PERFORMANCE OF CERAMIC CANDLE WATER FILTER MADE FROM SELECTED LOCAL CLAYS IN UGANDA

BY

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DECLARATION

I Onyait Justine do hereby declare that this Dissertation contains my original work and has not been presented to any University for an academic award.

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DEDICATION

I dedicate this work to my lovely son Lincoln Edmond Onyait.

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ABSTRACT

The focus of this study was to developa ceramic candle filter using local clay and mahogany saw dust and determine its filtration rate and E–coli removal efficiency.

The candle filters were developed using ball clay from Ntawo mixed with mahogany saw dust of particle size less than 1mm. Five different clay- saw dust ratios were used in the production of the filters by weight of 1:1, 5:4, 5:3, 5:2, and 5:1.

The highest porosity of 48.05% was obtained in a filter sample with the highest saw dust proportion (1:1) while the lowest porosity of 35.12% was obtained in a filter sample with the lowest saw dust proportion (5:1).Higher removal efficiencies of contaminants (99.9%) were observed in filter samples with low saw dust proportion (5:1). Ceramic candle filter (CCF) with clay to saw dust proportion of (5:1) was more effective in reducing turbidity, reduced turbidity to< 1 NTU. The candle filter with the lowest saw dust proportion (5:1) produced the lowest filtrationrate of water (196.43 $ml\ hr^{-1}$) and the filter with highest saw dust proportion had the highest filtration rate of water (917.67$ml\ hr^{-1}$).

From this research, it can be concluded that filters with higher initial filtration rates are more porous than those with low filtration rates. It can also be concluded that the filters were capable of filtering the turbidity of the water and filter samples also decreased the concentrations of microbial contaminants, therefore making the water safe for consumption.

Its recommended that further studies be carried on; the effect of grog on cohesive nature of the filter, flow rate of the water, turbidity of water, and total coliform removal of the filter. The effect of the application of colloidal silver on the adsorptive properties of the filter material and consequently on the quality of water should equally be explored.

CHAPTER ONE: INTRODUCTION

1.1 Background of the Study

An estimated 1.1 billion people worldwide stilldo not have access to clean drinking water. A large percentage of these people are from the developing countries, especially those living in the rural areas and are referred to as low-income communities according to the World Health Organisation report (2007). According to Kosek*et al* (2003) it is estimated that 1.8 million people die every year from diarrhoeal diseases. The majority of the deaths in developing countries are associated with diarrhoea which is rampant among children below five years of age according to Parashar et al (2003). In Uganda, an estimated one hundred children under five years old contract diarrhoea which results in to two deaths per day according to United Nations Children's Fund report (2009). This situation underscores the importance and the need for clean water world-wide especially in developing countries.

The safety and cleanliness of water is also linked to its source and surrounding. Uganda is endowed with abundant renewable sources of water providing up to 2085 m^3 of water per year. This is well above the international recommended volume of 1000 m^3 per year according to United Nations Educational, Scientific and Cultural Organisation report (2006). The natural water resources in Uganda include lakes, rivers, swamps, boreholes and springs. However, the water sector in Uganda is still under developed. Only about 0.5% of total available water resources are currently drawn per year for use in agriculture, 43% for municipal use and 17% for industrial consumption. This is according to the Ministry of Water and Environment from the online information Available on http://en.wikipedia.org/wiki/water_supply_and_sanitation_in_Uganda) as of June 2012. The source also indicates that access to safe and clean water within 1km distance in the rural areas is estimated to be 64% (which is a slight decline from 65% which was reported in year 2011). For the urban areas, access to safe clean water has increased from 66%, within 0.2km distance which was reported in year 2011, to 70%.

The urban dwellers are supposed to enjoy provision of piped water. However, more than 40% Ugandans living in urban areas live in unplanned settlements. This also means that they have also got unplanned water supply systems. Of the unplanned settlement residents only 17% have access to piped water, protected springs, bore holes and protected wells. The rest of the residents of unplanned settlements use open surface water sources like lakes, rivers, and wells to get their drinking water. The situation of availability of water in rural and semi-urban areas is worsened by the poor waste management systems in the rural and semi-urban areas. Whenever it rains the pathogen-laden human and animal faeces, food remains and garbage which pile up near homes and the surrounding areas drain into waterways, contaminating the open surface water sources. In addition, industrial effluents, dumping of untreated wastes and sewage from urban residential areas also pollute these open surface water sources into which they drain. This pose a challenge to the urban and semi-urban dwellers without access to treated water supply.

The other challenge to safety of drinking water is also the natural disasters that occur occasionally. Many parts of Uganda have experienced an increase in natural disasters such as mudslides, floods and landslides. Wherever the disasters have occurred, the victims are left fighting for basic needs of life that include need for clean water. Often when the call for help is sent out, other Ugandans think of the victims only in terms of the need of food, shelter and other domestic properties forgetting the most important and essential element of life which is the need for safe and clean water. The latest of such a disaster occurred in May 2014, when River Mobuku burst its banks causing flooding in Kasese district, which left residents in dire need for help. Most of water sources got contaminated with lime stone. The natural disasters such as flooding can considerably increase microbial contamination of surface water according to Faruque et al., (2005). The other water quality challenges following natural disasters include salinization and water contamination by hazardousmaterials release according to Young et al., (2004) and Violette et al., (2009). Hazardous materials such as radio nuclides were detected in water bodies following the Japanese earthquake disaster of 2011 according to Matsumoto and Inoue (2011). The debris contamination can make the water turbidity rise up to 10,000 Nephlometric Turbidity Unit (NTU) according to Garsadi et al., (2009). These show thecomplexity and level of water contamination in the aftermath of a disaster.

Groundwater would be anotherresource to provide clean water since it has the benefit of being naturally protected from bacterial contamination. However, the high costs associated with drilling for underground water presents challenges that limit tapping of the ground water resource. Groundwater is not a fully safe resource either when it comes to providing clean water. There may be contamination of the water with metal rusts, and bacteria may be introduced into drilled water sources by leaking septic systems or contaminated wells. For these reasons, it is important that groundwater be monitored frequently, which can be costly.

Several studies have shown that contaminated water sources have been associated with various waterborne diseases that can affect the communities living around the sources. This is particularly so for rural areas where according to Pritchard et al, (2009) an estimated 5 million people lose their lives due to water-related diseases each year. Bacterial pathogens in water tend to cause gastrointestinal infections such as diarrhoea, dysentery, typhoid shigellosis and human enteritis. Drinking water not only contains microbial contaminants, but also chemical contaminants that range from organic to inorganic compounds. The presence of organic and inorganic compounds in the water, make it toxic and dangerous for human consumption. Symptoms of consuming water with acute toxicity include diarrhoea, nausea, convulsions, blurred vision. Organic pollutants may also cause arteriosclerosis, heart diseases, hypertension, bronchitis, and kidney and liver dysfunction according to Leivadara et al, (2008). Some of the inorganic chemicals when taken into the body system are associated with health problems that may cause human system malfunction. Nitrates accumulate in the blood stream and result in methemoglobinemia, of which a conspicuous symptom is a bluish skin. High concentration of phosphate for example can cause health problems such as kidney damage and osteoporosis according to Rose et al, (1996). Other chemical contaminants such as chloride, magnesium, iron, aluminium, copper, arsenic and lead can also be present in drinking water. These contaminants pose public health risks at high concentrations.

Ugandan Government and Non-Government Organizations (NGOs) have invested in projects aimed at supplying clean water to the rural and semi-urban areas with the view of curbing the water borne diseases. National Water and Sewerage Cooperation (NWSC) is providing piped water to serve the population of Uganda. Unfortunately, piped water coverage in Uganda is still in sufficient, especially in the rural and semi-urban areas. Where piped water is available, the pipes have developed holes due to poor handling, rusting and aging. These holes provide channels through which the piped water often get contaminated. In some cases the piped water flows for only a few hours a day due to the frequent break down of the pumping systems. This has forced the residents in such areas to store water in storage tanks and these water containers are often not washed nor properly maintained, thus enabling micro-organisms to breed in them. The water obtained from such storage facilities is not usually treated before consumption, therefore making it unsafe for domestic use.

Contaminated water can however be purified to provide safe water for consumption using ceramic water filtration method. However, it is not a popular method for treating contaminated water at household levels in Uganda. The filters are in different designs, shapes and sizes which include hollow candle like filters, disk filters and pot filters. The main raw materials for the production of the ceramic filters are clay and material burnouts. Some filters are made entirely from ceramics such as the Potters for Peace filters, while some have a ceramic pot hanging in a plastic container such as Filter Pure (Agua Pure). The Potters for Peace ceramic pot filters are manufactured by an international organization code named Potters for Peace using 60% dry powdered clay and 40% screened sawdust mixture according to reports obtained from http://www.akvo.org/wiki/index/ceramic_pot_filters [Accessed: 2 Dec 2010]. The pots are fired at 887 °C and then impregnated with colloidal silver. The colloidal silver helps in removal of pathogens and prevents the growth of microorganisms within the filter itself. During use, the tiny silver particles (colloidal silver) are suspended in the liquid acting as a disinfectant to prevent bacterial growth in the ceramic filter. The silver enhances inactivation of the bacteria in the filter according to Lantagne et al., (2006).

National Water and Sewerage Cooperation (NWSC) uses chlorine to disinfect water which they pump to urban areas. Chlorine tablets are also used to disinfect water at domestic level. Unfortunately, majority of the population living in the rural and semi-urban areas cannot afford to buy these tablets. The common method people use to clean water is to boil it. The energy required for boiling water is becoming expensive and even firewood or charcoal is becoming expensive because the source of firewood and charcoal is dwindling. Electricity for example, the cost of electricity charged by UMEME(U) Ltd in Uganda now stands at UShs. 650.00/= per unit yet the average Ugandan living in the rural and semi-urban areas can hardly earn UShs. 10,000/=per month. Firewood is also becoming hard to get because the forest reserves are dwindling fast, Thus, purifying water for domestic consumptions by boiling is not only expensive but is also detrimental to the environment in terms of desertification of forests due to increased demand for fire wood and charcoal fuel by average Ugandans. There is therefore need, to develop a ceramic filter as an alternative to boiling water.

1.2 Statement of the Problem

Uganda's population growth rate is 3.24%, the fourth highest in Sub-Saharan Africa, and it is predicted to stay high with a projected rate of 2.36% by year 2030 compared to the projected average rate for Sub-Saharan Africa of 1.71% according to Uganda Bureau of Statistics (2012). Based on projected population growth, the total renewal water resources of the country per capita are expected to drop 1072 m^3per year by year 2030. This means that the demand for clean water for domestic use is increasing by the day. Therefore, to meet this increasing demand for clean water, readily available, cheap, efficient and effective local technologies of providing clean water for domestic use need to be developed.

There is a need to source and investigate local Ugandan clays in making ceramic candle filters (CCF) and the efficiency of ceramic candle filter (CCF) in contaminant removal as well as its potential sustainability. This study reports on the performance of the ceramic candle filter (CCF) in terms of flow rate, physiochemical contaminants (turbidity, fluorides, phosphates, chlorophyll a, magnesium, calcium and nitrates) and microbial contaminant (E-coli, V-cholera, Salmonella typhimurium, Shigelladysenteriae) removals.

Rural areas use pots and tanks to keep water without filter systems. There are available ceramic filters on sale but not widely available in homes, the technology could therefore be indigenized using local clays but efforts to find if possible has not been systematically tried.

1.3 Purpose of the Study

The study was todevelop a ceramic candle filter using local clay samples in Uganda and determine its potential and efficiency in filtering contaminated water.

1.4 Objectives of the Study

The study was designed to achieve the following objectives;-

(i) To produce ceramic candle filters of different porosities using local clays and mahogany saw dust.
(ii) To find the porosity of different ceramic candle filters.
(iii) Measure the filtration rate of water through the ceramic candle filters.
(iv) To determine the turbidity removal efficiency the ceramic candle filters.
(v) To determine total coliformremoval efficiency in filtered water.

1.5 Significance of the Study

The results of the study showed that, for the different filters produced with different porosities (48.05%, 44.33%, 42.31%, 38.40%, and 35.12%)their porosity decreased linearly with decrease in the amount of sawdust in the filters. The filtration rate of water through the filter decreased with a decrease in sawdust. The candle filter with the lowest clay to saw dust ratio (5:1) produced the lowest filtration rate of water (196.43 $ml\ hr^{-1}$) and the filter with highest saw dust proportion(1:1) gave the highest filtration rate (917.67$ml\ hr^{-1}$). Ceramic candle filter (CCF) with clay to saw dust ratio 5:1 was more effective, reduced turbidity to < 1 NTU. All filter samples decreased the concentrations of microbial contaminants from test water sample. Higher

removal efficiencies of contaminants (99.9%) were observed in filter samples with small saw dust proportion (5:1).
This result provides data for making filters of desired porosity. This can also be used to produce filters of desired filtration rates and removal efficiency values.

