria removal efficiency from contaminated water by determining levels of these contaminants in water before and after filtration through the filters. All filters showed capability of reducing pH and turbidity.Using 70C:30RH filters turbidity levels decreased from 23.01 NTU to less than 5NTU because of small porouristy is obtained using more clay soil and less rice husk ratios.More than 96% of the total coliform and 98% of the fecal coliform indicator bacteria are removed during filtration using filters before silver impregnation and 100% of the total coliform and 100% of the fecal coliform bacteria are removed after silver impregnation from contaminated water sources.The non-silver impregnated porous ceramic pot filters removed contaminants from environmental water samples 25.32% to 37.04%$CaCO3$*, 31.76% to 40%* $Flourides$ *and silver impregnated porous ceramic pot filters 31.19% to 44.68%*$CaCO3$*, 97.65% to 98.82%* $flourides$*.Hence, the information compiled from prepared silver impregnated ceramic water filter is greatest importance for providing microbiologically improved household drinking water to prevent and control waterborne bacterial diseases and reduce heavy metal contaminant from contaminated water.*

Keywords: *Ceramic filter, Clay soil, Rice Husk, Water filtration*

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LIST OF ABBREVATIONS

CFU	Colony Forming Unit
DC	Disease control
E coli	Escherichia Coli
FCR	Free Chlorine residual
FC	Fecal Coliform
GAS	Granular Activated Carbon
HWTS	Household Water Treatment and Safe Storage
NTU	Nephlometric Turbidity Unit
PFP	Potters for Peace
POU	Point-Of-Use
RH	Rice husk
SODIS	Solar Disinfection
TC	Total Coliform
UNEP	United Nation Environment Program
UNICEF	United Nation Children’s Fund
WHO	World Health Organization

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1. INTRODUCTION

1.1. Background

Purified water is essential for living a healthy life as such everyone should have access to it. Drinking water conditions have great impacts on people’s everyday life, especially in the rural and remote areas where access to safe drinking water is very crucial. Surface water often is the only source, thus water contaminations are difficult to avoid due to rigorous and reckless use of surface water. Unsafe drinking water may result in fatal diseases. Statistics shows that these diseases resulted in ninety percent of all deaths of children under five years old in developing countries, due to low immunization of children to infections. According to World Health Organization (WHO) over99.8% of death caused by poor quality of drinking water in the developing countries[1]. Strongly suggesting a need of safe (free from physical, chemical and biological contaminations) and adequate amount of drinking water. Filtration is a commonly used, physical, chemical, and in some instances, biological process of water treatment. The filtration process involves separation of suspended solids and impurities from water by passing it through porous media. Boiling water is a widespread practice despite its cost in both fuel and time. A temperature of 55°C or above over a period of several hours will inactivate most bacteria. The main drawback of handling large volumes of boiling water is a time consuming process to cool the water and disperse it into appropriate suitable containers. Chlorine is the most effective and simplest chemical disinfectant for drinking water at the household level. It is available a broad range of forms (e.g., pills, solution). The chlorine disinfection method is able to kill all forms bacterial and viral water-borne pathogens. However, at low concentrations normally used for water treatment, chlorine lacks activity against protozoa cysts. The reactivity of chlorine with any organic material can reduce its activity, if the correct chemical process is not used. Iodine is also very effective at killing or inactivating water-borne pathogens and has been widely used for drinking water treatment for short term or emerging situations. It is sold in the form of tablets or as ion-exchange resins. Iodine treatment is not recommended for daily treatments but instead for emergency situations[2]. The reason is that in the long run, this compound can damage health. The major problems with iodine is that it has a short contact time and poor control over the amount of iodine released which is given by the water quality and flow rates. Iodine is also known for giving an unpleasant taste to the water.

Ceramic filters were popularly used for centralized water treatment but in recent times they are being manufactured for point of use applications [3]. The World Health Organization (WHO) encourages its use as house-hold water treatment systems (HWTS) for effective treatment of drinking water[4]. These porous ceramic water filters which vary widely in design, effectiveness and cost, are now treated with a silver solution which acts as a microbicide to inactivate bacteria and this has contributed to the increased performance of ceramic water filters. However, the ceramic filters have been shown to be limited and incapable of treating viral and chemical contaminations in water[5].

While diarrhea is considered the most predominant water borne disease, infectious diseases caused by pathogenic bacteria, viruses, protozoa and fungi are regarded the most common and widespread health risk associated with drinking water[6]. Chemical contamination of drinking water sources is also issues of concern as millions of people are exposed to unsafe levels of chemical contaminants in their drinking water and long term exposure to chemical pollutants can have serious health implications. Household water treatment has been receiving increasing recognition as important interventions to address the safe drinking water problems, to substantially decrease the global burden of diarrhea. Despite recognition that safe water supplied by piped infrastructure is a noble goal[7] and despite considerable efforts to provide such facilities, the reality is that water supplies delivering safe water to all will not be available in the near term [8]. Household water treatment provides a means to make safe water available much more quickly than it will take to design, install and deliver piped community supplies [8]. Hence, simple, acceptable, low cost household water treatment options are capable of dramatically improving the microbial quality of household drinking water and reducing the risks of diarrhea [9]. A filter is defined as a device, instrument or material, which removes something from whatever passing through it. Therefore, ceramic water filtration is the process that makes use of a porous ceramic (fired clay) medium to filter microbes or other contaminants from water[10]. The pore size of the ceramic medium is sometimes small enough to trap anything bigger than a water molecule. From the ancient times to the present, water filters have evolved out of necessity, first to remove materials that affect appearance, then to improve bad tastes and further to remove contaminants that can cause disease and illness[11].

The most commonly used household water treatment options include biosand filtration, ceramic water filters, boiling, Aquatabs, solar disinfection (SODIS), P-u R purifier of water and flocculants. Each of the technologies has different benefits and drawbacks; no one technology is best for everyone, rather the most appropriate technology for the user depends on a number of factors such as existing water and sanitation conditions, water quality, cultural acceptability, cost, availability of the technologies and local conditions[12].

The main problem in treatment of drinking water is to reduce potentially pathogenic microorganisms and undesirable chemicals without introducing new hazards that might pose new and different threats to human health. Since the quality of the water supply is often variable and cannot be adequately controlled for millions of people in developing countries, one viable approach could be the implementation of simple household water treatment methods to ensure the provision of safe water for consumption[13]. Various household water treatment methods for reducing microbes in water have been widely known and practiced for decades and new ones continue to be developed[14]. One such technology is ceramic water filter. Ceramic water filters transmit water by adding a fine combustible material such as sawdust or coffee husk to clay soil [15]. Household water treatment technologies, such as household ceramic water filters, offer an affordable and effective means of treating water to standards suitable for drinking. The fact that ceramic water filters can be manufactured and produced by local ceramists with local materials makes ceramic filters particularly attractive as a Household treatment technology that is affordable, appropriate, and sustainable.

1.2. Statement of the problem

There are many problems within developing countries that feel the greatest water security issues having the least funding and lowest priority to do anything about the causal factors. Problems associated with the contamination of drinking water have led to the development of various technologies for drinking water treatment. However, the treatment technologies used in high-income nations are neither economically nor technically feasible in low-income countries. Ethiopia is one of the developing countries where the populations living in rural area have no access to safe drinking water and sanitation supply. The majorities of the population in rural areas of Ethiopia usually collects and use untreated water for their domestic consumption from unprotected sources. The use of this untreated water for drinking is one of the causes that expose people to diarrhea and other waterborne disease. The limited safe drinking water supply and low sanitation coverage attributed to the death of many children.

Household ceramic water filters are simple enough to produce as well as to use for household level water purification; however, the populations of living in rural area of Ethiopia have not use ceramic or silver-impregnated ceramic pot filter for their own water purification at home; Because, the technology of using ceramic water filter is not known at rural area of Ethiopia traditionally. The principal use of clay soil at Village is making of pots and other goods which are based on traditional knowledge for businesses and other household application. Ceramic filters provided with saw dust or rice husk in the shape of pots are very much efficient in microfiltration which removes suspended solids and microbes to great extents. Thus, the attempt of this study was to prepare ceramic pot filter and silver impregnated ceramic pot water filter at laboratory scale and evaluate their performance with respect to flow rate, turbidity reduction, and bacterial removal efficiencies using total coliform and fecal coliform indicator bacteria, total hardness and fluoride reduction.

1.3. Objectives of the Study

1.3.1. General Objective

The main objective of this study is to prepare silver impregnated ceramic filters and evaluate the removal efficiency of total plate count (bacteria) and reduce turbidity and total hardness of water

1.3.2. Specific Objectives

The specific objectives were:

- To prepare household ceramic water filter.
- To determine the turbidity reduction efficiency.
- To determine the level of removal efficiency of pathogenic microorganisms. (E. coli, total coliform) before silver and after silver nitrate solution use.
- To determine total hardness ($CaCO_3$) and Fluoride (F^-) reduction efficiency of the filter from contaminated water.

1.4. Scope of the study

This study is based on the preparation of ceramic filters from locally available materials such as clay soil and rice husk and silver impregnated ceramic filters. The preparations are using hand molding and firing using muffle furnace at three different temperatures and evaluate bacteria, turbidity, and total hardness, fluoride removal efficiency of the filters and the effect of silver on microorganisms.

1.5. Significance of the study

This study will have a significant contribution to give the clear idea about preparation and operation of low cost ceramic water filter at house-hold levels and water purification method at individual family, where the raw materials are low cost and available in most of developing countries and local potteries know how clay pot filters are prepared. Ceramic filters can be produced virtually anywhere in the country from commonly available materials and no chemicals or energy require for household use and has proven to be over 98% effective in eliminating water born bacteria.

1.6. Overall organization of the thesis

After the introduction in the first chapter, the second chapter focuses on the fundamentals and the basic consideration of the ceramic water filter preparation methods, clay soil, rice husk(friable organisms) and the literature on the preparation and silver nitrate application types are reviewed and parameters that influence on the performance of ceramic water filters are discussed. In chapter three the detailed methodology of the ceramic (fired clay) procedure and raw materials used are discussed. In chapter four the results and the bacterial, microorganism's removal efficiency of all filters before and after silver nitrate solution application based on three filters based on their clay and firing temperature are discussed. Finally in chapter five a summary of conclusion are presented and recommendations for future work are given.

2. LITERATURE REVIEW

2.1. Water Quality

The World Health Organization (WHO) defines safe drinking water as water that can be used for all domestic purposes (including personal hygiene) and not poses a significant health risk to users over lifetime consumption. The WHO has also outlined a guidelines health and aesthetic situations, which shows the minimum requirements for an array of biological, chemical, physical and aesthetic to ensure that drinking water is safe for consumption. These guidelines serve as guidance as to what can be considered as safe drinking water and directions to assist nations develop their own drinking water guidelines [19]. Many developing countries have actually adopted these guidelines. However, as a basic requirement, water should be free of pathogens; have a low turbidity; have little or no taste, odour or colour; free of salt or any chemicals that can cause corrosion, any adverse health effects [20].