Ministry of Health, Department of Public Health is one of the stake holders that benefits from this study; Reduction of water borne diseases by effectively removing E-coli from drinking water. This study provides knowledge to the local population in Uganda on the making of ceramic candle filter (CCF) which is efficient using only locally available materials and hence reduces prevalence of water borne diseases as well as infant mortality. This reduces the Ministry of Health's budget on treatment of diarrhoeal diseases.

Non-Governmental Organizations that Campaign for poverty reduction are beneficiaries too, from E-coli removal efficiency of the study. The ceramic water filters can be locally made and the technology is simple. Therefore, the community can be easily taught how to make the filters and sell them to eradicate poverty. It will also save house hold income, as most of the money that would be wasted in treating diseases due to contaminated water can be redirected to other useful activities.

Ministry of Lands and Environment benefits from turbidityande-coli removal efficiency of this study as an alternative to boiling. Currently, a lot of deforestation is taking place throughout the country as the rural and semi-urban people search for firewood to get the necessary energy to boil water in an effort to kill pathogenic organisms therein. Therefore the use of ceramic candle filter (CCF) to purify water for domestic use contributes towards environmental protection and forest conservation.

1.6 Scope Of the Study

The study was restricted to the use of ceramic candle filters made using ball clay obtained from Ntawo in Mukono District, mahogany-hardwood sawdust.

The ball Clay used, was from Ntawo which had a high content of silicon oxide ($Si\,O_2$) up to 65.73% by dry weight percentage according to Obwoya, (2004). It is therefore expected to have small crystalline structure compared to the other types of clay materials. The small crystalline structure of the Ntawo ball clay was chosen so that it would exhibit notable properties of high plasticity and greater dry mechanical strength when fired according to Prajapati et al, (2002).

The hardwood sawdust was chosen so that it would not cause bloating according to Katherine et al., (2000). This was to give more uniform pore formation with fewer defects in the filter produced. This was the reason for the choice of mahogany saw dust in producing the filter.

The study strictly dealt with water obtained from lake Victoria around Ggaba water treatment plant. Sewage pipes are seen to drain their contents towards the lake at Ggaba and therefore it is expected that the water possesses faecal coliform and was visibly turbid.

The study was also restricted to the use of the produced ceramic candle filters to determine the turbidity of the filtered water, efficiency of the filter in removal of pathogens (e-coli) from filtered water, the rate of water filtration through the filters, and also determine the porosity of the filters produced.

CHAPTER TWO: REVIEW OF RELATED LITERATURE

2.1 Introduction

The review of related literature in this report has covered some of the theoriesand processes connected with the topic of study. It has also covered discussion of results of earlier work done by other researchers that can make the understanding of the results of this study clearer. It has given theories about the structure of clay materials and chemical components of importance to understanding the properties of clay products. This section also involves understanding how combustible materials lead to pore formation, different types of pores, pore size distribution, pore size diameter and bubble- point test. It also has covered Ultrasonic Pulse Velocity (UPV) measurements and Density method of measuring porosity.

2.2 ClayStructure and Mineral Compounds

Clay is a mineral which is a productof chemical and/or physical weathering process of rocks over longperiods of time. There are three primary classes of clay: kaolinite, montmorillonite,and illiteaccording to *Shepard et al, (1968).* Each class differs slightly from the others in its structure and composition of mineral compounds it contains. However, all clays have a distinct crystalline structure that resembles "platy" sheets stackedon top of one another. The chemical composition generally consist of hydrous aluminium silicates combined with trace amounts of other mineral compounds of potassium, iron, calcium among others, which giverise to notable clay characteristics like their colors.

Kaolinites are clays with octahedral layer similar to gibbsite structure, their layers are electronically neutral with the bonding between layers is by weak van de Waal bonds. Kaolinites have the chemical formula $Al_2Si_2O_5(OH)_4$. Other kaolinites with similar structures are Anauxite, Dickite, and Nacrite.Kaolinites are formed by weathering or hydrothermal alteration of alumina silicate minerals. Thus, rocks rich in feldspar commonly weather to kaolinite. Kaolinites are preferred for ceramic industry because they do not absorb water and therefore do not expand when they come in contact with water. Montmorillinite is clay with structure similar to pyrophylllite structure, but can also have a significant amount of magnesium anf iron substituting into octahedral layers. Therefore montmorillinite are both dioctahedral and trioctahedral. Their most important aspect is the ability for water molecules to be absorbed between its sheets causing the volume of the mineral to increase when they come in contact with water and thus they are expanding clays. Illite clays have a structure similar to that of muscovite but typically deficient in alkalies with less aluminium substitution for silicon.

Clay minerals are used extensively in ceramic industry and are thus important economic minerals. Clays have the unique property of being plastic and hence workable, when mixed with a large volume of water. The plasticity of clay and the cohesive forcesacting between clay particles, allows the ceramist to form clay into shapesthat maintain their form. When heated to a sufficiently high temperature, clay fuses into a dense, strong cohesive solid product. Clays used in ceramics are called ceramic wares.

Ceramic products referred to as ceramic wares are often categorized as earthenware, stoneware, or porcelain depending onthe composition of the clay that is used to build the ware. Earthenware is defined as glazed or unglazed non vitreous porous clay-base ceramic ware. The natural red, gray, or brown colors that are common to earthenware clays are a function of the mineral content ofthe clay structure. The presence of iron oxide in clay, for example, typically gives rise to red color of clays. Earthen clays also have the lowest firing temperature at which they can mature, due to therelatively high concentration of iron and other mineral impurities that they contain.
Fired earthenware objects are themost porous of the three types of wares, with after firing porosities being of the order of 10-15% by weight. The stoneware objects have porosity of 2-5% by weight and porcelainhaveporosity

of 0-1% by weight. Earthenware claydoes not absorb water, and therefore does not expand when it comes in contact with water. This makes them a suitable choice for the production of ceramic water filters.

Uganda has a variety of earthenware clay types like kaolin, ball clay, fire clay, common clay, bentonite and fuller' earth, each of which has different properties suitable for different applications. The properties of these clays depend on their crystalline structure and chemical compositions. For example, according to Obwoya (2004), the chemical composition by dry weight percentage of Ntawo ball clay minerals from Mukono District is as shown in Table 2.1

Table 2.1: Dry weight % of Clay Mineral Oxides in Ntawo Ball Clay

SiO_2	Al_2O_3	Fe_2O_3	TiO_2	K_2O	MgO	CaO	Na_2O
65.73	26.35	3.94	1.65	0.87	0.39	0.30	0.20
ZrO_2	P_2O_5	Cr_2O_3	MnO	ZnO	Au_2O	CuO	NiO
0.06	0.08	0.04	0.05	0.02	0.01	0.02	0.01

The Ntawo Ball clay has a high content of silicon oxide (SiO_2)and hence has small crystalline structures. The small crystalline structures of the Ntawo ball clay enableit to exhibit the notable propertyof higher plasticity and greater dry mechanical strength when fired. As a result, the high plasticity and great dry mechanical strength make Ntawo ball clay most suitable for producing ceramic water filters. This is because the high plasticity allows for shaping and manipulation in a useful cohesive solid product which has a great mechanical strength when fired. These properties are essential for ease of storage and handling of the fired material produced from ball clays.

2.3 Pores and Pore Formation

Pores and pore formation is important in the operation of a filter. Therefore explanation of how pores are formed in clay materials makes one understand how filters can be formed. The shape, size and diameter of the pores are important aspects which also discussed here.

The main raw material for the production of a ceramic candle filteris the highly plastic ball clay and the easily combustible material. The behaviour of the porous material ishighly dependent on the properties of the starting material and suspensions such as zeta potential, particle size and volume ratio of the powders according to Sakka*et al*, (2003). The combustible material can be any material that burns off into ashes during the firing process to create voids in the earthenware. It is the voids that provide the earthenware with its porosity. Combustible materialsare used to increase the porosity of the ceramic filters. Their combustion during firing of the filters creates voids within the filter structure. Organic materials from plants and animals are suitable for pore formation in ceramics because they burn off during the firing process of the ceramic product. The examples of combustible materials that can be used for pore formation include, but not limited to, grain flour, sawdust, sorghum husk, rice flour, rice husk, millet husk, milled corn cobs. However, Katherine et al., (2000), noted that hardwood sawdust is better than softwood sawdust because it does not cause bloating. It's burn off results in a more uniform pore formation with fewer defects in the filter. Therefore mahogany saw dust that was usedwas meant to provide suitable combustible material for pore formation in filter production.The size of the combustible material influences the final pore size in the ceramic filter. The use of large particle size combustible material would make the filter become too porous and fragile. Very small size combustible materials make the filter chalky or dusty. This implies that screening for a uniform grain size combustible material using two screens is preferred to screening with just one sieve. The clay is tobe mixed with water first before mixing in the combustible material. Otherwise, the combustiblematerial, rather than the clay, would absorb too much of the water.

The burnout of combustible materials in filters can cause several types of void spaces. They can form a continuous phase within the porous medium, called 'interconnected' or'effective' pore spaces. They can also form 'isolated' pores and 'dead end' pores as shown in Figure 2.1.

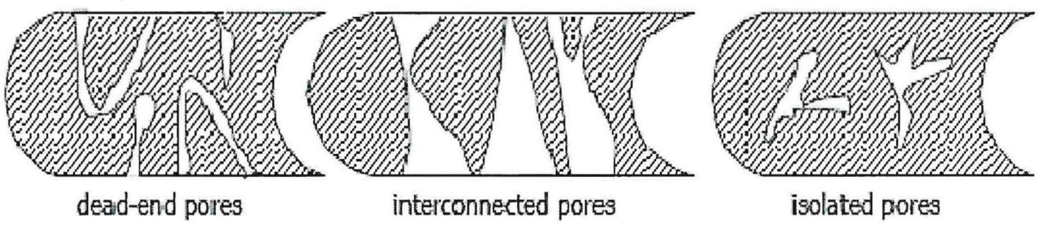

Figure 2.1:Different Types of Pores [Xiaolong, 2005]

The isolated pores donot contribute to filtration of water across the filter. The 'Dead-end' pores are interconnected from one side only.Some of the dead-end pores can also be connected to the interconnected pores, but as long as the route of those pores is a dead-end it will not contribute to the water filtration across the filter. When the filter is filled with water all pores connected to the inside would fill with water, including the 'dead-end' pores. This will result in a delay before a steady-state discharge of the filter is reached.

The shape and the size of pores are important physical parameters that determine thecharacteristics of the ceramic filter. The size and the shape of pores can be determined byobserving the microstructure of the material. The most widely used optical methods areobservations of thin sections with transmitted light and observations of polished sections with reflected light according to Kingery et al, (1976). The grain size of the ceramic material canalso be observed by analysing the microstructure of the material

A mercury intrusion porosimeter is another method used to get specific information on the pore size diameters in the filters. The diameters measured by porosimeters range from 0.003 µm to 360 µm, depending on the pressure range of the porosimeter. To measure these pore diameters it is a necessity to work with a non-wetting fluid, to ascertain that pressure needed to fill the pores with the fluid. The behaviour of a non-wetting fluid (Hg) differs froma wetting fluid as shown in Figure 2.2.

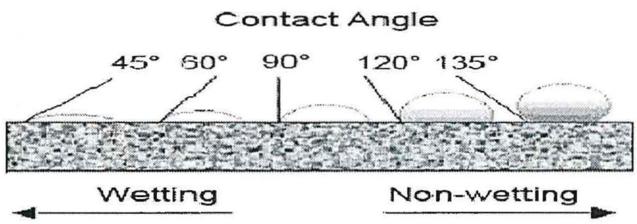

Figure 2.2: Contact Angles of Wetting and Non-wetting Fluids [Webb, 2001]

A non-wetting fluid resists entering a capillary according to Webb, (2001). To describe this intrusion of the liquid, three physical parameters are needed. These are; the surface tension, the contact angle, and the geometry of the line of contact at the solid-liquid-vapour boundary.

Washburn [1921] first suggested the measurement of pore size distribution by the use ofmercury injection. He derived an equation from the Laplace equation describing theequilibrium of the internal and external forces on the solid-liquid-vapour system in terms ofthe three parameters mentioned before. Washburn's equation assumes that the pore is cylindrical and the opening is circular in cross-section.

$$-2\pi r\gamma \cos\theta = \pi r^2 P \qquad (2.1)$$

The relationship between applied pressure and the minimum pore size diameter into which mercury will be forced to enter is:

$$D = \frac{4\gamma \, Cos\theta}{P} \quad \text{..................................} 2.2$$

P –Applied pressure [Nm^{-2}]
γ -Surface tension of the liquid [Nm^{-1}]
θ - Liquid-solid contact angle [°]
D -Pore diameter [m]

A mercury intrusion porosimetry test involves placing a sample (approximately 1 cm^3) into a container as shown in Figure 2.3 below.

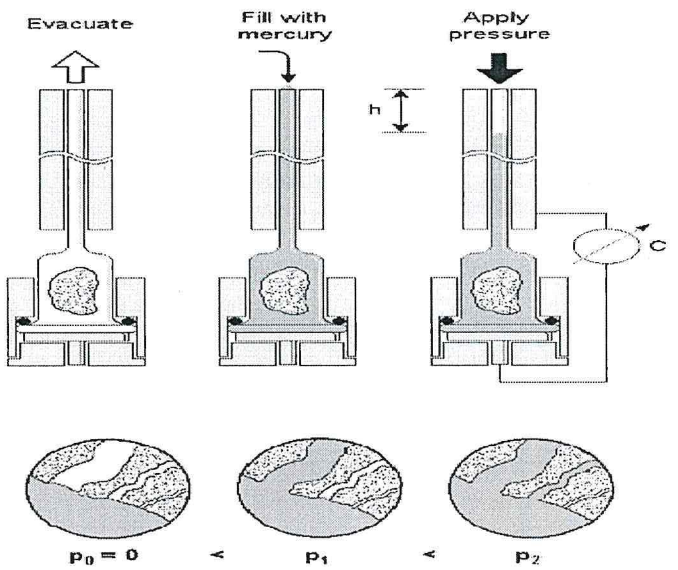

Figure 2.3:Mercury Intrusion in Determination of Porosity

Air is evacuated from this container to remove contaminant gases and vapours (usually water), subsequently mercury is allowed to enter. This creates an environment consisting of solid, a non-wetting fluid and mercury vapour. Next, pressure is built up and the volume of mercury entering larger openings is monitored.

The volume of mercury that intrudes into the sample due to an increase in pressure from $P_i$to $P_{i+1}$is equal to the volume of the pores in the associated size range $D_i$to D_{i+1}.

The total pore area is calculated with the assumption that all pores are cylindrical. From acylindrical pore model the pore wall surface area is determined from the incremental porevolume (V_{Ii}) by the equation:

$$A_{Wi} = \frac{4V_{Ii}}{D_i}\text{..............................}2.3$$

The sum of all pore areas per representative diameter (D_i) for the size class equals the totalpore (surface) area.

Pore diameteris also another important physical parameter that needs to be determined.Pore diameters is thepath travelled by particles determines whether they are retained or not. Effective pore size diameter is calculated by measuring the bubble-point of the filter. Water travels through many paths in the filter, the pore diameters on these pathsdetermine which particles are retained in the filter. The largest effective diameter in a filter element is the effective pore diameter of thefilter as illustrated in Figure 2.4 by a capillary tube.

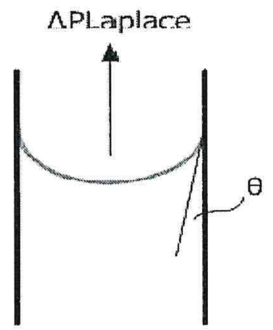

Figure 2.4: **Solid-Liquid Contact Angle**

To determine the size of the effective pore, a bubble-point test is performed. The bubble-pointtest is based on the fact that, for a given fluid and pore size with a constant wetting, thepressure required to force an air bubble through the pore is inversely proportional to the sizeof the pore. According to the theory of capillarity, the height of rise of water column in a capillary isinversely proportional to the capillary tube diameter. In practice this means that the largesteffective pore size of the filter can be determined by forcing air through the pores. Bygradually increasing the pressure in the filter the air is pushed through the pores. At a certainpressure, a steady stream of air bubbles will escape from the filter, this is called the bubblepoint.

The bubble-point is the moment at which the air has passed the route with the largesteffective pore diameter. The relation between the air pressure at bubble-point and theeffective pore diameter is described by a modification of the Laplace equation (similar to theWashburn equation):

$$\Delta P = \frac{4\,\gamma\, Cos\theta}{D} \qquad \text{2.4}$$

ΔP - Pressure difference over filter [Nm^{-2}]

γ -Surface tension of the liquid [Nm^{-1}]

θ - liquid-solid contact angle [°]

D -Pore diameter [m]

2.4 The Filtration Process

Filtration can be a physical, chemical or biological process of removing contaminants from water. Filtration involves removal of suspended solids and impurities from the water by passing it through a porous medium. Water filtration is therefore the process of separating pure water from solid impurities which may include contaminants such as pathogens and solid particles.The overall removal of impurities associated with the process of filtration, is done by acombination of different mechanisms which include, mechanical screening, sedimentation, adsorption, chemical and biological activity.

Mechanical screening is sometimes called mechanical straining, it is a process that involves retaining particles of suspended solids that are larger than the pore size of the filter at the surface or inside the filter. In this way the impurities and contaminants that cling themselves on the suspended solids are trapped and removed from the filtered water. Clogging of the filter element will reduce pore sizes and, theoretically at least, the screening efficiencywill increase with time.

Sedimentation process removes particulate suspended matter of finer sizes than the pore diametersthat have been trapped inside the pores bysettling within the pores of the filter material. Due to the larger density of thesuspended matter than water it will follow a different path resulting from gravitational force.

Diffusion is the random motion of particles caused by collision with surrounding molecules, which could eventually lead to adsorption to the filter material as shown in Figure 2.5.

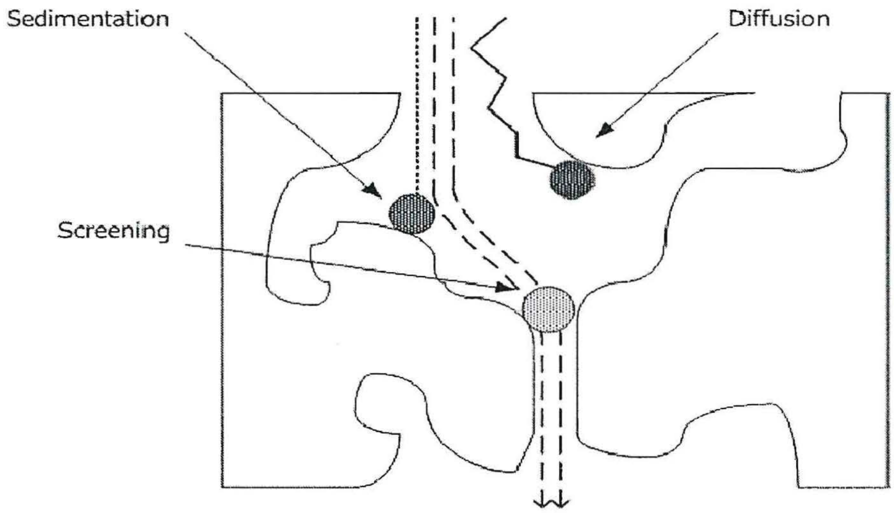

Figure 2.5: Mechanisms of Filtration

Adsorption is a purifying process, which removes finely divided suspended matter as well as colloidal and molecular dissolved impurities. When an adsorbent such as activated carbon is used as a filter material, contaminants are removed by chemical adsorption. Adsorption process is only effective when it is combined with a second mechanism to bring the particle in the immediate vicinity of the clay surface. Many of these transport mechanisms are present in the flowing water. The forces responsible for the adsorption of suspended matter at a short distance from the filter material are: physical attraction between two particles (Van der Waals' forces); and electrostatic attraction between opposite electrical charged particles (Coulomb forces).

Chemical activity is aprocess of filtering water that, where the dissolved impurities in water are either broken down into simpler, less toxic compounds, or converted into insoluble compound after which straining, sedimentation and adsorption may remove them from the flowing water.

Biological activity for purification of water involvesforming a biologically active layer on the surface of the filter material. The microbiological contaminants present in the water are trapped by the filter media, where they are converted to less harmful substances due to biochemical action

The ceramic filtration technology is sometimes called "dead-end filtration" and "depth filtration" according to http://doultonusa.com/HTML%20pages/technology.htm [Accessed: 20 Dec 2010]. This technology also involves other mechanisms by which the ceramic element filters out particles from the water as a dead-end filtration. These mechanisms include direct interception or sieving, bridging and inertial impaction.

During the direct interception or sieving process, when a particle of size 0.5 μm and larger "runs into" a pore at the topmost layer of the ceramic filter that is smaller than the particle, it is captured as with absolute pore rated synthetic dead-end membranes as illustrated in Figure 2.6.

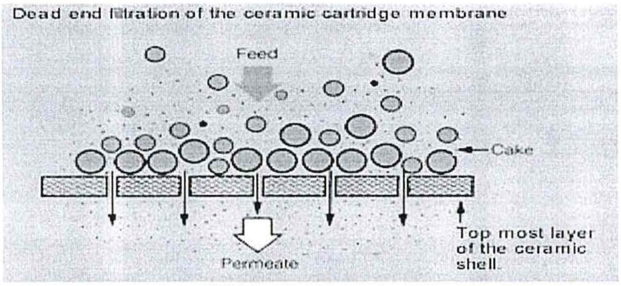

Figure 2.6:Direct interception Mechanism

(Adopted from Doulton Water Filter Ceramic Candle & Cartridge Technologies, http://doultonusa.com/HTML%20pages/technology.htm, accessed on 20/12/2010)

Particles of sizes smaller than 0.5 μm may be too small to be intercepted. However, during the bridging process, when two smaller particles hit the obstruction at the same time, they will form a bridge across the pore by adhering to each other. Bridged particles may not block the pore but create an even smaller pore gradually forming a "filter cake" as shown in Figure 2.7.

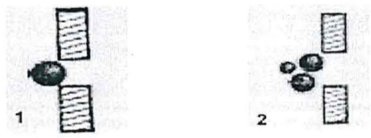

Figure 2.7: Bridging of Pores Mechanism

(Adopted from Doulton Water Filter Ceramic Candle & Cartridge Technologies, http://doultonusa.com/HTML%20pages/technology.htm, accessed on 20/12/2010)

This "cake" creates a finer filtration for subsequent interception at the cost of decreased flow rate and eventually no flow rate. Mechanical regeneration of the filter "cake" is simple. The topmost blocked layer can be removed with stiff brush or nylon scouring pad. This can be repeated many times before the filter has to be changed.

When a particle flowing through the filter hit a non-porous surface barrier, it becomes captured while the water flows around the barrier. This phenomenon is called inertial impaction and is more prevalent with smaller particles in range of 0.1 μm to 0.4 μm size as these particles are easily affected by molecular bombardmentas shown in Figure 2.8.

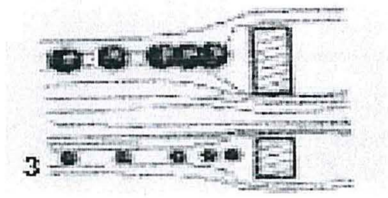

Figure 2.8: Inertial impaction Mechanism

(Adopted from Doulton Water Filter Ceramic Candle & Cartridge Technologies, http://doultonusa.com/HTML%20pages/technology.htm, accessed on 20/12/2010)

Unlike with synthetic membranes, all of the above methods of capture are dependable under variable operating conditions. However, ceramic depth filtration will filter out considerably smaller particles than equivalent pore size membrane as illustrated in Figure 2.9 below.

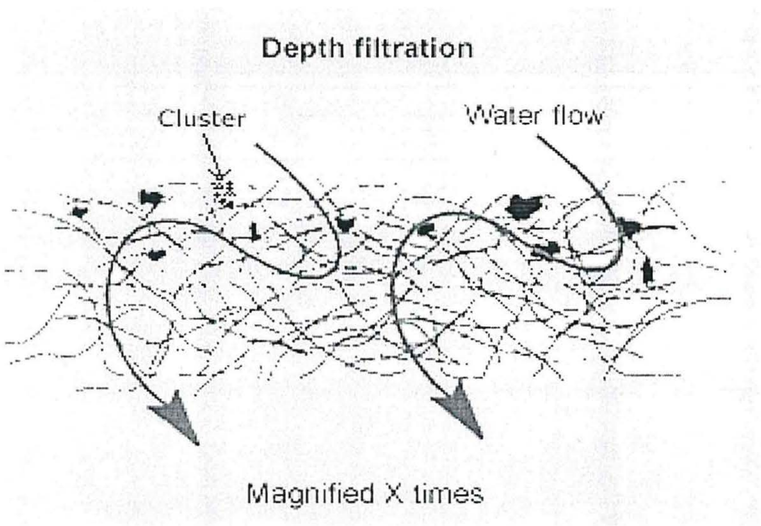

Figure 2.9: Depth Filtration Mechanism

(Adopted from Doulton Water Filter Ceramic Candle & Cartridge Technologies, http://doultonusa.com/HTML%20pages/technology.htm, accessed on 20/12/2010)

Particles interceptedwithin the ceramic depth are much smaller than the pores measured by porometry. This is because particle laden water has to navigate through intricate maze of labyrinths. The path through the filter twists and turns through sharp angles due to the complicated ceramic structure and so the particles that may have penetrated the topmost layer become trapped within the structure. Small particles can combine with other particles to form a cluster of particles large enough to become trapped as a group or individual in dead end cavities. In addition, weak Van der Waals forces attract the small suspended particles to the ceramic, causing them to be adsorbed onto the wall of the ceramic.