2.2. Water Treatment Process

Water treatment describes those processes used to make water more acceptable for a desired end use. These can include use as drinking water, industrial processes, medical and many other uses. The goal of all water treatment process is to remove existing contaminants in the water, or reduce the concentration of such contaminants so the water becomes fit for its desired end use[21]. The series contaminants for groundwater under the direct influence of surface water and groundwater are unwanted chemicals, pathogenic microorganisms and different dissolved solids[22].

Production of biologically and chemically safe water is the primary goal in the water treatment process[23]. A Properly organized water treatment process is not only a requirement to guarantee safe drinking water, but also skillful and alert plant operation and attention to the sanitary requirements of the source of supply and the distribution system are equally important. The second basic objective of water treatment is the production of water that is appealing(interesting) to the community[23]. Ideally, appealing water is one that is clear and colorless, pleasant to the taste, odorless, and cool. It is none staining, neither corrosive nor scale forming, and reasonably soft [24].

The consumer is principally interested in the quality of water delivered at the tap, not the quality at the treatment plant. Therefore, water utility operations are not impaired during transmission, storage and distribution water to the consumer. Storage and distribution system should be designed and operated to prevent biological growths, corrosion, and contamination by cross-connections. In the design and operation of both treatment plant and distribution system, the control point for the determination of water quality should be the customer's tap [25].

2.3. Impact of Groundwater Contamination

High fluoride content in water is the cause for yellowing of teeth, damaged joints and bone deformities. Prolonged(continuing for a long time) exposure to water containing salts (TDS above500 ppm) can cause kidney stone[26]. Arsenic contamination of drinking water causes a disease called arsenicosis. Sulfur contaminates groundwater in the form of hydrogen sulfide and affects the nervous system. Giardia lamblia is one of the biological contaminant that causes diarrhea, stomach cramps, upset stomach and nausea [27].

2.4. Water Treatment Mechanisms

The raw water, i.e. surface water and ground water may contain pathogenic organisms, suspended particles, dissolved chemical substances, unpleasant tastes and odors and mineral impurities[28]. This raw water can be used as the source of public water when the pathogenic microorganisms are eliminated, the excess amount of total dissolved solid (TDS) and turbidity are minimized and destructive minerals are removed. The raw water from such objectionable aquifers should be treated chemically, physically and biologically before distributed to the community for drinking and other purposes [29].

2.4.1. Physical Treatment

Particulate matter such as sand and soil can be removed from raw waters by filtration which is called physical treatment processes. Filtration of water is defined as the separation of colloidal and larger particles from water by passage through a porous medium, usually sand, granular coal, or granular activated carbon. Several different types of medium arrangements and rates of flow through filters are available and some of these are rapid gravity filters, horizontal filters, diatomite filters and pressure filters. Rapid gravity, horizontal and pressure filters can be used for direct filtration of raw water, without pretreatment. Rapid gravity and pressure filters are commonly used to filter water that has been pretreated by coagulation and sedimentation [15].

2.4.2. Chemical Treatment

Chemical treatment of water is the removal of different inorganic and organic chemical contaminants which are the cause for unpleasant taste and odor, objectionable color, hardness, turbidity, corrosion and scale of groundwater. There are several types of chemical treatment of water such as aeration, chemical coagulation-flocculation, activated carbon adsorption, ion exchange and membrane processes. Aeration process is used to add oxygen to ground water for the oxidation of iron and manganese, partial removal of carbon dioxide to reduce the cost of water softening by precipitation with lime and to increase pH, reduction of the concentration of taste and odor producing substances, such as hydrogen sulfides and volatile organic compounds and Removal of volatile organic compounds which are suspected carcinogens. Chemical coagulation-flocculation processes are used to aggregate smaller particles to form larger particles which will readily settle in sedimentation basins. Activated carbon adsorption is used for the removal of pesticides and other organic chemicals, taste and odor compounds, cyanobacteria toxins and total organic carbon. Ion exchange is used for the softening of hard water, to remove contaminants such as nitrate, arsenic and selenium species. Membrane processes such as reverse osmosis, ultra filtration, and microfiltration and Nano filtration are mostly used for desalination of water [1].

2.4.3. Biological Treatment

Biological treatment or disinfection of water is the process of destruction or inactivation of disease producing organisms which are present in groundwater that is essential in providing a safe drinking water to the community[30]. There are several water disinfection methods such as chlorination, ozonation, chloramination, chlorine dioxide, ultraviolet (UV) radiation and advanced oxidation processes. Chlorination is primarily used for microbial disinfection. However, chlorine also acts as an oxidant and can remove or assist in the removal of some chemicals[31]. A disadvantage of chlorine is its ability to react with natural organic matter to produce trihalomethanes (THMs) and other halogenated disinfection by products (DBPs). However, by-product formation may be controlled by optimization of the treatment system. Ozone is an extremely powerful disinfectant which can also be used for the degradation of a wide range of pesticides and other organic chemicals. Chlorine dioxide is a highly effective disinfectant that producing minimal trihalomethanes (THMs) in the presence of their precursors. Chloramines are a less effective disinfectant than free chlorine, but it is persistent, and it is therefore an attractive secondary disinfectant for the maintenance of a stable distribution system residual [6].

The selection and design of the above physical, chemical and biological water treatment processes to be used at a particular place are depend on number of factors such as practicability, reliability, flexibility, accessibility, environmental effect, overall economics and the physical, chemical and biological characteristics of raw water[32].

2.5. Household Water Treatment and Safe Storage (HWTS)

Household water treatment and safe storage (HWTS) methods have been receiving increasing recognition as important interventions to address the safe drinking water problem. In many circumstances, such as disaster situations, HWTS is a more practical option than improving water at the source[33, 34]. Water that comes from an improved source, and is thought to be safe, is often times susceptible to contamination during collection, transport, or storage[35] When used correctly, HWTS eliminates or reduces the risk of recontamination post-treatment and can be very effective.

2.5.1. Household Chlorination

Chlorine treatment consists of dilute sodium hypochlorite solution and a storage container. To treat water, a capful of solution is added to the container, and then users must wait 30 minutes prior to consuming the treated water. One of the advantages of chlorination is that it provides residual protection to water during storage. This method costs anywhere between 0.01-0.05 US cents per liter and generally has high user acceptance rates in people who do not object to the slight chemical taste and odor. Diarrheal reductions in users range from 22% to 84%. However, chlorine can be ineffective at killing some parasites and can lose effectiveness when used with highly turbid water.

Figure 2:1 Sodium hypochlorite solution[36]

2.5.2. Solar Disinfection SODIS

SODIS disinfection is inactivation of microorganisms by UV-A-radiation and thermal treatment. SODIS disinfection requires sunlight and a plastic bottle. The bottles are filled with water, shaken to oxygenate the water, and placed in the sun for one to two days depending on the amount of available sunlight[37]. Increased temperatures, UV light, and oxidative chemistry inactivate most bacteria, viruses, and protozoa. The only cost for this treatment method is that of the plastic bottle. Reductions in diarrhea vary between 9% and 86%. Although the treatment process is simple, users may be unsatisfied with the limited quantity of water produced and length of time necessary to treat water. SODIS disinfection is not effective with highly turbid water unless it is pretreated.

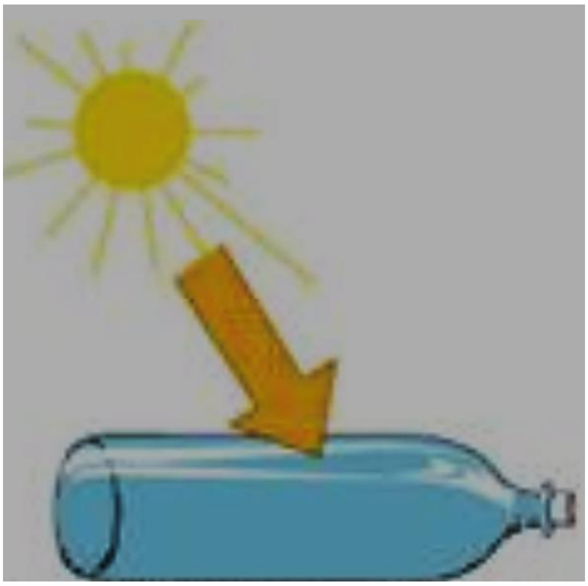


Figure 2:2 Solar disinfection[38]

2.5.3. Flocculants / Disinfection Powder

The first step in flocculants/disinfectant treatment is to combine one packet of the flocculants/disinfectant with 10-20 liters of water in a container. Next, it is stirred for five minutes. The solids will coagulate and settle to the bottom of the container and then must be strained through a cloth by pouring the contents into another container. After 20 more minutes the water is fully treated and the hypochlorite component of the product will provide residual protection to stored water.

Flocculants/disinfection treatment is capable of removing bacteria, viruses, protozoa, and some heavy metals and pesticides. Reductions in diarrhea range from 16% to 90%. This intervention costs about 1 US cent per liter and requires two buckets, a cloth, and something to stir with. It also requires the user to correctly perform a number of steps and produces a flocculants waste. Flocculants/disinfection is a popular option for responding to emergency and disaster situations.

Figure 2:3Flocculants/ disinfection packet[39]

2.5.4. **Household Water Treatment for Fluoride Removal using Bone Char Filter**

Bone was one of the earliest media suggested for fluoride removal from water. It was not widely implemented due to the bad taste of treated water, the high cost and unavailability. But in 1988, the World Health Organization claimed it to be an applicable technology for developing countries. Bone char is a blackish porous granular media capable of absorbing a range of contaminants.

The bone char grains are packed in a filter (bucket, drum or column) and water flows through. Bone char made from animal bones are charred (burnt) and crushed. Correct preparation of the bone char is essential to ensure good fluoride removal and to avoid unattractive taste, colour and odour in the treated water. Decades ago, bone char was industrially produced and widely available, but now the supply is limited. However, bone char grains can be produced locally by communities.

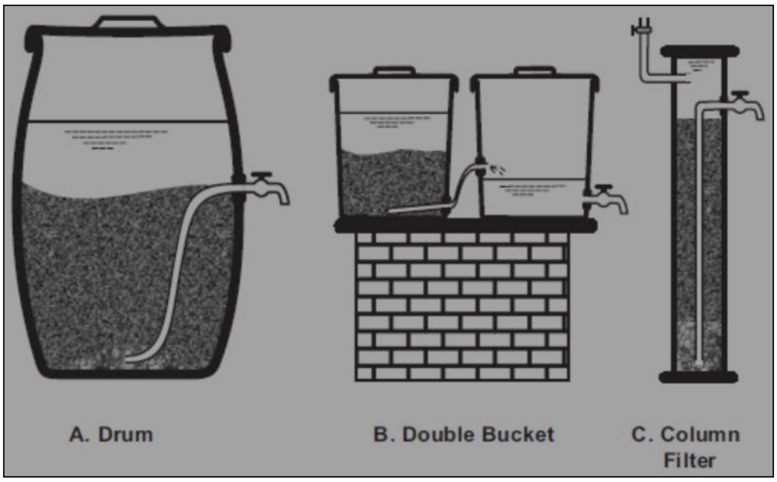


Figure 2:4 Three Common Households Units for Sorption Defluoridation [50]

The water level in the filter should never drop below the top of the bone char. If the bone char is left dry, its adsorption capacity will decrease. The water should be in contact with the bone char for a minimum of 20 minutes. The filter can be combined with a ceramic candle to remove microbiological contamination as well[40] For new filters or after changing the media, the first few containers of treated water should be discarded due to high turbidity and colour [41, 42]

Major components of bone char are calcium phosphate, activated carbon and calcium carbonate. Fluoride is removed from water through a process based on ion exchange. When raw water containing fluoride comes into contact with bone char, the fluoride ion changes places with the carbonate ion in the bone char, and the fluoride becomes stuck to the bone char. Bone char has high fluoride removal efficiency, and can also absorb a wide range of other contaminants. The fluoride adsorption capacity is 2mg fluoride per gram of bone char[43]. The use of bones in water treatment might not be consistent with local customs and beliefs. Depending on the community, it may be important to consider the implications of religious beliefs, etc. on acceptance of using bone char for water treatment.