2.5 Porosity

The volume of water that percolates through a filter depends on the porosity of the filter. The measure of porosity of a filter becomes an important measure of the characteristic property of the filter.Higher Porosity means higher filtration of water through the filter material. Porosity of the filter is therefore, the fraction of the volume that is occupied by pore or void space.The porosity of a ceramic material, particularly a fired ceramic is usually a very carefully controlled property according to Jones and Berard, (1972). Porosity is calculated by dividing the total pore volume by the bulk volume. The total pore volume consists of both closed pore and open pore volumes as shown in Figure 2.10.

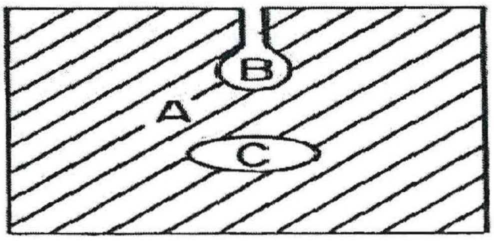

Figure 2.10: Types of Volumes in a Ceramic Body

A – solid volume, B – open pore volume, C – closed pore volume

Only the open pore volume can be directly measured. Furthermore, since the porosity of concern for filtration process is the open pore, only the apparent porosity, consisting of only the open pore volume, is discussed.

The apparent porosity of a ceramic material can be calculated by the following equation.

$$\%Pa = \frac{V_{OP}}{V_b} x\, 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.5$$

Where$V_{O\,P}$ and V_b are open pore volume and bulk volume respectively.

The volumes can be measured by submerging the material into a liquid and measuring the volume of liquid displaced. The ratio of the volume of open pores to the bulk volume of the material can be determined by a number of different methods.

The ultrasonic pulse velocity (UPV) method is a non destructive method of measuring porosity. It is a simple, accurate and can detect size and defects like lack of fusion and porosity according to Elineudoet al, (2008). The fundamental relation relating UPV to porosity is:

$$V_l = V_{lo}(1 - mp) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.6$$

whereV_l , is the UPV in the porous material,V_{lo}, is the UPV of the same material at zero porosity, m is a constant which is a function of Poisson ratio and p is porosity according to Yaman et al, (2008); V_{lo} is fictitious and can only be calculated by extrapolating from the measure of UPV in specimen with decreasing porosity. Rearranging equation 2.6 gives

$$p = \frac{\Delta V}{m\,V_{lo}} \quad \text{.....} 2.7$$

where ΔV is the change in UPV of the specimen. The constant m is one of the parameter on the instrument used to measure the UPV.

Porosity can also be measured by 'density method'. The bulk density of the sample, ρ_B , and the density of the pure solid, ρ_s, are accurately determined independently by gravimetric means. The definition of porosity gives the following simple results.

$$\rho_B = p\,\rho_a + (1 - p)\rho_s \quad \text{.....} \quad 2.8$$

where ρ_a, is the density of air which is much smaller thanρ_s and p , is the porosity.

The total porosity of the filters can also be determined by the 'direct method' which includesweighing the filter dry and saturated. Complete saturation is achieved after 24 hours according to Nederstigt et al, (2005). After this period all air is released from the filter and the interconnected and dead-end pores are filled with water. The isolated pores are taken intoaccount when weighing the filter dry, but this is not the case when weighing it saturated.

Although the isolated pores do not contribute to the filtration, they do influence the outcome of the direct method. The total porosity (P) can be calculated with the following formula

$$P = \frac{(m_s - m_d)}{\rho_{water} x\, V_{filter}} x100\% \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.9$$

P total porosity [%]

m_s mass of saturated filter [g]

m_d mass of dry filter [g]

ρ_{water} density of water [1000 $g\ l^{-1}$]

V_{filter} volume of filter [l]

The direct method does provide some information on the porosity, but the total porosity only. This has the same disadvantage as the filter discharge; many small pores can give the same outcome as a few large pores. Additionally it is unknown if the measured pore voids contribute to the flow or not (dead-end pores). So it can be concluded that the direct method does not provide reliable information on both sufficient filter discharge and E-coli removal efficiency. The accuracy of the direct method is debatable, but can give an indication of the porosity. Furthermore this method might prove useful as a testing method of the filter quality in the factories, since it is simple and inexpensive.

2.6 Material Permeability and Tortuosity

The water flow through a filter can be described by introducing two parameter and these are; permeability and tortuosity. Permeability is a basic permeable medium property that, unlike porosity, depends on fluid flow. In order to calculate the permeability, the characteristic length, L_C, must be determined. The characteristic length is determined from the threshold pressure (P_t), using the Washburn equation. The threshold pressure is the pressure at which the (cumulative) intrusion volume versus pressure curve is steepest. This inflection point is determined experimentally by Katz and Thompson to correspond closely to the pressure at which mercury first spans the sample and the point at which percolation begins.

The calculated characteristic pore length (diameter) is used to calculate the permeability of the sample. Katz and Thompson [1986], give an expression for calculating absolute permeability (κ) using data from a single mercury intrusion pressure curve:

$$k = \frac{1}{226} L_C^2 \frac{\Phi}{\Phi_O} \text{..................................} 2.10$$

k = permeability [darcy]

L_C = characteristic length [μm]

$\frac{\Phi}{\Phi_O}$ =conductivity formation factor [−]

The permeability of water through the filters can also be calculated using equation 2.11. The filtration rate of water through the filter is determined following the steps described in section 3.5.2, the thickness of the filters is determined using a vernier calipers and the depth difference of the water above the filter was 21.2 ± 0.1 cm. To vary the thickness of the filters, different weights of the mixture were pressed.

$$P = \frac{v\ x\ h}{t\ x\ A} x\ H \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.11$$

where P is pearmeability

v is volume of air passed through(ml)

h is height of test piece (cm)

t is time of flow (s)

A is area of cross-section of test piece (cm^2)

H is pressure head (cm H_2O)

The path the suspended matter in the raw water travels through the filter gives an indicationof the chances of retention by screening, sedimentation or adsorption as shown in Figure 2.11.

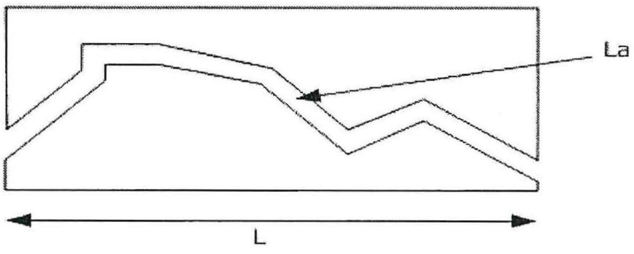

Figure 2.11: Actual Particle Distance Traversed

The term to account for this non-direct route through the microscopic pores within the filter is tortuosity. Theterms tortuosity and tortuosity factor are often used interchangeably in literature.

Tortuosity is the ratio of the actual distance a particle must travel to get through the filter (La) divided by the thickness of filter (L):

$$\xi = tortuosity = \frac{L_{actual}}{L} \quad \text{..........................2.12}$$

Thus, the more tortuous the path, the more actual distance bacteria travel to get across thefilter element. In practice, the tortuosity can be determined after calculating the weightedaverage pore size (D_{avg}) from the mercury intrusion porosimetry test

$$D_{avg}{}^2 = Y_S\left[\frac{1}{2}I_iO_i{}^2 + \sum I_iD_i{}^2 + \frac{1}{2}I_nO_n{}^2\right] \quad \text{............2.13}$$

$$\xi = \sqrt{\frac{D_{avg}{}^2}{96k(1-YI_{tot})}} \quad \text{..2.14}$$

D_{avg}: weighted average pore size (m)

Y_S: skeletal denisity ($g\ ml^{-1}$)

I_i: intrusion volume for the ith point [$ml\ g^{-1}$]

D_i: pore diameter for the ith point (m)

κ: permeability (m^2)

I_{tot}: total specific intrusion volume $[ml\ g^{-1}]$

A second approach to determine the tortuosity of the filter material is the theory on packedcolumns. In the theory on packed columns, the Blake-Kozeny equation is often used inlaminar flows. In this method the packed column is visualised as a bundle of tangled tubes ofweird cross-section; the theory is developed by applying the results for single straight tubesto the collection of crooked tubes as shown in Figure 2.12 below.

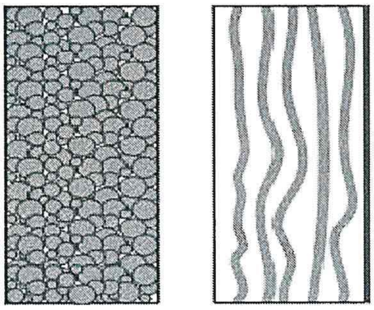

Figure 2.12:Cylindrical Tube packed and 'Tube Bundle' Model [Bird, 2002]

In each capillary there is a Poiseuille velocity distribution so the volume rate of flow can be calculated for one capillary.

The theoretical capillary radius can be calculated from the pressure drop, filter discharge,porosity and filter dimensions.

$$r_c = \sqrt{\frac{8LQ}{\Delta PA}} = 2\sqrt{\frac{kC}{}} \qquad \text{...............................2.15}$$

$r_c$radius of capillary [m]

Q Filter discharge $[m^3 s^{-1}]$

η Viscosity $[N\ s\ m^{-2}]$

L Thickness of the filter material [m]

A Surface area $[m^2]$

ΔP Pressure drop over the column [m]

ε Porosity [-]

κ Permeability [m^2]

C Kozeny constant

Equation 2.15 is generally good for materials with void fractions less than ε=0.5. All variables, expect the Kozeny constant (C), are known in theequation. This constant is normally 4.2 for packed beds, but for ceramic candle filter (CCF) the calculated constants are much higher, as depicted in the table below. The Kozeny constant is calculated with three different pore radii; average pore size from the filter discharge (rc, Equation 2.15),characteristic pore length from the mercury intrusion porosimetry (Lc) and the effective poresize from the bubble-point test (re). The major difference between the value of the Kozeny constant for packed beds in Figure 2.12 andceramic candle filter (CCF) can be explained by the two considerations: (i) the pores in ceramic candle filter (CCF) are not straight but have narrow and wide passages, and (ii) the flow of the fluid through the pores is not straight according to Heijman, (1993). The length of the capillaries is greater than the thickness of the filter element, due to the previously discussed tortuosity of the material.

2.7 Water Filtration Rate

The water filtration rate is an important parameter of the operation of a filter. It is also currentlyused as a test method to determine which filters are approved for selling. Generally, a higher filtration rate is desired for the filter to be used conveniently by the users. However, higher filtration rates may mean that the porosity is high with largerpore size, letting more impurities pass through the filter. Thus, the filtration rate of a filter isoften inversely related to the contaminant removal performance.

The first step in understanding the flow through ceramic candle filter (CCF)is an analytical estimation of thedischarge through the filter. The analytical model of the discharge through the filter is based on Darcy's law, which described laminar flow through porous media with a linear relation. A modification is made to include the changing water head over the height of the filter. The surface area of the bottom of the filter is obviously equal to that of a circle and with a constant water head h_W the discharge is formulated using the filter surface area dimensions in Figure 2.13.

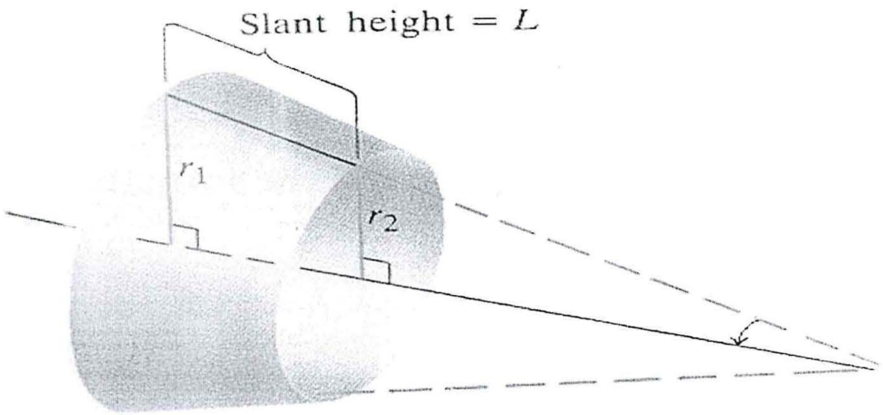

Figure 2.13:**Filter Surface Area Dimensions**

The flow through the filter wall is more complex, since the driving force (water head) and the surface area vary over the height of the filter. Anintegral for the water head and the surface areais used to describe the discharge throughthe filter wall.

$$Q_{Darcy} = k\frac{A\,h}{t}$$

$$Q_{Filter\,bottom} = \frac{k}{t_b}\pi r_2^2 h_w$$

$$Q_{Filter\,wall} = \frac{k}{t_f} A \int_0^{h_w} (h_w - z)\, dz$$

$$= \frac{k}{t_f} 2\pi r_z \int_0^{h_w} (h_w - z)\, dz$$

$$\text{But } r_z = \frac{(r_1 - r_2)}{L} z + r_z$$

$$Q_{Filter\,wall} = \frac{k}{t_f} 2\pi \int_0^{h_w} (h_w - z) \left(\frac{(r_1 - r_2)}{L} z + r_z \right) dz$$

Combining the two formulae derived in Figure 2.14 results in a description of the totaldischarge through the filter:

$$Q_{filter} = \frac{k}{t_f} 2\pi \int_0^{h_w} (h_w - z) \left(\frac{(r_1 - r_2)}{L} z + r_z \right) dz + \frac{k}{t_b} \pi r_2^2 h_w \text{........} 2.16$$

Q_{Filter} Filter discharge $[m^3 s^{-1}]$

k hydraulic conductivity [ms^{-1}]

$r_1$radius at the top of the filter [m]

$r_2$radius at the bottom of the filter [m]

$h_w$water level in filter [m]

$t_f$thickness of the filter wall [m]

$t_b$thickness of the bottom of the filter [m]

The volume of water through the filter for a given time can also be measured using a measuring cylinder. The water filtration rate of the filter will be calculated using the equation

$$Q = \frac{V_F}{A\, t_E} \text{..} 2.17$$

where V_F, is volume filtered A, the area of the filter and t_E, is the time of filtration. The surface area of the filters was calculated from equation 2.18.

$$A = \frac{\pi d^2}{4} \quad \ldots\ldots 2.18$$

where d, is the diameter of the filter.

2.8 Water Turbidity

Turbidity is an expression of the optical property that causes light to be scattered and absorbed rather than transmitted in straight lines through the sample. Turbidity is a water quality parameter which quantifies the degree to which light travelingthrough a water column is scattered by the suspended organic (including algae) and inorganic particles. The scattering of light increases as the suspended particle load increases. Suspended matter such as clay, silt, finely divided organic compounds, and other microscopic organisms' causes' turbidity in water. Water possessing many suspended particles (high turbidity) and/or high organic content will not flow through the filter as quickly as cleaner water, resulting in a smaller volume of water filtered over a given period of time. Polluted water will often times clog the filter, resulting in the need for more frequent cleaning of the filter element.

Turbidity cannot be correlated with suspended solids because the size, shape, and refractive index of particulate are quite variable. Turbidity is very important for aquatic life, especially for photosynthetic organisms. It causes reduction in light penetration in waters, thus, affecting the photosynthetic efficiency of plants. Organic constituents in water may harbour microorganisms, and thus water with high turbidity generally has a higher concentration of pathogens and a higher possibility of transmitting waterborne diseases.

Light scattering by transparent isotropic media is accurately described by a macroscopic fluctuation theory first formulated by Einstein. Turbidity, τ, is dependent on fluctuations in the refractive index (or the dielectric constant) in volume, V, according to the equation

$$\tau = \frac{32\,\pi^3 V\, n^2 \langle(\delta\, n)^2\rangle}{3\,\lambda_0^4} \quad \text{...2.19}$$

where λ_o, is the wavelength of the incident radiation in vacuum, $\langle(\delta\, n)^2\rangle$is the fluctuation average in the refractive index n. In an absorbing media the refractive index is complex and therefore $\langle(\delta\, n)^2\rangle$ can be replaced by $(\langle(\delta\, n)^2\rangle + \langle a_o\rangle)$where a_o is the imaginary part of the complex refractive index, the absorption coefficient a_c must be much smaller than the real part if one is to be able to detect any scattered light.

Turbidity is commonly measured in Nephelometric Turbidity Units (NTU), but may also be measured in Jackson Turbidity Units (JTU). The WHO standard for the turbidity level in drinking water is set at 5 NTU. Although there are two standard methods for measuring turbidity, the Nephelometric method is most commonly used. This method is based on a comparison of the amount of light scattered by a standard reference suspension under the same conditions. The more light is scattered the higher is the turbidity.

Before running the turbidity test, review factors that can interfere with good test results. Floating debris and rapid settling particles will cause artificially low readings. If this occurs, take another sub-sample. Dirty scratched, or chipped sample tubes can cause high readings. Clean the tubes and discard those that are scratched, or chipped, or cracked. Air bubbles in the sample will cause high readings. If this occurs, allow the air bubbles to clear. Vibration can cause high readings, for this reason the turbidimeter must be located on a sturdy bench rested on a solid footing such as concrete ground level floor. Do not touch the bench during the test.

2.9 Total Coliform

Total coliforms include species that may inhabit the intestines of warm-blooded animals or occur naturally in soil, vegetation, and water. They are usually found in faecally-polluted water and are often associated with disease outbreaks. Although they are not usually pathogenic themselves, their presence in drinking water indicates the possible presence of pathogens. E–coli, one species of the coliform group, is always found in faeces and is, therefore, a more direct indicator of faecal contamination and the possible presence of pathogens. In addition, some strains of E. coli are pathogenic. Since the water in Uganda is often contaminated with faecal pollution this is an important parameter to be tested for in drinking water. The presence of E-coli, a subset of the faecal coliform group, or faecal coliforms, theoretically confirms the suspected presence of pathogenic organisms in the water according to DeZuane, (1996). The WHO drinking water guideline states that the total coliform and E-coli concentrations in the water must be zero colony forming units per 100 *ml* of sample.

E.coli are almost exclusively of faecal originand their presence confirms faecal contamination. The general coliform group also includes coliforms found in aquatic environment, in soil and on vegetation. Coliforms are naturally present in canal water and should give an indication of the removal of pathogenic bacteria. The World Health Organisation guideline value for all water directly intended for drinking water is that the E-coli concentration must not be detectable in any 100 *ml* sample.

Twomethods are mainly used to determine the total coliforms and these include colilert (CL) and membrane filtration (MF). MF is superior to CL according to Olson *et al, (*1991*)*. The MF procedure has the advantage of being able to examine larger volumes of water as well as having increased sensitivity and reliability. However, the MF procedure has disadvantages of lengthy incubation time, potential interference by heterophic bacteria, labor and materials intensive. It also requires precise control of laboratoryconditions and a high degree of technical skill to perform andinterpret results.

Membrane filtration (MF).In this method, Total coliforms (TC) are those bacteria that produce fluorescent colonies upon exposure to long wave ultraviolet light (366 nm) after primary culturing on MI agar or broth. The fluorescent colonies can be completely blue-white (TC other than *E. coli*) or blue-green (*E. coli*) in color or fluorescent halos may be observed around the edges of the blue-green *E. coli* colonies. In addition, non-fluorescent blue colonies, which rarely occur, are added to the total count because the fluorescence is masked by the blue color from the breakdown ofchromogenIndoxyl- ß -D-glucuronid(IBDG). *Escherichia coli* (*E. coli)* in this method are those bacteria that produce blue colonies under ambient light after primary culturing on MI agar or broth. These colonies can be fluorescent or non-fluorescent under longwave ultraviolet light (366 nm). This test method describes a sensitive and differential membrane filter (MF) medium, using MI agar or MI broth, for the simultaneous detection and enumeration of both total coliforms (TC) and *Escherichia coli* (*E. coli*) in water samples in 24 hours or less on the basis of their specific enzyme activities. Two enzyme substrates, the fluorogen 4 –Methylumbelliferyl –ß – *D* –galactopyranoside (MUG) and a chromogenIndoxyl– ß – *D* – glucuronide (IBDG), are included in the medium to detect the enzymes ß –galactosidase and ß – glucuronidase, respectively, produced by TC and *E. coli*, respectively.

An appropriate volume of a water sample is filtered through a ceramic candle filter material; the filter retains the bacteria present in the sample. The filtered water is placed on a 5-mL plate of MI agar or on an absorbent pad saturated with 2-3 mL of MI broth, and the plate is incubated at 35°C for up to 24 hours. The bacterial colonies that grow on the plate are inspected for the presence of blue color from the breakdown of IBDG by the *E. coli* enzyme ß-glucuronidase and fluorescence under longwave ultraviolet light (366 nm) from the breakdown of MUG by the TC enzyme ß-galactosidase

Equation 2.21 will be used to calculate the percentage e-coli removal efficiency of the filters from the raw data contained in Appendix:D

Percentage Removal Efficiency= $\frac{(Unfiltered-filtered)}{Unfiltered}$ x **100%**................. 2.20

Where;

- Unfiltered: microbial (e-coli) concentration in the raw water sample (Coliform colonies per $\mathbf{100}ml$)
- Filtered: microbial(e-coli)concentration in the filtered water sample (Coliform colonies per100$m\ l$).

Note: If the treated concentration = 0 Coliform colonies per 100$m\ l$, then a value of 1 Coliform colony per100 $m\ l$wasused.

CHAPTER THREE: METHODOLOGY OF THE STUDY

3.1 Introduction

This chapter covers the research design and the sampling technique used in this study. The methodology of sample preparation and the experimental measurements.

3.2 Research Design

This was a descriptive quantitative research designed to determine the relationship between a set of **independent variables** and their corresponding **dependent variables** of ceramic candle filter made from selected Ugandan clays. The research design adopted was therefore both **descriptive** and **relational** in nature. It was descriptive in that the results of the study were to lead to the description of the ceramic candle filter samples developed and relational in that the results obtained were to lead to the establishment of the relation between the independent and dependent variables of the ceramic water filters developed.

For purposes of this study, some independent variables were selected and fixed which included; Clay type, sawdust type, water pressure,size of clay and saw dust particlesizes, filter thickness and, compaction pressure;

There are many types of clay with different kinds of properties. These properties determine the ability to work with clay and its usefulness for certain purposes. Plasticity is a very important property for the clay to be used in the manufacture of ceramic filters. Different processes require different plasticity, very plastic clays (such as ball clays) can be rolled into a rope like shape and wrapped around a thumb without breaking. Ball clay was therefore used because it is very plastic and has a high green mechanical strength when fired.

Saw dust from Mahogany hard wood was used; hardwood sawdust will not bloat as much as sawdust from other woods resulting in more uniform pores and fewer defects in the filter according to Mcallister, 2005.

Afilter in operation will not be continuously filled with water, in practice the water flows through the filter element and the water head is lowered. The lowering water head has a direct effect on the discharge. There the water pressure was fixed by continuously adding water to the filter set up.

The shape and the size of pores are also important physical parameters that determine the characteristics of the ceramic material and therefore the porosities of the filters were determined. The two fine particles (clay and saw dust) are each sieved through a 1 *mm* sieve separately, this is to ensure that they are of the same size which ensures uniformity during mixing.

The path the suspended matter in the raw water travels through the filter gives an indication of the chances of retention by screening, sedimentation or adsorption. Therefore the thickness of the filter was fixed.
Clay to sawdust ratio was varied to give different porosities.

Three dependent variables were considered to determine the effectiveness of the filter sample in terms of ; filtration of water through theceramic candle filter (CCF), Turbidity of the filtered water from the ceramic candle filter (CCF), and E-coli removal of ceramic candle filter (CCF).

Experimental study design was also adopted. In this type of design measurements of the dependent variables were taken **before** and **after** filtration.

3.3 Samples and Sampling Techniques

Ball clay contains kaolinite and certain micas, and has strong bonding properties. Kaolinite does not absorb water and doesn't expand when it comes in contact with water. As a result, Ntawo ball clay mineral was used in this study because of its properties which were crucial in developing the ceramic candle filter. Hence **purposive or criteria sampling technique** was used in this study to select the clay type. The criterion used was the high silicon content clay type exhibited by Ntawo ball clays. **Purposive or criteria sampling technique** was also used in this study to select the combustible material. The criterion used was the uniform pore formation and the lack of bloating which result from the use of hardwood sawdust. It's for this reason that mahogany saw dust was used.

Thus, for the purpose of this study;

Contaminated water samples were collected from L. Victoria at Ggabba water treatment plant whereNational Water andSewage Cooperation pipes drain into. Therefore the water was highly turbid and had a high concentration of total coliforms. Most coliform are found in faeces and in intestines of warm blooded animals.

3.4 Production of Prototype Ceramic Candle Filters

The six steps that were carried out to come up with a prototype filter included;making clay powder, making sawdust powder, mixing the dry powder, forming a green body, drying and firing, and fitting the filter sample in a bucket

The organic and coarse materials in the clay were removed by hand. The clay was then mixed with water to form a colloidal mixture with sufficient plasticity. The colloidal mixture was sieved through a 500 μm sieve to remove any large particles that remained. A 220 μm sieve was used to perform a second sieving so that fine clay mineral particle sizes are obtained. The fine claywas then poured into a plaster of Paris mould to remove the excess water and semi-dry cast was left to dry in air. The dried cast was thenpounded by pestle and mortar to form uniformand smaller grains,which was then sieved through the 1*mm* sieve.

The mahogany sawdust was dried, milled and sieved through a 1*mm* sieve to obtain a powder of fine sawdust with the same particle size as the processed clay mineral powder. The two fine powders (clay and sawdust) were then thoroughly shaken and mixed by hand in predetermined ratios of 1:1, 5:4, 5:3, 5:2, and 5:1 by volume of clay to sawdust, the ratios were determined by gradually reducing the amounts of saw dust in each of the compositions. A small amount of water was added to the mixture to improve on the workability of the mixture. The combination was allowed to stand up to about two hours to permit it to develop sufficient plasticity.