2.5.5. Ceramics for Water filtration

Ceramics are generally compounds that fall between metals and non-metals. They are oxides, nitrides and carbides. Examples include aluminum oxide (Al_2O_3), silicon dioxide (SiO_2), silicon carbide (SiC) and silicon nitrite (Si_3N_4). Compounds of clay such as porcelain, cement and glass are also ceramics and are usually referred to as traditional ceramics [44]. Ceramics that are used in water filtration are made from clay. These clay ceramics are used for water filtration because the pores that are present in them are smaller than most of the debris and bacteria present in the water[45]. As the water passes through the filter, these unwanted substances are trapped in the filter, leaving only clean water to pass out. Since not all bacteria can be filtered out of the water due to their size, colloidal sliver coated on to the surfaces of the filters[46]. This disinfects/kills or incapacitates (weak to live) the bacteria. It also helps stop the growth of mold and algae on the surface of the filters.

There are two main types of ceramic filters that are made from clay. The pot type and the candle type filter which differ in the shape and assemblage of the ceramic membrane. In the pot type of filter, they are shaped in pot forms and are placed in plastic containers that have a tap at the base. The filter is filled with water, which is then filtered out into the container. The filtered water can then be accessed through a tap. In the case of the ceramic candle filters, the pail of the filter is filled with water and by the action of gravity, the water moves through the ceramic candle which is the connector between the pail and the reservoir plastic. The ceramic candle is responsible for the purification of the water and the filtered water flows into the reservoir plastic and is ready for use.

Ceramic water filtration systems generally consist of a porous ceramic membrane, a plastic or ceramic receptacle, and a plastic tap. Water is poured into the upper portion of the receptacle, or directly into the membrane, where gravity pulls it through the pores in the ceramic and into the lower portion of the receptacle. Water is safely stored in the receptacle until it is accessed through the tap.

2.5.6. Steps in Ceramic water filter preparation.

To identify possible options for increasing the flow rate, it is first necessary to understand how the filter is made and how it functions.

i. The raw materials are preparation

A combustible material that has been sifted through a screen so that particles are uniform in size Once the clay has dried, pound it into a powder using mortar and pestle. The particle size of the majority of the powder should be less than the sieve opening, i.e., less than 1.12 mm in diameter. Clean water that is free of heavy metals and chemicals.

ii. Mixing

Various combinations of clay, water, combustibles, and/or grog are mixed together to form a relatively dry, but cohesive, mixture that is then pressed or molded into a filter shape. The most optimal material combination, or recipe, depends on the properties of the materials, the equipment used, and the methods employed by the ceramist throughout the production process. These recipes are determined partly by experience and partly by trial-and-error. A recipe for one location may not work at another location with different materials, equipment and or methodology. In particular, the properties of the clay will dictate what mixing recipe is most optimal in terms of filter performance. Method of Mixing Materials is as follows; once the clay, grog, and combustible material have been prepared, they must be mixed to create a uniform composition. Based on the recommendations of [47] and [48], the following recipe shall be used:

Table 2-1 Recipe for Manufacture of Ceramic Pot Filter on the PFP Press

Quantity of filters	Dry clay powder mass(kg)	Dry fine rice husk mass (kg)	Grog(kg)	Total mix mass
1	5.5	2	0.5	8

Mixing can be a long and labor-intensive process; especially if it is done by hand. Mixing is one of the current bottlenecks in the production of ceramic water filters at Madhyapur Clay Crafts[49] Hari Govinda Prajapati believes that he can produce 100candlesor 200 disks per day using Reid Harvey's Pottery Purification Media method, which uses grog. He currently has a production capacity of 150candles per day using his methods and materials (white kaolin clay imported from India mixed with a combustible, but no grog).Combine the dry materials on the tarp (plastic bowl). Mix for several minutes until the entire mix appears and feels homogenous. Add water from the plastic bucket and continue to mix by hand. Stop adding water to the mix once it becomes cohesive enough to be wedged (packed in together).

a. The only reason for the addition of water is to create a malleable mix (Capable of being shaped, bent or drawn out) the water will be removed during the drying and firing process.

b. Adding too much water will make it difficult to remove the filter from the mold. Furthermore, adding too much water will make it difficult for the filter, once pressed, to maintain its shape while drying.

iii. Filter Pressing or Shaping

The next step in the production process is the shaping of the filter element. This typically involves the use of a mold, which can either be a hand-mold, into which the clay is pressed by hand, or a component of a filter press machine to compact the material into its desired shape. Pressing the clay manually into a mold is very time consuming. Filter press machine softer a number of important advantages over manually pressing the clay: the two most critical being speed and consistency. The speed in which filter elements are produced can be increased dramatically by virtue of a press machine, eliminating the need to shape the element by hand. The consistency between elements is maintained more readily with the use of a press machine compared to molding the filter element by hand or throwing a shape on a wheel.

Pressing ceramic filters with a press machine is often referred to as dry pressing due to the low water content of the material being pressed. In fact, it is because of the dry composition of the material that the filter units require a press machine to properly compress the clay mixture. In contrast, pressing a shape by hand requires the clay mixture to contain relatively more water so that the material maintains its shape and holds together

iv. Drying and Firing

After pressing the clay material, the filter element is left to dry for two to three days. The purpose of drying is to prevent the clay from cracking due to rapid drying or heating during the firing process. The initial rate of drying (rate of water escaping from the disk due to evaporation at the surface) is comparable to the evaporation from a free water surface up to the point where the moisture within the smaller pore spaces is held back by capillary forces[50]. The time it takes for the filter to dry enough for firing depends on many factors and is determined partly by experience and partly by trial-and-error.

The elements are heated at 100℃ for two hours for drying off water excess within the ceramics. Then, the temperature is gradually increased to 850℃ over 8 to 10 hours to allow for verification (silica and alumina molecules within the clay melt and bond and the chemical structure of the clay is altered. The firing temperature and time depends heavily on the number of elements and the unique properties of the clay mixture. Filters are fired in the kiln where the combustible material burns away forming pores and the clay becomes hard.

v. Application of Colloidal Silver (if used)

Dartmouth (A college in New Hampshire) Toxic Metals Research Program also states that silver is not toxic to humans and will not cause cancer or other chronic advert effects. As a result, it is safe to apply a coating of silver solution onto the walls of the filter element. Filters are allowed to gradually cool

a. They are first cooled in the kiln for about 24 hours.
b. They are then moved to drying racks where they continue to cool.
c. Silver is applied to the filter as a chemical barrier to bacteria.
d. The silver solution can be made with silver nitrate or colloidal silver and solution concentrations vary depending on the purity of the silver.
e. The silver solution is either painted on to both the inside and outside of the filter or it is submerged in the silver solution

2.5.7. Mechanism of Ceramics Filtration

The ceramic water filter removes pathogens through the processes of mechanical screening, sedimentation, adsorption and chemical activity[51, 52]. Concerning the mechanical filtration, the untreated water passes through pores in the filter created by combustible material incorporated in the clay that burn off during firing. The size of the pores depends on the size and amount of combustible material, as well as properties of the clay and grog in the mixture. The target pore size is 1.0 micron in order to restrict the passage of small bacteria [53]. Sedimentation and adsorption of fine particles occurs within tortuous pores in the filter[54].

To gather information about the pores of the filter, several methods are used. Scanning Electron Microscope analysis of a piece of a Nicaraguan filter lip showed that the pores were in the range of 0.6-3.0 microns[55-57]both used mercury intrusion porosimetry to gather information about pore size diameters and total pore areas. [56]Determined that filters from Ghana had 39% porosity, with 1.31 m^2/g total pore area; these were middle values between Nicaraguan and Cambodian filters[58]. Similar experiments showed that the addition of colloidal silver to the filters reduces the porosity and total pore area, suggesting that pores are filled or coated with the silver used a changing-head flexible wall permeameter test to determine hydraulic conductivity [57] and bubble-point tests to determine the effective pore size of several filters, and concluded that all of the filters had effective pore diameters between 33-52 microns, much higher than the target of 1 micron[59].

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[60]. The ceramic water filter technology should remove 99.98% of total coliform and E.coli under laboratory conditions [61]. Most ceramic water filters are effective at removing most of the larger protozoan and bacterial organisms, but not at removing the smaller viral organisms[62].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[60].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 (waterborne pathogens) in higher concentrations. 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.

2.7 Previous works

Hasan in 1990 studied the **c**ontact aeration for iron removal method. The iron removal process utilized the catalytic effect of ferric iron. Again in this experiment it was theoretically demonstrated that by keeping high concentration of ferric iron, the volume of the aeration tank can be significantly reduced and it was according to the oxygenation rate equation. Ferric iron is very much effective in decreasing the reactor volumes at lower pH values. It is proposed to recycle the ferric sludge to maintain the high ferric iron concentrations in the reactor.

William, et al. in 1992 studied the impact of dissolved organic carbon on the removal of iron during water treatment. He used the iron removal process by oxidation and coagulation method. Humic and fulvic acids, tannic acid and oxalic acid were estimated in the organic content. Potassium permanganate, chlorine dioxide and free chlorine were used as oxidizing agent.

Catherine in 1988 studied the control of biological iron removal from drinking water using oxidation-reduction potential. In this study a pilot plant was used for treating raw water with pH 5.7 for biological removal of iron to produce drinking water. Here oxidation- reduction potential was used as a tool for evaluation and determination of relationship with dissolve oxygen and residual iron concentration in the infiltrate by using a biological filter.

Tomotada studied the Current bioremediation practice and perspective in 2001. In the method he used in-situ fluorescence hybridization (FISH), in situ PCR, and quantitative PCR for removal of contamination by bioremediation .In this method the detection and reorganization of bacteria and pathogens is very vivid and these are being directly related to the rate of degradation of contaminants.

Wang, et al. in 2003 studied the removal of heavy metal ions from aqueous solutions using various adsorbents with minimal cost. He used various low cost adsorbents like Fe_2O_3, Fe_3O_4, FeS, steel wool, Magnesium pallets, Copper pallets, Zinc pallets, Aluminum pallets, Iron pallets, coal, GAC for removal of heavy metal ions like cobalt and zinc from ground water.

Choo, et al. studied in 2005 the removal of iron and manganese in ultra-filtration and also the process of membrane fouling. He also examined to remove the residual chlorine due to pre-chlorination which is opted as a convenient option for safe drinking water. The membrane fouling was caused due to the oxidation of iron and manganese which was also visualized thoroughly at microscopic level and the steps for eradicating the degradation of membrane was proposed.