The third step involved fabricating a plaster of Paris mould to make the ceramic candle filter (CCF). The mould was lined with paper along its sides and the bottom to prevent the mixture from sticking. The mould was then filled with the colloidal slip of the mixture to the top so that the excess water can be absorbed by the mould. After the excess water had been removed from the mixture, the semi-dry body was dry pressed, at about 150 kN press, into cylindrical candles of diameter 8 cm and thickness 5 mm which are conducive for effective firing. The mould was then carefully inverted to prevent the mixture from falling apart. The paper that gets stuck to the mixture is peeled away carefully. For easy identification, each mould of the mixture obtained was labelled.

The drying process is the fourth step. After pressing the clay material, the filter element was left to dry for two to three days.The higher the sawdust content, the more water was absorbed thus the longer the drying period. Thepurpose of drying was to prevent the clay from cracking due to rapid drying or heating duringthe firing process (Dies 2001). In addition, GrimShaw (1971), noted that the dryer the mixture, the less likely for it to crack during firing.The filter unit was ready for firing in a kiln once the drying stage was complete

GrimShaw, (1971) noted that, the firing temperature and the firing period are the most important parameters of the manufacturing process. If the firing periods were not closely followed, the ceramic material would likely crack due to non-uniform shrinkage. A longer firing time was preferred because the carbon material (from the sawdust) in the mixture had to be burned slowly. Prajapati et al., (2002), noted that if insufficient firing time was provided, those carboneous combustible materials would remain inside the filter disk even if a higher firing temperature was used. After firing, the ceramic disks took on a lighter color and became slightly smaller due to shrinkage resulting from the loss of water.

The fifth step was the firing process. Firing was done in three phases: dehydration, oxidation, and vitrification. Dehydration occurred at low temperatures and involved the removal of excess water trappedwithin the filter. The rate of temperature increase was monitored closely to ensure thatthe rate of dehydration was kept within the limits of the filter's ability to withstand the imposedstress caused by the water evaporating from the small pores according to Dies (2001). This was done by air dryingthe green body for three days after which it was fired in stages in a furnace; first to a temperature of 105°C to drive off the remaining water in the mixture,and then to (450-500) °C to remove the water that was chemically combined with the clay minerals. Otherwise rapid firing would cause the filter to shatter according to Shepard et al, 1968

The temperature and time over which oxidation occurred depended on the properties of the clay. An important consideration for filterwas the temperatureat which the combustible material, such as sawdust oxidized. There was need carefully slow the rate of temperature increase at the point when the combustible materialbegan to oxidize so as to minimize the stress imposed on the filter element. At a temperature of 450°C, the temperature at which saw dust oxidized, the rate of increase in firing temperature was reduced asthe temperature inside the kiln approached450°C, which allowed the sawdust particles to slowly burnoff.

During vitrification, the constituents of the clay material began to soften and adhere into aglass-like material. The temperature over which this occurred again depended on the propertiesof the clay material. It was interesting to note that the density of the pottery increased and thusthe porosity decreased during vitrification. The porosity of the final ceramic material could, in fact, have been used to measure the degree of vitrification that took place during firing. The samples were then sintered at a fixed temperature of 860°C for 5 hoursto ensure that the filters were hard enough. The 5 hours gave enough time for the burnout material to escape leaving residual ash which constituted a very small percentage of 0.1 to 1% by volume. The furnace was allowed to cool slowly until the candle could be held by hand, taking care not to damage the candle while it was hot.

During firing, the combustible material burnt off, leaving pores in the clay. Some of the pores connected to form channels that allow water to move through the filter. The sizes of the pores were crucial in the water purification and percolation process.

Lastly the filter was fitted in the bucket as follows: burnt clay was crushed then mixed in drops of water with wood glue. This combination had a strong binding property however, it was water soluble.

To overcome its solubility challenge some shoe glue was added on the outside of the filter and the filter fitted on a hole drilled through the bucket. The setup is shown in Figure 3.1 below

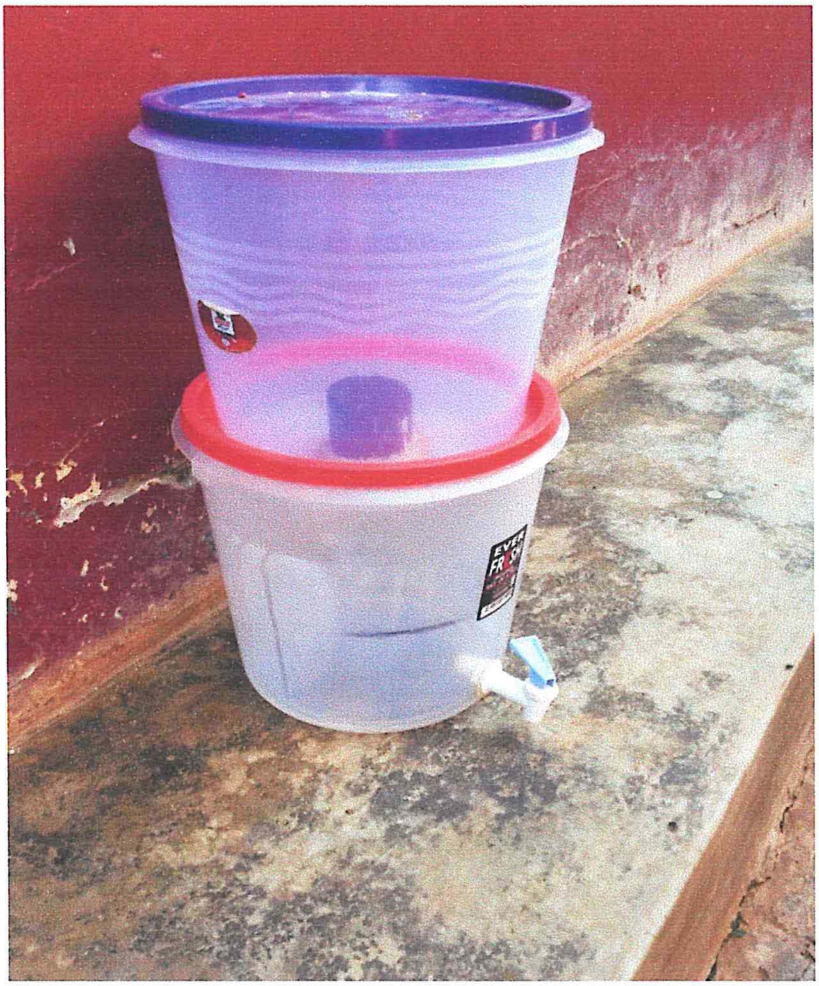

Figure 3.1:TheCeramic CandleFilter Setup

All the parts of the filtration unit were sterilized in steam before use. This was done to ensure that bacteria that could be on the component were killed before the filtration process

3.5 Experimental Measurements

Important measurements were taken to provide results of the study. These measurements included; porosities of the ceramic candle filters, Filtration rate of water through the filter,Turbidity of water,and Total coliform Removal Efficiency.

3.5.1 Porosity

The Porosity of the filters was determined by weighing the sample when dry in air and then soaked in distilled water at room temperature for 24 hours and weighed again. The water with the sample was then boiled for about two hours and allowed to cool to room temperature for another 24 hours. This was done to ensure that the air in the open pores of the filter samples was replaced by the distilled water. The soaked samples were weighed while immersed in distilled water, then removed and surface wiped with tissue paper and weighed in air. The weight of the wire was subtracted from the value obtained while determining the weight of the sample suspended in water. Apparent porosity was then calculated using the expression

$$P = \left(\frac{\mu-\alpha}{\mu-\beta}\right) x100 \quad \text{..............................} \quad 3.1$$

whereμ is the weight of the specimen when immersed in water, α, is the weight of the dry specimen and β,is theweight of the soaked specimen.

The porosity of the different filter samples was calculate and tabulated in Table 3.1 below

Table 3.1: Porosity of the Ceramic Candle Filter

Clay: Saw dust Ratio	Porosity/ %
1:1	48.05
5:4	44.33
5:3	42.31
5:2	38.40
5:1	35.12

The percentage porosity of the filter samples decreases with the decrease in clay to saw dust ratio

3.5.2 Water Filtration Rates

The volume of water through the filter for a given time was measured using a measuring cylinder and the averages tabulated below.

Table 3.2: FiltrationRate of Water through the Ceramic Candle Filter

	Time /hr				
Volume/ml	1:1	5:4	5:3	5:2	5:1
50	0.038	0.049	0.262	0.311	0.284
60	0.044	0.077	0.273	0.323	0.326
70	0.055	0.106	0.314	0.362	0.370
80	0.065	0.114	0.341	0.404	0.422
90	0.077	0.129	0.366	0.436	0.476
100	0.090	0.158	0.394	0.495	0.524
110	0.098	0.167	0.425	0.557	0.584
120	0.107	0.193	0.447	0.609	0.668
130	0.129	0.213	0.463	0.638	0.696
140	0.137	0.230	0.489	0.685	0.738
150	0.142	0.243	0.498	0.724	0.796

There wasa reduction in the water filtration through the filter with time. This reduction was caused by blocking of the poresin the filter element. By scrubbing the element on the inside, the filtrationwas temporarily increased. Initially the pores on the surface of the filter element were blocked, but inthe course of time, constituents infiltrate further and further into the material. This would eventually result in a zero $l\,hr^{-1}$ filter discharge. Obviously the rate of reduction indischarge depended largely on the water quality: turbidity, size of particles and concentrationof organic compounds

3.5.3 Turbidity Removal Efficiency in Water

One of the objectives of the research was to determine the purity of the filtered water in terms of the water turbidity. The water filtered through the CCF was subjected to a turbidity test using Turbid-meter found in the Chemistry Department of National Water and Sewage Cooperation main Laborotory. The Turbid-meter measures turbidity for drinking using the formazin based metric method to report turbidity in Formazin Nephelametric Units (FNU) and it guarantees both high performance and reliable results.

10 ml of a sample of the filtered water was poured into a cuvet and then enclosed in the turbid-meter. When light from an infrared LED was passed through the water sample, it was scattered by the suspended particles in the sample. The microprocessor of the instrument then used the scattered light to report the turbidity of the water sample in the cuvet. The results obtained from these measurements were recorded in Table 3.3 below

Table 3.3: Turbidity Removal Efficiency in Water

Clay: Saw dust Ratio	Turbidity before Filtration /NTU	Turbidity after Filtration /NTU
1:1	57.60	4.205
5:4	57.60	2.365
5:3	57.60	1.677
5:2	57.60	0.308
5:1	57.60	0.237

3.5.4 E-coli Removal Efficiency in Water

Escherichia coli (E-coli) bacteria normally live in the intestines of healthy people and warm blooded animals. Most varieties of E-coli are harmless or cause relatively brief diarrhoea. But a few particular nasty strains such as E-coli 0157:H7, can cause severe abdominal cramps, bloody diarrhoea and vomiting. E-coli are also responsible for causing urinary tract infections in young women, acute and chronic diarrhoea, sepsis, and meningitis in infants according to Jawetzet al, (2010). One may be exposed to E-coli from contaminated water or food especially raw vegetables and under cooked beef.

The number of E-coli in 100 ml of water before and after filtration was determined by the colilert procedure at the National Water and Sewage Cooperation mainlaboratory.Using one hand to hold a Quanti –Tray upright with well side facing the palm, the upper part of the Quanti- Tray was squeezed so that the Quanti –Tray bends toward the palm. The foil tab wasgently pulled in order to separate the foil from the tray. The inside of the foil or tray should not be touched otherwise the filtered water samples will be contaminated. The filtered water sample mixture was directly poured into the Quanti-Tray, avoiding contact with the foil tab. The small wells are tapped 2-3 times to release any air bubbles. The foam is allowed to settle and the sample – filled Quanti-Tray is placed onto Quanti - Tray rubber holder and inserted in the Quanti –Tray sealer with the well side (plastic) of the Quanti-Tray facing down. Sealing was done according the Quanti –Tray Sealer instructions using the machine in Figure 3.2.

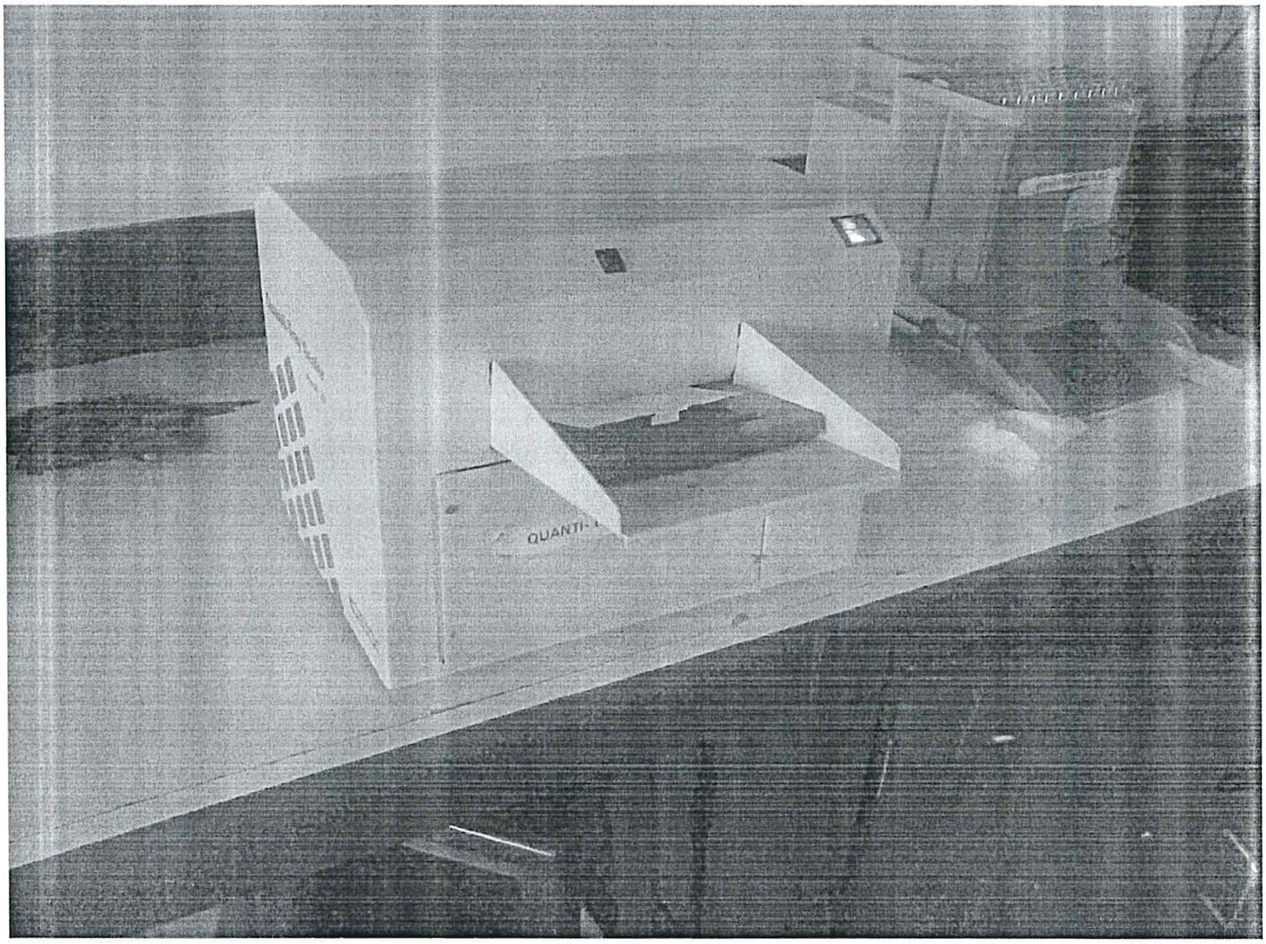

Figure 3.2: Tray Sealing Machine

The sealed trays were then incubatedat 35°C for 24 hours in an incubating machine shown in Figure 3.3 below.

Figure 3.3: Incubating Machine

The wells turn to yellow if there is total coliform after the incubation period.To confirm for E-Coli, the yellow trays are place in UV light which fluoresces blue under UV light which indicates positive (E-coli) using the machine in Figure 3.4 below.

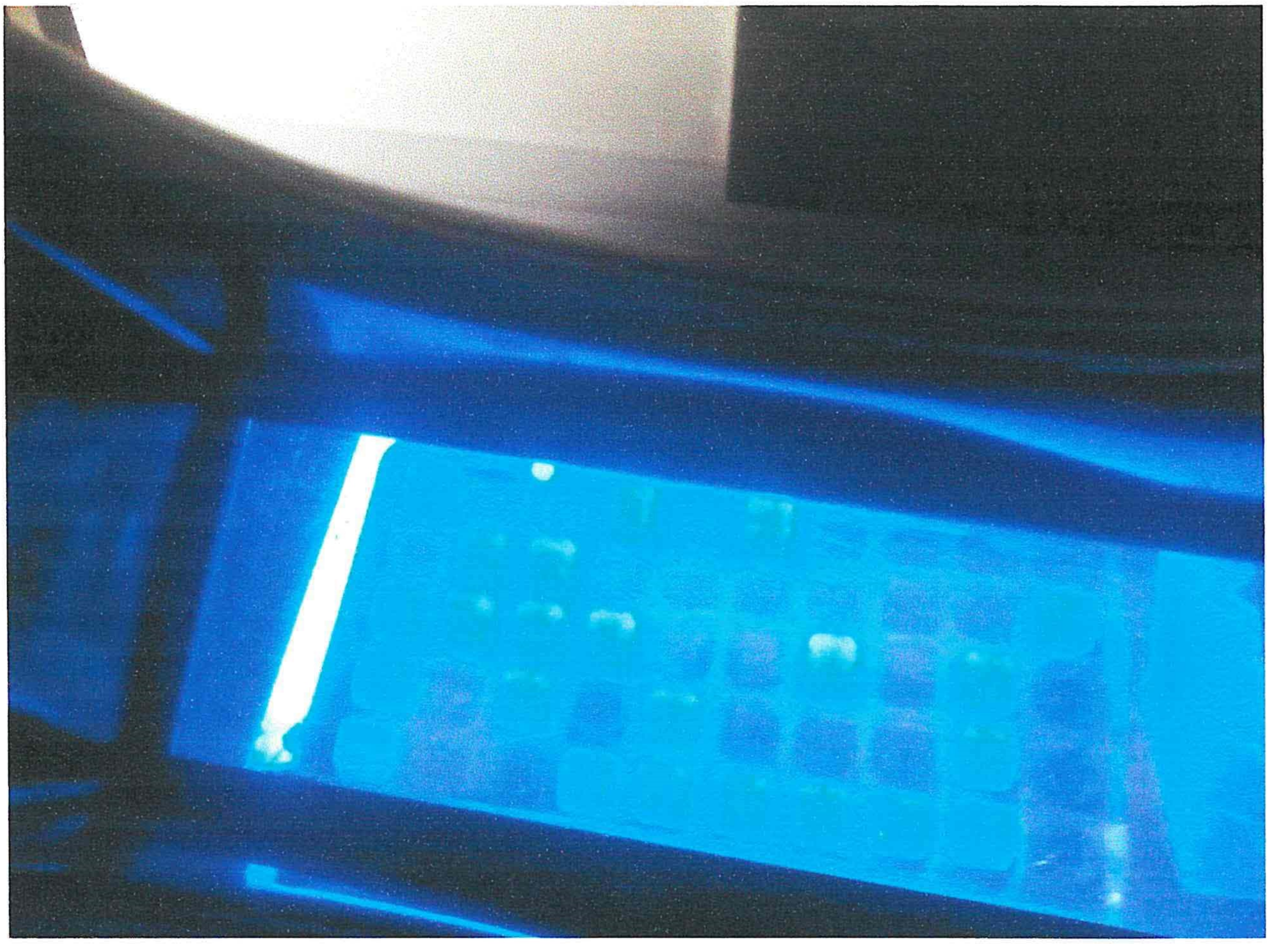

Figure 3.4: Blue Fluoresces under Ultra Violet Light

The blue wells were counted and the Quanti –Tray table was used to find the Most Probable Number (MPN) and The raw data obtained from experimental measurements of the number of e-coli colony forming units present in the water filtered through the filters were entered in Table 3.4.

Table 3.4: E-coli Removal Efficiency in Water

Clay: Saw dust Ratio	Un filteredWater in cfu/100 ml	FilteredWater in cfu/100 ml	Percentage Removal /%
1:1	2010	153	92.4
5:4	2010	48	97.6
5:3	2010	7	99.6
5:2	2010	4	99.8
5:1	2010	1	99.9

CHAPTER FOUR: RESULTS OF THE STUDY

4.1 Introduction

This study was designed to achieve four main objectives. Thus the experimental results obtained and presented in this chapter address the objectives of the study which include; Porosity, water filtration rates, Turbidity removal and E-coli removal efficiency.

4.2 Porosity of the Ceramic Candle Filters

The firstobjective was to determine the porosities of the filters which give the physical characteristics of the filters. The results are presented in Table 4.1 for each set of filters that were made.

Table 4.1 Porosities of Ceramic Candle Water Filters

Clay: Saw dust Ratio	% of Saw dust in mixture	Porosity/ %
1:1	50.00	48.05
5:4	44.40	44.33
5:3	37.50	42.31
5:2	28.60	38.40
5:1	16.70	35.12

The t–value from the table is 2.306 at 5% significance level, however the calculated t– value is 18.53. It therefore means that the results are significantly different since 18.53> **2.306** .

It is seen from the above table that, porosity is directly proportional to the percentage of saw dust in the filter material.

A graph of percentage porosity against percentage proportion of saw dust was plotted.

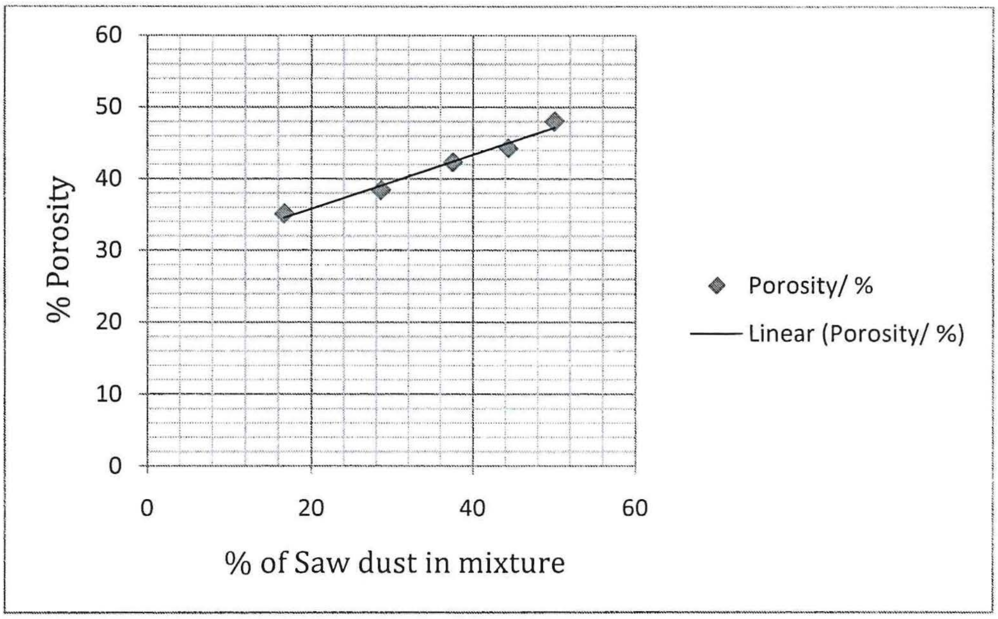

Figure 4.1: A Graph of % Porosity against % of Saw dust

The graph shows that porosity decreases with a decrease in the percentage of saw dust in the filter sample. This could be due to the difference in chemical phase changes that take place during the firing and mineral composition of the filter samples.

4.3 Water Filtration Rates through the Ceramic Candle Filters

The second set of experimental results was to determine the rate of water percolation through the ceramic candle water filters. The results are presented in Table 3.2for each set of filters that were made. The graph of volume against time was plotted.