Takerlekkopoulou, et al. studied in 2006 the physio-chemical and biological iron removal from potable water. He used the technique of trickling filter and constructed a model for it including the pilot-testing. The main mechanism was physio-chemical and biological oxidation of iron. The detailed chemical reaction and extent of each oxidation was studied. Experimentation was done with specified temperature, optimum feed iron concentration and volumetric flow rate. First order kinetics and Monod-type kinetics was observed in physiochemical and biological oxidations respectively.

Gupta studied in 2006 the non-conventional low-cost adsorbents for dye removal. He studied an extensive number of adsorbent for filtration and in the review he showed the critical analysis of these materials, characteristics, advantages, limitations and mechanisms of adsorption. He used activated carbon of agricultural solid waste, industrial by product, clay and materials containing silica.

Bordoloi, et al. in 2007 studied the removal of iron from water using the ash produced from banana residue[63, 64].Ashes from different materials i.e. dry banana leaf, pseudo stem, rind, bamboo, rice husk were produced by controlled combustion. The mechanism of removal includes oxidation of iron at high pH or alkaline medium produced by potassium present in banana due to subsequent formation of potassium hydroxide. The study included analysis of chemical composition of banana ash and its efficiency in removal of iron from prefabricated water. Further it has been used in a low cost household water purification model in which after treated with ash, the water is being filtered with a cotton cloth and being used for drinking.

Chaturvedi in 2012 studied the removal of iron for safe drinking water. He used the methods of iron removal from drinking water such as electro coagulation; oxidation filtration, ion exchange, lime softening, adsorption by activated carbon, BIRM media, Anthracite [65], green sand, pebble and sand mixture, ultra filtration etc. have been discussed.

Ganvir, et al. in 2011 studied the removal of fluoride from groundwater by aluminum hydroxide coated Rice husk ash[66, 67]. Activated aluminum hydroxide has been used for activating the RHA surface which forms a complex with fluoride ion in water and accelerates the process of removal. RHA was obtained by controlled burning of dry and crushed rice husk and treating with hydrochloric acid before activation.

Simonis in 2012 studied the manufacturing a low-cost ceramic water filter[68] and filter system for the elimination of common pathogenic bacteria and suspended solids**.** A micro porous ceramic water filter in which clay was mixed with rice husk in a ration 2:1 by weight and a cylindrical shaped filter was manufactured by tradition oven drying and then burning in kiln at specified sintering temperature. After being coated with silver nitrate solution for preventing the growth of microbes, the filter was tested for removal of suspended solids and pathogens.

3. MATERIALS AND METHODS

3.1. Raw Materials

The raw materials that were used for this research work are represented in Table **3-1**. The major materials constituents were clay soil, Rice husk and water as solvent. Clay refers to naturally occurring material composed primarily of fine-grained minerals, which is generally plastic at appropriate water contents and will harden when fired or dried. Clay minerals are natural, colloidal materials which have ion exchange capacity and adsorption properties. In environmental engineering clay minerals are used generally as adsorbance and ion exchanger in order to treat both water and wastewater, and as an impermeable layer in order to prevent groundwater contamination in landfill areas. Clay was bought from local potters for this thesis. Rice husk is the dry outer part of rice grain and purchased from Worota local farmers. Rice husk used mainly to create the porosity of the filters and was burnt off during firing. Water was added to make paste. Table 3.1 shows the percentage composition of the raw materials used in preparation of the filters. Three filters of different constituents were produced: sample 1 contained 52% clay soil and 48% Rice husk. Sample 2 contained 60% clay and 40%Rice husk, while Sample 3 contained 70% clay and 30%Rice husk.

Table 3-1 Percentage composition of the raw materials

Samples	Rice husk volume (%)	Clay volume (%)
1	48	52
2	40	60
3	30	70

The ratios were taken by assuming high amount of rice husk has more pore size and high flow rate and low amount of rice husk has low pore size, low flow rate and high removal efficiency.

3.2. Methods

3.2.1. Steps in preparation/Production of filter and Experimental Setup

Porous pots were made using clay and Rice Husk. The Rice husk was ground and sieved using 0.7 μm sieve size. The clay and rice husk were mixed in the ratios 52:48, 60:40 and 70:30 to make the pots, which were then dried for a week and fired in the muffle furnace at 800^{o}C, 900^{o}C and 950^{o}C. The temperature used for sintering is below the melting point of the clay. Since the melting point clay is approximately 1,780 °C (3,240 °F) and its boiling point is over 9,000 °C (16,230 °F). The temperature below 1,780 °C (3,240 °F) is the sintering temperature (heat treatment applied to compact in order to impart strength and integrity) of ceramics. Firing time was 6 hour and cooling time was 12 hours and filters approximate thickness of 1cm were made.

As shown in Figure 3.1 the detail preparation procedures steps are displayed. The raw materials (Clay soil and Rice husk) are prepared, grinded into small pieces get appropriate size, sieve to separate un-materials from fine particles, weighing the raw materials according to their recipes and preparing them for mixing, The raw materials were mixed together and add water then mix well for certain minutes to prepare uniform mix. Water is added until the mixture is well wet; three filters are prepared by means of hand moulding methods. The produced filters were dried for some days and later fired at a temperature of 800℃, 900℃ and950℃ . These temperatures are taken randomly for this study because at rural area potteries used unknown firing temperatures until the clay produces red color.

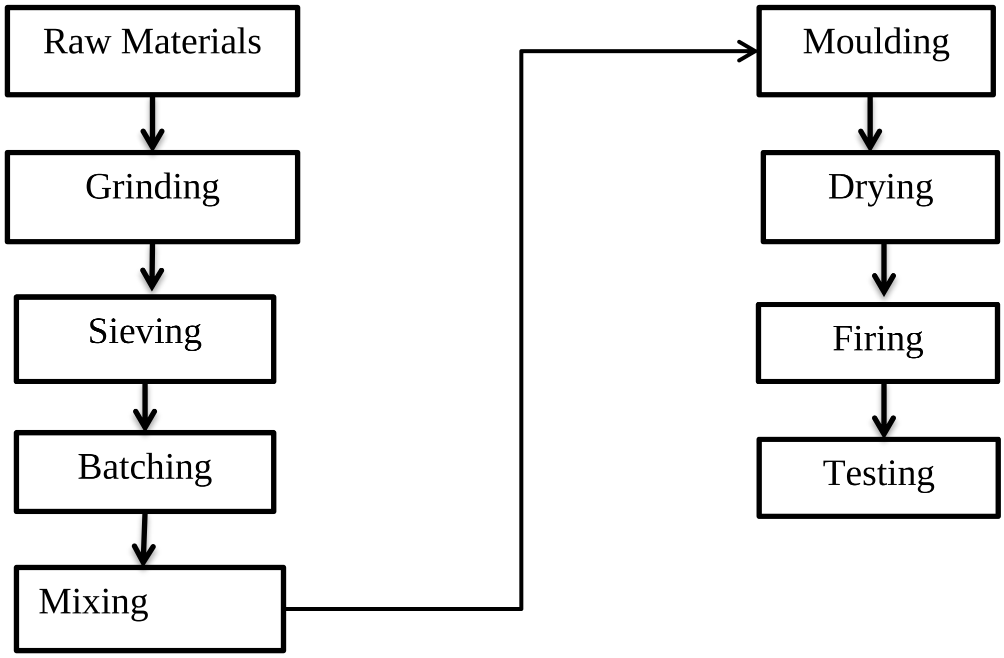
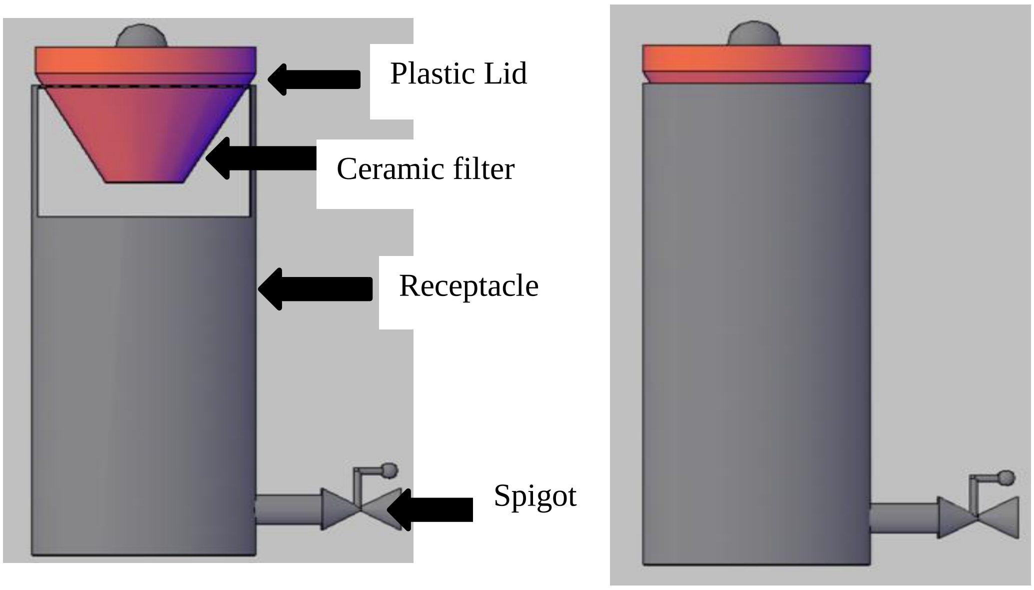


Figure 3.1 Sequential steps for ceramic filter preparation/production

Raw water, collected from surface water (Abbayi River and Lake Tana) were collected and filtered using the ceramic pots filters. Both the raw and filtered water were tested for total coliform, turbidity, and total hardness.

Finally for fabrication and continuously using the filters at house hold-level water treatment (filtration) the clay pot water filters are suspended inside plastic receptacles as shown in Figure 3.2.and poured water into the filter at the top and the pure water pass through the micro-porous of the filters and collected at bottom side of the receptacle.

The whole ceramic water treatment system at house-hold level is generally containing four parts as indicated in figure 3.2a. The filter covered and keeps out dirt contamination particles at the top side by plastic lid, the filter put in receptacle tank (plastic bucket) during operation and the pure water collected in receptacle remove into outside for use through valve(spigot). Figure 3.2b shows the Mechanism of water flow through a ceramic pot filter for house- hold application. A clay ceramic filter is inside a plastic bucket with installed spigot/valve.



a) b)

Figure 3:2 the entire parts of filter and working principle of the filter system

3.2.2. Total hardness and Fluoride Laboratory Test procedures

Total hardness Test procedure

Unfiltred and filtered water by the three different ceramic filter was tested as follows:

1. Fill the tube with sample to the 10ml mark
2. Add one calcicon No-1 tablet crush and mix to dissolve
3. Add one calcicon No-2 tablet crush and mix to dissolve
4. Stand for two minutes to allow full color development.
5. Select wave length 570nm on the phothometer
6. Take photometer reading

The same process was proceded for the ceramic pot water filters and silver impregnated ceramic pot water filters and then the data recording the value obtained from the experiment in the form chart as showed in figure 4.4-4.7. The experimental test was done before filtration and after filteration to evaluate the reduction efficies of the filters.

Fluoride concetration Test

Fluoride is very toxic, when it is taken in excess (3.18mg/L), leading to inhibition of infant's brain/mind development. Flouride occurs naturally in some ground waters and is often introduced in to drinking water for the prevention of tooth decay. Excessive amounts of fluorde are however objectionable and can cause tooth discolorination.The palintest fluoride test provides a simple method of monitoring fluorides in natural waters and for the control of flouridation plant at water works.

In the palintest fluoride test two tablet reagents(palintest fluoride No-1 and palintest fluoride No-2) are used. The test is simply carried out by adding one of each tablet to each sample the water before and after filtration. The procedures are the same with the calcium carbonate testing.

3.2.3. Preparing the ceramic filter by step by step

As shown in figure 3.3 to prepare the ceramic water filter and silver-impregnated ceramic water filter from locally available materials (Clay soil and rice husk) as the following process steps. The unfired clay soil purchased from Merawi local potteries and rice husk purchased from Worota farmers. When the filters are fired, rice husk burn-out off and create pores that increase the total porosity of the filters. The clay and rice husk preparation completed by grinding and sifting as shown in figure 3.3a and figure 3.3b.

(a) Clay soils (b) Rice husk

Figure 3.3 Preparation of Clay soil and rice husk

The second step is mixing; the mixing of the raw material was done by hand and Water was added to make it possible to press the filters in to the final desired shape (figure 3.4a) and the molded filters were put in sun-dry for five to fifteen days depending on weathering conditions(figure 3.4b). The purpose of drying was to remove moisture from the filters before the filters fired in the muffle furnace. If the filters have excessive moisture, the water evaporates inside the clay when we fire it and cause the filters to explode.

(a) (b)

Figure 3.4 Pressing the wet mix to the desired shape and Air drying the filters

Finally, the preparations of Ceramic Water Filters are completed after firing using muffle furnace and three different temperatures **Figure 3.5**. The purpose of firing at random three temperatures is to evaluate the performance of the filters at three different temperatures at constant time because, of firing temperature is not known with local potteries and they can recommended only by firing time.

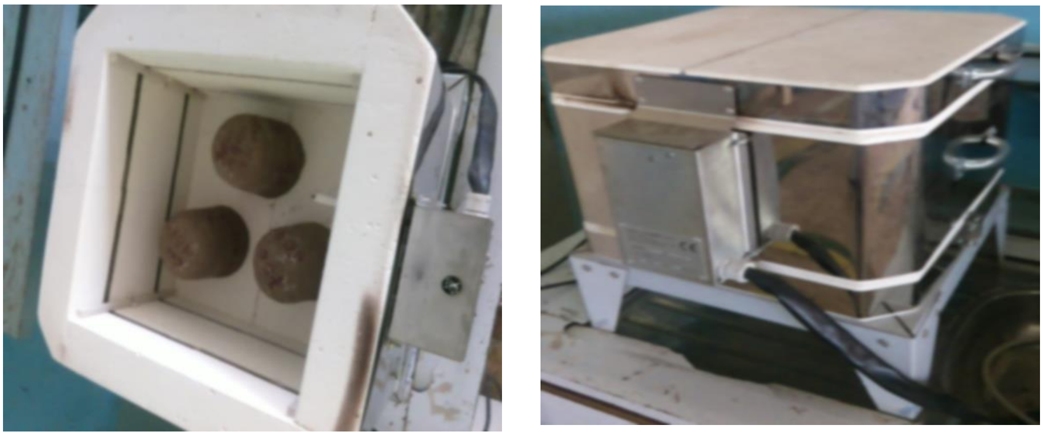


Figure 3.5 Firing the filters

3.2.4. Filter Performance Testing

Before and after treatment, water samples were analyzed to determine the filtration performance of the filters. The Laboratory experimental setup for testing the performance of the filters is organized as figure 3.6; soaking and checking the quantity of water filtered are the first step before analyzing other parameters.

Figure 3.6 Laboratory scale experimental setup

Flow Rate

Flow rate is an important factor to be considered in determining the performance of ceramic water filter. Higher flow rate means that the porosity of the filter is high with larger pore size, letting more impurities pass through the filter. Thus, the flow rate of a filter is often inversely related to the contaminant removal efficiency.

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 volume of water filtered while recording the time required flowing out. The ceramic water filters should be wetted or soaked in water (figure 3.7a) for 12-24 hours prior to flow rate test to saturate the filters and also to remove any remaining ashes of the combustible material. The flow rates were measured by taking the volume ratio of water measured in plastic container to the time taken for which the volumetric measurement is taken (figure 3.7b).

(a) (b)

Figure 3.7 Ceramic water filters soaking in water and Quantity of water filtered testing

3.3. Silver solution Impregnation

Silver coating of the ceramic element is another option for the treatment of water. Filters were impregnated of silver after being heated **Figure 3.8**. This final phase process coating is preventing bacterial growth as silver has bactericidal properties.

Silver is recognized for its ability to kill microorganisms and the application on the filter walls also prevents algae growing on the outside of the filter wall. There are three ways that ceramic pot filters impregnate filters with colloidal silver for disinfection: dipping, painting and incorporating the silver in the clay mix.

Figure 3.8 Impregnated Filters by silver solution after being heated

Silver (Ag) is a chemical substance that kills germs and helps stop wounds from becoming infected and including applications for point-of-use drinking water disinfection. Silver used in the ceramic water filter is a stable solution of macromolecules and the size of a particle of colloidal silver is .005µm to .015µm or smaller than micro-organisms such as bacteria and protozoa. Silver particles have large surface areas per volume ratio and high reactivity compared with the bulk solid. This feature gives Silver particles antimicrobial properties.

Three possible antimicrobial mechanisms of Silver solutions are raised:

(1) Silver particles can damage cell membrane and intracellular components[69, 70]
(2) Silver ions released from silver nitrate solution can be sorbed into the cell wall and cause lysis and death [71-73]
(3) Reactive oxygen species (ROS) can be formed in silver solution [74-77].

4. RESULTS AND DISCUSSION

4.1. Flow rate test

The filtration performance of the filters were tested by filling the filters with water the quantity of water filtered was recorded from each of the filters before silver impregnation (table A1in appendix A)were 1.38L from 52C:48RH, 0.94L from 60C:40RH and 0.52L from 70C:30RH at 800℃ firing temperature, 1.86L from 52C:48RH, 1.53L from 60C:40RH and 1.04L from 70C:30RH at 900℃ firing temperature and 2.44L from 52C:48RH, 1.56L from 60C:40RH and 1.06L from 70C:30RH at 950℃ firing temperature for the first one hour and increased with time and also the filtrated recorded after silver impregnation(table A3 in appendix A) were 1.29L from 52C:48RH, 0.87L from 60C:40RH and 0.46L from 70C:30RH at 800℃ firing temperature, 1.74L from 52C:48RH, 0.1.42L from 60C:40RH and 0.90L from 70C:30RH at 900℃ firing temperature and 2.28L from 52C:48RH, 1.44L from 60C:40RH and 0.92L from 70C:30RH at 950℃ firing temperature. Among the three ceramic potwater filters, the quantity of water filtered was maximal for the filter prepared from 52C:48RH while itis minimal for the filter prepared from 70C:30RH at the three of firing temperature. This indicates that as the ratio of clay to rice husk increases less water drips from the filter because of increasing rice husk and firing temperature increases the pore size of the filters.

Flow rate is the amount of water which passes through the filter per unit time. The flow rates were measured by taking the volume ratio of water measured in the plastic container to the time taken for which the volumetric measurement is taken during the process of filtration.

$$\text{Flow Rate} = \frac{\text{Volume of water measured at time t in L}}{\text{Elapsed time, t, from start of test in hour}}$$

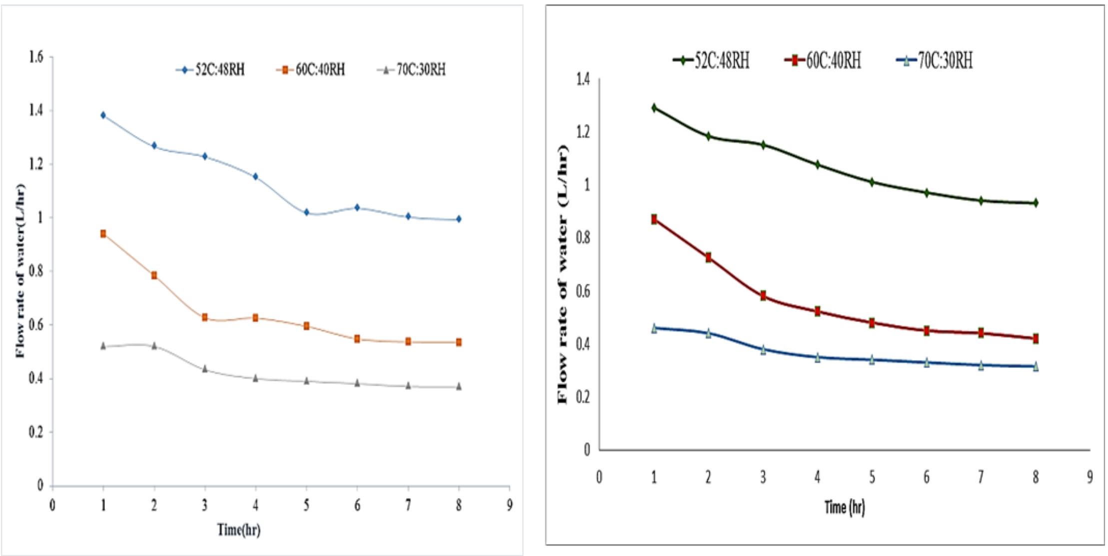
The flow rate of all the filters ranged from 0.520 L/hr to 2.440 L/hr before silver nitrate solution impregnated (table A2 in appendix A) and 0.460L/hr to 2.281L/hr after silver nitrate solution impregnated(table A4 in appendix A) respectively.

Figure 4.1shows the flow rates of the three ceramic water filters at firing temperature of 800℃ in case of both before silver impregnation and after impregnation.

First the ceramic water filter prepared from 52C:48RH before silver impregnation (Figure 4.1a) has initially flow rates of 1.38L/hr at the first hour and with increasing time the flow rates decreased to 1.265L/hr at the second hour, 1.23L/hr at three hours and in the same way by decreasing we observe at last test 0.99L/hr and this filter at the same firing temperature after silver impregnation (Figure 4.1b) the filter has initially flow rates of 1.29L/hr at the first hour and with increasing time the flow rates decreased to 1.183L/hr at the second hour, 1.15L/hr at three hours and in the same way by decreasing we observe at last test 0.93L/hr .

Second the ceramic water filter prepared from 60C:40RH before silver impregnation (Figure 4.1a) has initially flow rates of 0.94L/hr at the first hour and with increasing time the flow rates decreased to 0.784L/hr at the second hour, 0.627L/hr at three hours and the at last test 0.53L/hr and this filter at the same firing temperature after silver impregnation (Figure 4.1b) the filter has initially flow rates of 0.87L/hr at the first hour and with increasing time the flow rates decreased to 0.725L/hr at the second hour, 0.58L/hr at three hours and in the same way by decreasing we observe at last test 0.42L/hr .

Third the ceramic water filter prepared from 70C:30RH before silver impregnation (Figure 4.1a) has initially flow rates of 0.52L/hr at the first hour and this filter is initially constant flow rate 0.52L, L/hr and then decreased at three hours to 0.433L/hr and the at last test 0.37L/hr and this filter at the same firing temperature after silver impregnation (Figure 4.1b) the filter has initially flow rates of 0.46L/hr at the first hour and with increasing time the flow rates decreased to 0.44L/hr at the second hour, 0.38L/hr at three hours and in the same way by decreasing we observe at last test 0.315L/hr .Hence, silver is reduce little bit the pore sizes of the filters. All these discussion are plotted in figure 4.1a and figure 4.1b.



(a) (b)

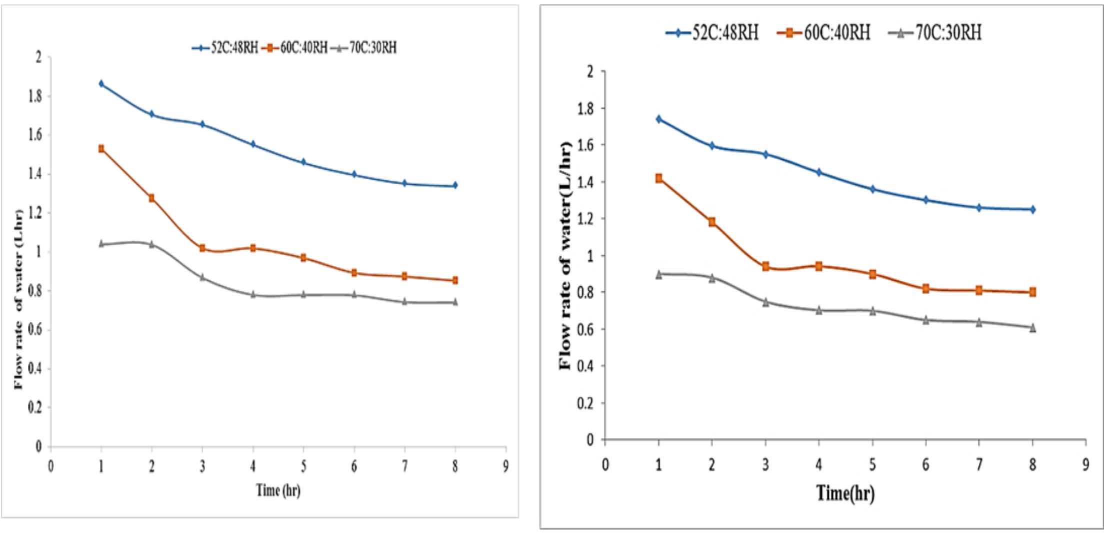
Figure 4-1: Flow rate versus time for 800°Ca) before silver impregnation after silver impregnation

Figure 4.2 shows the flow rates of the three ceramic water filters at firing temperature of 900°C in case of both before silver impregnation and after impregnation.

First the ceramic water filter prepared from 52C:48RH before silver impregnation (Figure 4.2a) has initially flow rates of 1.86L/hr at the first hour and with increasing time the flow rates decreased to 1.705L/hr at the second hour, 1.653L/hr at three hours and in the same way by decreasing we observe at last test 1.34L/hr and this filter at the same firing temperature after silver impregnation (Figure 4.2b) the filter has initially flow rates of 1.74L/hr at the first hour and with increasing time the flow rates decreased to 1.594L/hr at the second hour, 1.55L/hr at three hours and in the same way by decreasing we observe at last test 1.25L/hr .

Second the ceramic water filter prepared from 60C:40RH before silver impregnation (Figure 4.2a) has initially flow rates of 1.53L/hr at the first hour and with increasing time the flow rates decreased to 1.275L/hr at the second hour, 1.02L/hr at three hours and the at last test 0.85L/hr and this filter at the same firing temperature after silver impregnation (Figure 4.2b) the filter has initially flow rates of 1.42L/hr at the first hour and with increasing time the flow rates decreased to 1.18L/hr at the second hour, 0.94L/hr at three hours and in the same way by decreasing we observe at last test 0.80L/hr .

Third the ceramic water filter prepared from 70C:30RH before silver impregnation (Figure 4.2a) has initially flow rates of 1.04L/hr at the first hour and with increasing time the flow rates decreased to 1.037L/hr at the second hour, 0.867L/hr at three hours and the at last test 0.74L/hr and this filter at the same firing temperature after silver impregnation (Figure 4.2b) the filter has initially flow rates of 0.90L/hr at the first hour and with increasing time the flow rates decreased to 0.88L/hr at the second hour, 0.75L/hr at three hours and in the same way by decreasing we observe at last test 0.61L/hr .In this cause the results indicates that increasing firing temperature increase the pore size of the filters.



(a) (b)

Figure 4-2: Flow rate versus time for 900°C a) before silver impregnation b) after silver impregnation

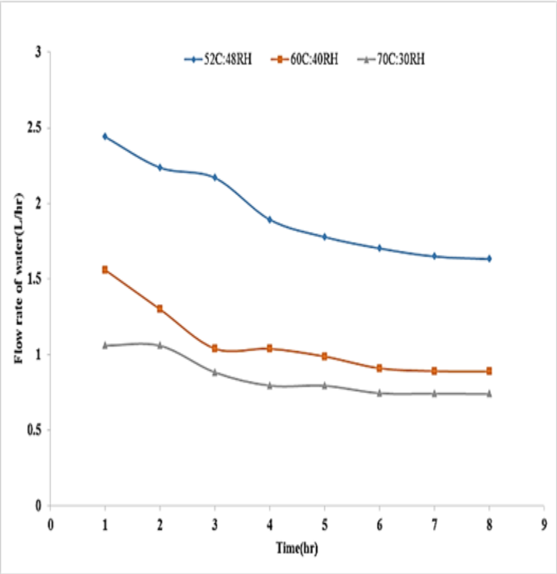
Increasing the firing temperature, increase the pore size of the filters because, since firing temperature is increase the firing all rice husk composition in filters are increase(100% burned out).

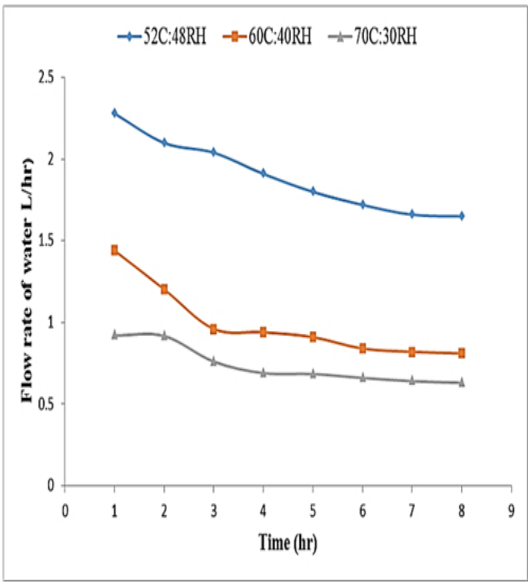
Figure 4.3 shows the flow rates of the three ceramic water filters at firing temperature of 950℃ in case of both before silver impregnation and after impregnation.

First the ceramic water filter prepared from 52C:48RH before silver impregnation (Figure 4.3a) has initially flow rates of 2.44L/hr at the first hour and with increasing time the flow rates decreased to 2.237L/hr at the second hour, 2.169L/hr at three hours and in the same way by decreasing we observe at last test 1.63L/hr and this filter at the same firing temperature after silver impregnation (Figure 4.3b) the filter has initially flow rates of 2.28L/hr at the first hour and with increasing time the flow rates decreased to 2.10L/hr at the second hour, 2.04L/hr at three hours and in the same way by decreasing we observe at last test 1.65L/hr .

Second the ceramic water filter prepared from 60C:40RH before silver impregnation (Figure 4.3a) has initially flow rates of 1.56L/hr at the first hour and with increasing time the flow rates decreased to 1.30L/hr at the second hour, 1.04L/hr at three hours and the at last test 0.88L/hr and this filter at the same firing temperature after silver impregnation (Figure 4.3b) the filter has initially flow rates of 1.44L/hr at the first hour and with increasing time the flow rates decreased to 1.203L/hr at the second hour, 0.96L/hr at three hours and in the same way by decreasing we observe at last test 0.81L/hr .

Third the ceramic water filter prepared from 70C:30RH before silver impregnation (Figure 4.3a) has initially flow rates of 1.06L/hr at the first hour and with increasing time the flow rates decreased to 1.059L/hr at the second hour, 0.883L/hr at three hours and the at last test 0.74L/hr and this filter at the same firing temperature after silver impregnation (Figure 4.3b) the filter has initially flow rates of 0.92L/hr at the first hour and with increasing time the flow rates decreased to 0.917L/hr at the second hour, 0.76L/hr at three hours and in the same way by decreasing we observe at last test 0.63L/hr . This means rice husk plus the firing temperature affected the performance of the filters because increasing rice husk to clay ratio and increasing firing temperature increases pore size of the filters.





(a) (b)

Figure 4-3: Flow rate versus time for 950°C a) before silver impregnation b) after silver impregnation

The study results indicate that as the percentage of rice husk and firing temperature increased the flow rate also increased since rice husk and temperature are pore creating agents. This shows as the proportion of clay to rice husk increased, the flow rate decreased. Another observable trend from the flow rate tests performed was that the flow rate decreased with time for all the filters tested. The cause of the flow rate decreases when the time increases the accumulation of contamination increases on surface of the pore of the filters and after a certain time the filters needs regeneration by re-firing. 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. 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. An average estimate based on a review of the literature for adult males is 2.9 L/person/day, adult females is 2.2L/person/day and children is 1.0 L/person/day[6]. If properly scaled up and manufactured, the prepared ceramic pot water filters are capable of producing sufficient safe drinking water at house-hold level for small family (average less than eight members). This is assuming the situation where the filter is consistently refilled throughout the day.

4.2. PH and Turbidity Measurements

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 Nephlometric 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.

Turbidity is characteristics of cloudiness of water. The amount of solid particles that are suspended in water can cause scattering of light. Low turbidity is essential for effective disinfection. Turbidity is resulted from the erosion of colloidal materials such as silt, sand or rock fragments and metal oxides from the soil, vegetation fibers and microorganisms. PH is the measurement of for how acidic or basic something is.PH is measured on a scale from 0 to 14, with 7 being neutral; If the PH of water is too high (basic) or to low (low) it is become toxic and not used for drinking and sanitation. According to world health organization (WHO) guideline the standard public drinking water should have a total dissolved solid less than 800 mg/l, pH value of 6.5-8, turbidity of less than 5nephelometric turbidity unit (NTU) is usually adequate and levels of color below 15 true color units (TCU) are usually acceptable.

The data collected during filters run where the initial pH and turbidity (NTU) of water sample from local river (Abaya River) is 8.80 and 23.01 respectively.

Table 4-1 pH and Turbidity (NTU) measurement

Filter ID	Firing Temp. (℃)	Raw water		Filtered Water	
		PH	Turbidity(NTU)	PH	Turbidity(NTU)
52C:48RH	800	8.80	23.01	8.38	8.14
	900	8.80	23.01	8.45	8.23
	950	8.80	23.01	8. 50	8.27
60C:40RH	800	8.80	23.01	7.6	7.18
	900	8.80	23.01	7.72	7.29
	950	8.80	23.01	7.80	7.87
70C:30RH	800	8.80	23.01	7.21	4.41
	900	8.80	23.01	7.34	4.44
	950	8.80	23.01	7.52	4.46

All filters showed capability of reducing PH and Turbidity pH of all the filtrates ranged from 7.21 to 8.50. Table 4.1 indicates the effects of firing temperatures and compositions of rice to clay ratios. 52C:48RH results pH and turbidity at 800℃ were 8.38, 8.14 respectively and increases as rice husk to clay ratio increases because of increasing the rice husk and firing temperatures are increases the pore size of the filters in cease of this some impurities pass through the filters with water. The ceramic water filters prepared from 70C: 30RH have the capability of reducing turbidity to less than 5 NTU. 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 Nephlometric 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. Additional parameters tested to characterize source water included pH. Results of the analysis of pre and post-filtration water samples collected showed some interesting indication. PH of the filtered water is decreased. This may be due to the entrapment of some ions within the filter element by clay.

4.3. Microorganism test

4.3.1. Coliform Analysis

Coliform bacteria are described and grouped, based on their common origin or characteristics, as either Total or Fecal Coliform. The Total group includes Fecal Coliform bacteria such as Escherichia coli (E .coli), as well as other types of Coliform bacteria that are naturally found in the soil. Fecal Coliform bacteria exist in the intestines of warm blooded animals and humans, and are found in bodily waste, animal droppings, and naturally in soil. Most of the Fecal Coliform in fecal material (feces) is comprised of E. coli, and the serotype E. coli 0157:H7 is known to cause serious human illness.

Total Coliform do not necessarily indicate recent water contamination by fecal waste, however the presence or absence of these bacteria in treated water is often used to determine whether water disinfection is working properly. The presence of Fecal Coliform in well water may indicate recent contamination of the groundwater by human sewage or animal droppings which could contain other bacteria, viruses, or disease causing organisms. This is why Coliform bacteria are considered indicator organisms; their presence warns of the potential presence of disease causing organisms and should alert the person responsible for the water to take precautionary action. A basic laboratory test is the best way to tell if Coliform organisms are present, as they can be there with no appearance or taste difference. When water is tested for Fecal or Total Coliform, the results are usually given as the number of colony forming units per 100millilitres (CFU/100ml) of water sampled. No sample should contain Fecal Coliform or E.coli, and ideally there should be no Total Coliform, however a single sample may contain up to 10 Total Coliform CFU/100 ml. If any Coliform bacteria are detected in drinking water, the source should be immediately investigated. If known or suspected to be Fecal Coliform or E. coli, the water should not be consumed without treatment such as boiling for one minute.

Sources of Total and Fecal Coliform in surface and groundwater can include: Agricultural runoff, Effluent from sewage discharges, Infiltration of domestic or wild animal fecal matter, Poor well maintenance and construction (particularly shallow dug wells) can also increase the risk of bacteria and other harmful organisms getting into a well water supply. The presence of Fecal Coliform bacteria or E. coli indicates contamination of water with fecal waste that may contain other harmful or disease causing organisms, including bacteria, viruses, or parasites such as Giardia. Drinking water contaminated with these organisms can cause stomach and intestinal illness including diarrhea and nausea (vomit), and even lead to death. These effects may be more severe and possibly life threatening for babies, children, the elderly or people with immune deficiencies or other illnesses.

4.3.2. Determination of total and fecal coliform analysis

Analysis of water for all the known pathogens would be a very time consuming an expensive proposition. So that, the quality of water is checked using indicator organisims. An indicator organism is one whose presence presumes that contamination has occurred and suggests the nature and extent of contamination of water. The organisms most nearly meeting the requirements of indicator organisms belong to the fecal coliform group.

There are other coliform groups which fluorish outside the intestinal track of animals. These organisms are native to the soil and decaying vegetation. Indicator organisms those of both fecal and non-fecal origin are determined as total coliforms.

For total coliform (TC) and Fecal coliform(FC), an incubating temperatures are 44℃ and 37℃ respectively for 24 hours is used during bacteria culture.

theMicrobial removal efficiency of the filters were determined by:

$$\%\text{Removal Effciency} = \frac{(\text{Untreated} - \text{treated})}{\text{untreated}} \text{ x}100\%$$

Where,

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

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

Table 4-2 Total coliform and fecal coliform Test before silver impregnate

Firing Temp. (℃)	Mixing ratios (Filters Name)	Raw water from Lake Tana		Filtered Water		RemovalEfficiency	
		TC (cfu/100mL)	FC (cfu/100mL)	TC (cfu/100mL)	FC(cfu/100mL)	TC (cfu/100mL)	FC (cfu/100mL)
800	52C:48RH	79	51	3	0	96.2%	100%
	60C:40RH	79	51	2	0	97.5%	100%
	70C:30RH	79	51	0	0	100%	100%
900	52C:48RH	79	51	4	1	95%	98%
	60C:40RH	79	51	3	0	96.2%	100%
	70C:30RH	79	51	1	0	98.7	100%
950	52C:48RH	79	51	4	1	95%	98%
	60C:40RH	79	51	3	0	96.2%	100%
	70C:30RH	79	51	1	0	98.7%	100%

Table 4-3 Total coliform and fecal coliform Test after silver impregnated

Firing Temp. ℃)	Mixing ratios (Filters Name)	Raw water from lake Tana		Filtered Water		RemovalEfficiency	
		TC (cfu/100mL)	FC (cfu/100mL)	TC (cfu/100mL)	FC(cfu/100mL)	TC (cfu/100mL)	FC (cfu/100mL)
800	52C:48RH	83	56	0	0	100%	100%
	60C:40RH	83	56	0	0	100%	100%
	70C:30RH	83	56	0	0	100%	100%
900	52C:48RH	83	56	0	0	100%	100%
	60C:40RH	83	56	0	0	100%	100%
	70C:30RH	83	56	0	0	100%	100%
950	52C:48RH	83	56	0	0	100%	100%
	60C:40RH	83	56	0	0	100%	100%
	70C:30RH	83	56	0	0	100%	100%

From the bacteria test and results, it can be concluded that, the silver impregnated ceramic filters are effective at removing disease causing bacteria and microorganisms.All filters showed capability of removed more than 96% of the total coliform and 98% of the fecal coliform indicator bacteria before silver impregnated and 100% of the total coliform and 100% of the fecal coliform indicator bacteria after silver impregnated from contaminated water sources respectively. This is shows us the silver impregnated filters are can removes other microoganisms such as viruses, protozao,Fungi,algea and Helminthes since silver is microbicide.

4.3.3. Total hardness and fluoride reduction efficiency test

Determine calcium hardness in water interms of calcium carbonate($CaCO_3$ because Hardness is expressed as mg/L $CaCO_3$. Calcium salts can be readily precipitated from water and high level of calcium hardness in an important control test in industrial waste water systems such as boilers, steam raising plant and for swimming pool waters.

The palintest calcicol test provides a simple method of determining calcium hardness over the range 0-500mg/l$CaCO_3$. The palintest calcium hardness is based on the calcicol indicator reagent method calcium ions react specifically with calcicol indicotor in alkaline solution to give an orange coloration. The reagent itself gives a violent color in solution. Thus at different calcium levels a distinictive range of colors from violent to orange is produced.The reagents for the method are provided in the form of two tablets(palintest calcicon No-1 and palintest calcicon No-2). The test is carried out simply by adding one of each tablet to a sample of the water. The produced is indicative of the calcium hardness and is measured using a round test tubes,10ml glass and palintest photometer. By doing the same process and using different reagent for each of total hardness ($CaCO_3$) and Fluoride (F^-) the results obtained experiments are recorded in the table form.

$$\%\text{Reduction Efficiency} =$$

$$\frac{(\text{mg/L CaCO3 } in \text{ the raw sample } - \text{mg/L CaCO3 } in\ the\ filtered\ \ sample)}{\text{mg/L CaCO3 } in\ the\ raw\ water\ sample} \text{ x100\%}$$

Table 4-4: Total hardness (mg/L CaCO3) Test before silver impregnated

Firing Temp.(°C)	Mixing Ratio	Raw water from Lake Tana	Filtered Water	Removal Efficiency
		mg/L CaCO3	mg/L CaCO3	mg/L CaCO3 (%)
800	52C:48RH	47	45.23	3.80
	60C:40RH	47	42.12	10.40
	70C:30RH	47	40.56	13.70
900	52C:48RH	47	46.10	2.00
	60C:40RH	47	43.08	8.34
	70C:30RH	47	41.20	12.34
950	52C:48RH	47	46.11	1.9
	60C:40RH	47	43.10	8.30
	70C:30RH	47	41.24	12.30

As the results from table 4.4 shows removal of total hardness using clay minerals are not achieved at all there is somewhat reduced because of certain calcium ion leached out by ion exchanging with clay minerals.

Table 4-5: Total hardness (mg/L CaCO3) Test after silver impregnated

Firing Temp. (°C)	Mixing Ratio	Raw water from Lake Tana	Filtered Water	Removal Efficiency
		mg/L CaCO3	mg/L CaCO3	mg/l CaCO3 (%)
800	52C:48RH	47	41.65	11.40
	60C:40RH	47	38.04	19.10
	70C:30RH	47	36.00	23.40
900	52C:48RH	47	42.17	10.30
	60C:40RH	47	38.87	17.30
	70C:30RH	47	36.41	22.53
950	52C:48RH	47	42.34	10.00
	60C:40RH	47	39.00	17.02
	70C:30RH	47	37.98	21.30

Table 4.5 indicates the removal efficiencies of the filters after silver impregnation still now the removal of total hardness from the water is not achieved totally at all. Since most of populations of the Ethiopia living in rural area is using surface water such streams, rivers, lakes, Ponds, reservoirs(a large natural or artificial lake used as a source of water supply) and canals (man-made lakes and streams); there is not more problem with chemical contaminants in Ethiopia considering to drinking water.

$\%Removal\ Efficiency\ =$

$$\frac{\left(\frac{\mathrm{mg}}{\mathrm{L}}\,\mathrm{Flouride}\ in\ \mathrm{raw\ sample}\ -\mathrm{mg/L\ Flouride}\ in\ the\ filtered\ \ sample\right)}{\mathrm{mg/L\ Flouride}\ in\ the\ raw\ water\ sample}\ \mathrm{x}100\%$$

Table 4-6: Amount of Fluoride (mg/L Fluoride) Test after silver impregnated

Firing Temp.(°C)	Mixing Ratios	Raw water from Lake Tana	Filtered Water	Removal Efficiency
		mg/L Flouride	mg/L Flouride	mg/L Flouride
800	52C:48RH	0.85	0.55	35.292
	60C:40RH	0.85	0.52	38.82
	70C:30RH	0.85	0.51	40.00
900	52C:48RH	0.85	0.58	31.76
	60C:40RH	0.85	0.54	36.47
	70C:30RH	0.85	0.53	37.65
950	52C:48RH	0.85	0.58	31.76
	60C:40RH	0.85	0.53	37.65
	70C:30RH	0.85	0.54	36.47

The experimental data obtained from table 4.6 was the results of filtered using ceramic water filters before silver impregnation. As the result indicates the filters reduces fluoride concentration from contaminated water due to ion exchange capacity of clay minerals acts as cation ion exchange. According to World health Organization (WHO) guideline the standard puplic drinking water should have a fluoride concentration 1.5mg/L. Therefore the raw water sample collected from Lake Tana for the experimental was less than maximum recommended concentration.

Table 4-7: Amount of Fluoride (mg/L Fluoride) Test after silver impregnated

Firing Temp.(℃)	Mixing Ratio	Raw water from Lake Tana	Filtered Water	Removal Efficiency
		mg/L Flouride	mg/L Flouride	mg/L Flouride
800	52C:48RH	0.85	0.01	98.82
	60C:40RH	0.85	0.01	98.82
	70C:30RH	0.85	0.01	98.82
900	52C:48RH	0.85	0.02	97.65
	60C:40RH	0.85	0.02	97.65
	70C:30RH	0.85	0.02	97.65
950	52C:48RH	0.85	0.02	97.65
	60C:40RH	0.85	0.02	97.65
	70C:30RH	0.85	0.02	97.65

From the same raw water from Lake Tana the experimental data (figure 4.7) shows the silver impregnated ceramic water filters more effective to reduce or remove fluoride from drinking water. Almost 98% fluoride concentration was removed in silver impregnation cause. Silver impregnated ceramic water filter was more effective to remove both bacterial (total coliform and fecal coliform) and fluoride contaminant from contaminated water source; in this cause two assumptions are considered, the first one is silver is act as bactericide and in second cause fluoride is ion exchange with silver ion on a pore size of the filters and also rice husk ash ion exchange with fluoride if totally not burnout and the rice husk ashes are also not removed at low firing temperatures.

5. CONCLUSSION AND RECOMMENDATIONS

5.1. Conclusion

This thesis attempted to prepare silver impregnated ceramic water filter providing clues with the ceramic water filter production process and procedures (i.e. material preparation, mixing materials, shaping, drying and firing) and filter performance testing. The performance of three ceramic filters was evaluated for volume of water filtered for a given period of time for filters without silver solution impregnation and with silver solution impregnation. The results obtained from laboratory experiment revealed that the ceramic water filters can produce high amount of water at high amount of rice husk to clay ratio and low amount of water filtered at low rice husk to clay ratios because rice husk is pore creating agent. The filters effectively reduce the concentration of indicator bacteria from contaminated water sources. The prepared ceramic water filters were able to remove 97% of the total coliform and 100% of fecal coliform indicator bacteria from the contaminated water sources before silver impregnation and 100% of the total coliform and 100% of fecal coliform indicator bacteria from the contaminated water sources after silver impregnation. Silver impregnated ceramic water filter is more effect on removing microorganisms from contaminated water since silver is microbicide. Due to high concentration of impurities attached on the surface of the pore of the filter and refiring is needed for regeneration.

The implications of the results in this work suggest that point-of-use ceramic pot water filters with different porosities can be used to filter out most of the bacterial pathogens in water. The use of the ceramic water filters in rural area of developing countries can contribute significantly to the removal of dieses causing microbial pathogens from drinking water where the most of people die every day from the effects of consuming contaminated water.

5.2. Recommendations

This study was focused on preparation of ceramic (fired clay) from clay soil and rice husk with three different clays to rice husk ratios and three different firing temperatures and the performance of the filters were evaluated for quantity of water filtered and bacteria, fluoride, turbidity and total hardness reduction efficiency.

Considering the results of this study, the following recommendations are suggested:

- ✓ Investigating the potential for the production of homemade ceramic filters at large scale/cottage level, fabricate and test its field effectiveness for microbial and removal and turbidity reduction.
- ✓ Transferring *(*disseminating*)* technology to users.
- ✓ More research is needed in Ethiopia to understand how the ceramic water filter element works on microscopic level. In particular, mechanisms that leads to an effective filter element that reduces microbial contamination from water sources.

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APPENDIX A: QUANTITY OF WATER FILTERS MEASUREMENT

Table A1: Quantity of water filters in Liter from each of the filters before silver nitrate solution impregnated

Firing Temp. (℃)	Mixing Ratio	Quantity of water filtered in Liter after							
		1hr	2hrs	3hrs	4hrs	5hrs	6hrs	7hrs	8hrs
800	52C:48 RH	1.380	2.530	3.68	4.60	5.405	6.210	7.015	7.95
	60C:40 RH	0.940	1.567	1.88	2.51	2.977	3.290	3.761	4.55
	70C:30RH	0.520	1.040	1.3	1.56	1.950	2.340	2.600	3.10
900	52C:48RH	1.860	3.410	4.96	6.2	7.285	8.370	9.455	10.7
	60C:40 RH	1.530	2.550	3.06	4.08	4.845	5.355	6.120	7.40
	70C:30RH	1.040	2.080	2.60	3.12	3.90	4.68	5.20	6.24
950	52C:48 RH	2.440	4.473	6.56	7.57	8.894	10.219	11.54	13.6
	60C:40 RH	1.560	2.600	3.12	4.16	4.940	5.460	6.240	7.54
	70C:30RH	1.060	2.120	2.65	3.18	3.975	4.470	5.300	6.36

Table A2: Flow rate of water filtered in L/hr. from each of the filters before silver nitrate solution impregnated

Firing Temp. (℃)	Mixing Ratio	Flow rates of water filtered in L/hr. after							
		1hr	2hrs	3hrs	4hrs	5hrs	6hrs	7hrs	8hrs
800	52C:48RH	1.38	1.265	1.23	1.15	1.081	1.035	1.00	0.99
	60C:40RH	0.94	0.784	0.627	0.63	0.595	0.548	0.54	0.53
	70C:30RH	0.52	0.520	0.433	0.40	0.39	0.38	0.37	0.37
900	52C:48RH	1.86	1.705	1.653	1.55	1.457	1.395	1.35	1.34
	60C:40RH	1.53	1.275	1.02	1.02	0.969	0.893	0.87	0.85
	70C:30RH	1.04	1.037	0.867	0.78	0.779	0.778	0.74	0.74
950	52C:48RH	2.44	2.237	2.169	1.89	1.778	1.703	1.65	1.63
	60C:40RH	1.56	1.30	1.04	1.04	0.988	0.91	0.89	0.88
	70C:30RH	1.06	1.059	0.883	0.79	0.794	0.745	0.74	0.74

Table A3: Quantity of water filters in Liter from each of the filters after silver nitrate solution impregnated

Firing Tem(℃)	Mixing Ratio	Quantity of water filtered in Liter after							
		1hr	2hrs	3hrs	4hrs	5hrs	6hrs	7hrs	8hrs
800	52C:48RH	1.29	2.37	3.44	4.30	5.06	5.808	6.56	7.42
	60C:40RH	0.87	1.45	1.74	2.09	2.42	2.676	3.06	3.38
	70C:30RH	0.46	0.88	1.15	1.38	1.72	2.05	2.31	2.62
900	52C:48RH	1.74	3.19	4.64	5.8	6.81	7.82	8.84	10.0
	60C:40RH	1.42	2.36	2.83	3.77	4.48	4.944	5.66	6.38
	70C:30RH	0.90	1.80	2.25	2.81	3.50	3.888	4.51	4.88
950	52C:48RH	2.28	4.20	6.11	7.64	8.98	10.31	11.6	13.2
	60C:40RH	1.44	2.41	2.89	3.84	4.56	5.04	5.76	6.51
	70C:30RH	0.92	1.83	2.29	2.75	3.44	4.11	4.56	5.14

Table A4: Flow rate of water filtered in L/hr. from each of the filters after silver nitrate solution impregnated

Firing Tem (℃)	Mixing Ratio	Flow rates of water filtered in L/hr. after							
		1hr	2hrs	3hrs	4hrs	5hrs	6hrs	7hrs	8hrs
800	52C:4RH	1.29	1.183	1.15	1.075	1.01	0.97	0.94	0.93
	60C:40RH	0.87	0.725	0.58	0.522	0.48	0.45	0.44	0.42
	70C:30RH	0.46	0.44	0.38	0.35	0.34	0.33	0.32	0.32
900	52C:48RH	1.74	1.594	1.55	1.45	1.36	1.30	1.26	1.25
	60C:40RH	1.42	1.18	0.94	0.942	0.90	0.82	0.81	0.80
	70C:30RH	0.90	0.88	0.75	0.703	0.70	0.65	0.64	0.61
950	52C:48RH	2.28	2.10	2.04	1.909	1.8	1.72	1.66	1.65
	60C:40RH	1.44	1.203	0.96	0.960	0.91	0.84	0.82	0.81
	70C:30RH	0.92	0.917	0.76	0.69	0.68	0.66	0.64	0.63

APPENDIX B: PATHOGENS SIZE

Pathogens are micro-organisms that can cause disease in humans.

Bacteria are single-celled organisms, typically 1 to 5 µm in size (1000 µm =1mm).

Viruses are protein-coated genetic material that lack many cell structures, and are much smaller than bacteria in most cases 10 to 300 nm (1000 nm = 1µm). Parasites are single-celled organisms that invade the intestinal lining of their hosts. The two main types of parasites are protozoa and helminthes (intestinal worms). Parasites have a complex life cycle, and most at some stage form large protective cysts or eggs (4-100 µm), which can survive outside of the host bodies.

Table C1: Sizes of pathogens

Pathogen	Size in diameter
Virus	0.03 µm- 0.1µm
Bacteria (E.coli)	1 - 3 µm
Protozoa	1.5 µm

(https://www.culliganmidmissouri.com/water.../bacteria-protozoa and viruses in water)

APPENDIX C: WATER QUALITY STANDARD

According to world health organization (WHO) guideline the standard public drinking water should have a total dissolved solid less than 800 mg/l, pH value of 6.5-8, turbidity of less than 5nephelometric turbidity unit (NTU) is usually adequate and levels of color below 15 true color units (TCU) are usually acceptable. A level for a water constituent which does not result in significant health risk and which ensures acceptability of the water to consumers.

Table D1: Bacteriological quality for drinking water

Parameter	**Maximum Value**
Fecal Coliforms or E. coli	0 per 100 mL
Total coliforms	0 per 100 ml

Table D2: Inorganic constituents of health significance in drinking water

Parameter	Maximum Valuemg/1
Arsenic	0.05
Barium	0.7
Cadmium	0.003
Chromium	0.05
Cyanide	0.07
Fluoride	1.5
Lead	0.01
Mercury	0.001
Nickel	0.02
Nitrate as N03-	50
Nitrite as N02-	3
Selenium	0.01

Table D3: Physical and chemical quality of drinking water

Parameter	Maximum Value (mg/1)
Taste	Acceptable
Odor	Acceptable
Color	5 TCU
Turbidity	5 NTU
Residual chlorine	0.2-0.5
pH	6.5 - 8.5 (no unit)
Ammonia	1.5
Chloride	250
Copper I Hardness	300
Hydrogen Sulfide	0.05
Iron	0.3
Manganese	0.1
Sodium	200
Sulfate	250
Total dissolved solids	800
Zinc	3