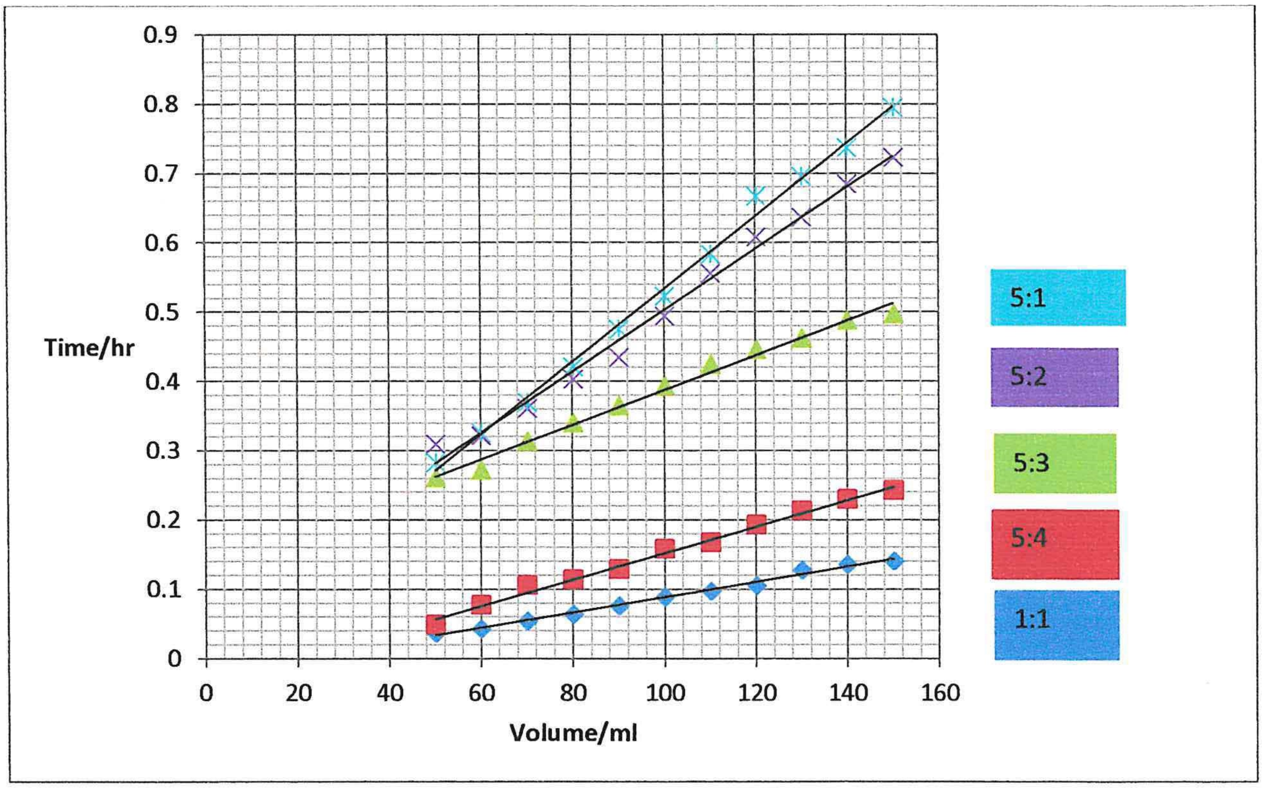

Figure 4.2: A Graph of Time against Volume of Water Filtered

The slopes of the graphs in Figure 4.2 were calculated and the reciprocals of the slopes determined to give the average volume in*ml* of water filtered per hour through the set of filters. The results were entered in Table 4.2

Table 4.2 Average Filtration Rate of Water through Filters

Clay : Saw dust Ratio	Water Filtration Rate / ml hr^{-1}
1:1	916.67
5:4	521.95
5:3	400.00
5:2	224.00
5:1	196.43

The results obtained showed that the average rate of water filtration through a ceramic candle filter decreased with a decrease in the saw dust proportion for each of the compositions above. A 1 :1 composition of clay to saw dust gives the highest filtration rate of 916.67 ml hr^{-1}.Based on the experiments in this research it can be concluded that the guideline of 1 to 2 $l\,hr^{-1}$of Potters for Peace was not achieved.

4.4 Water Turbidity Results

The third objective of this study was to determine the purity of the water by measuring the turbidity of the water filtered through the Ceramic Candle Filter (CCF) developed in the study. The experimental results obtained from the measurements of the turbidity of water filtered through the different sets of filters are shown in Table 4.3

Table 4.3Water Turbidity Results for Water Filtered

Clay : Saw dust Ratio	Water Turbidity/NTU
1:1	4.205
5:4	2.365
5:3	1.677
5:2	0.308
5:1	0.237

The t–value from the table is 2.306 at 5% significance level, however the calculated t– value is 21.486. It therefore means that the results are significantly different since 21.486> 2.306 .

The results showed that the turbidity of the water filtered through the filters reduced with increased clay to sawdust ratio.

Turbidity is caused by the presence of suspended matter,which usually consists of a mixture of inorganic matter, such as loose clay and soil particles, and organic matter particle. High turbidity in filtered water is therefore a matterof concern, as this indicates the presence of suspended organicmaterial, which promotes the growth of microorganisms according to Momba et al, 2003. Drinking-water turbidity, a measure of thecloudiness of the water, is commonly used as a proxy measurefor the risk of microbial contamination and the effectiveness of the treatment of public drinking water. Several studieshave shown a correlation between turbidity levels and microbial contamination of raw and treated water according to LeChevallier et al, 1993 and afew documented waterborne disease outbreaks were associatedwith increased turbidity levels according to Schwartz et al, 2000.

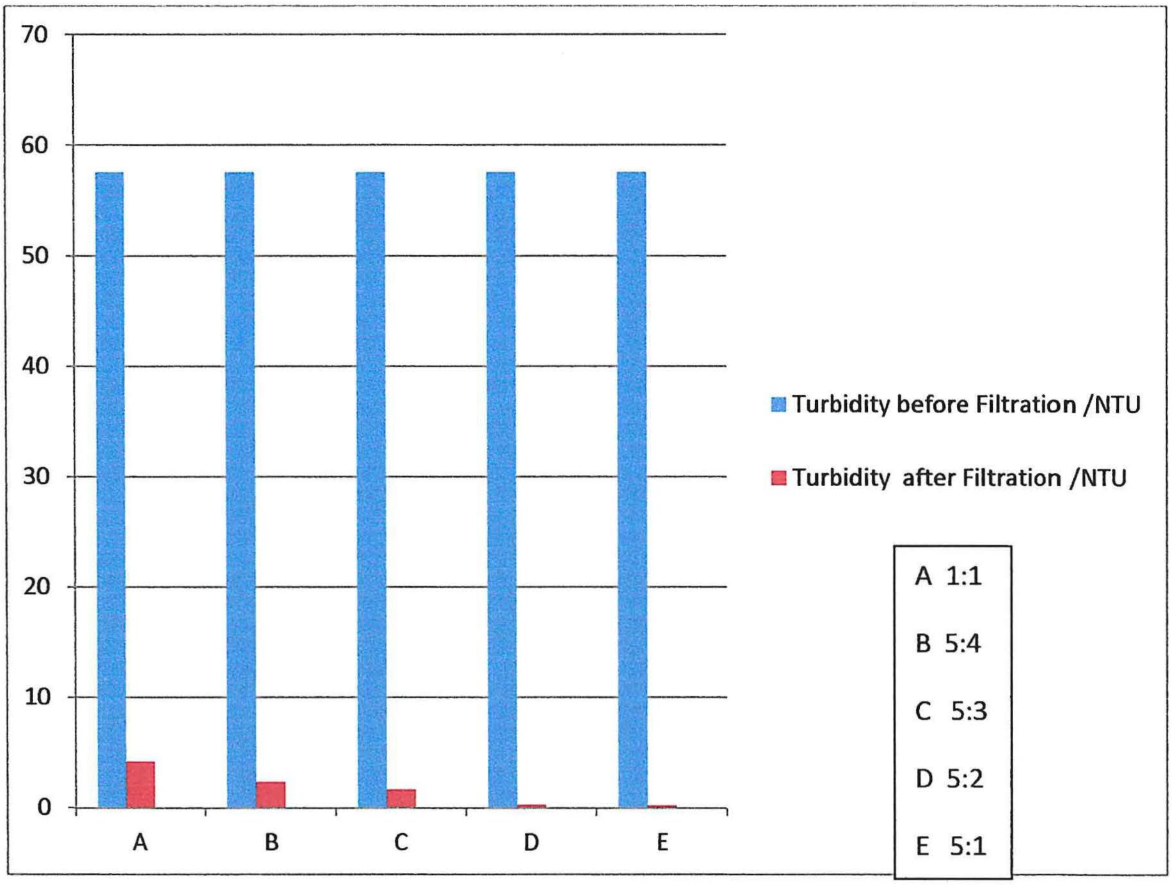

Figure 4.3: A bar Graph of Turbidity of Unfiltered and Filtered Water for the different Clay-Saw dust ratio Filters

Turbidity removal is goodtypically approaching < **1** NTU removal efficiency which is above the WHO guideline of 5 NTU.

4.5 E-coli Removal Efficiency Results

The last objective of this study was still to determine the purity of water by measuring the efficiency of the developed ceramic filters in removal of e-coli from unclean water. The percentage E-coli removal efficiency were tabulated below.

Table 4.4 E-coli Removal Efficiency Results for Water Filtered

Clay: Saw dust Ratio	FilteredWater in cfu/100 ml	E-coli Removal Efficiency /%
1:1	153	92.4
5:4	48	97.6
5:3	7	99.6
5:2	4	99.8
5:1	1	99.9

The results showed that the percentage E-coli removal efficiency was higher for a low sawdust ratio (5:1). It is obvious that these pores are much larger than the maximum of 1 µm pores aimed at by Potters for Peace for 100% E-coli removal efficiency. Filters with composition ratio 1:1 exhibited the lowest performance with regard to E-coli removal with 92.4% E-coli removal efficiency observed. The poor performance of these filters can be attributed to the fact that they had a high percentage of sawdust in their composition and thus, after firing, they had a high number of voids. The high number of voids meant that many suspended particles and other organisms could easily pass through the filters.

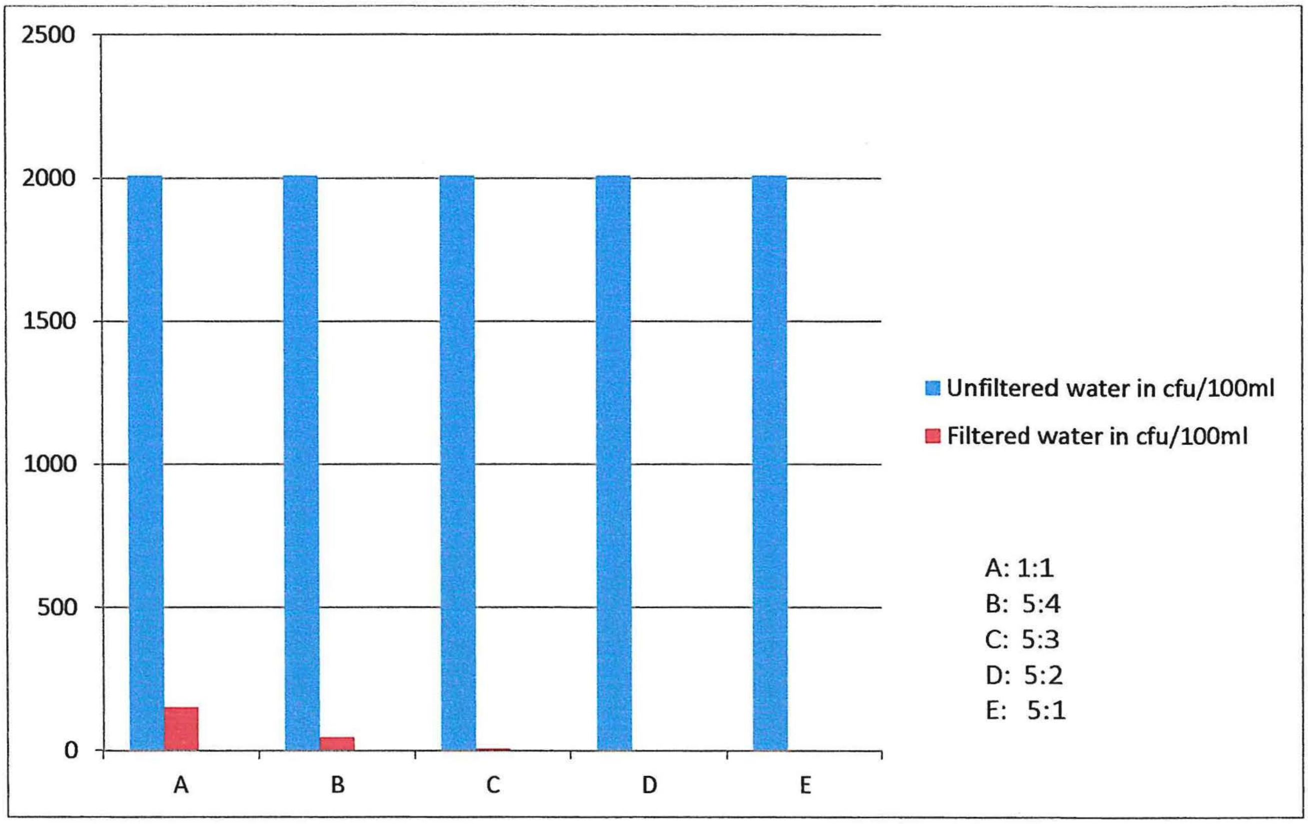

Figure 4.4: A bar Graph of E- Coli in Unfiltered and Filtered Water for the different Clay-Saw dust ratio Filters

E-coli removal ranged from153cfu/100 *ml* to 1cfu/100 *ml* which did not meet the strict World Health Organization (WHO) guideline of 0cfu/**100 *ml***

CHAPTER FIVE: DISCUSSIONS, CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

This chapter presents the discussions of the experimental results obtained in this research with regard to water percolation through the ceramic candle filter, the water turbidity and the e-coli removal efficiency of the ceramic candle filter. It also presents the conclusions drawn from the discussions and the recommendations for further research.

5.2 Discussion of Results

Porosity, Water flow rate, Turbidity removal efficiency, and E-coli removal efficiency have been discussed here.

The porosities of the filters all decreased linearly with a decrease in saw dust proportion. Theceramic candle filter with a 5:1 clay to saw dust ratio had the lowest percentage porosity of 35.12% and the filter with a 1:1 clay to saw dust ratio produced the highest percentage porosity of 48.05%. The porosity of the filters was as a result of the pores or voids left behind when the sawdust in their composition burnt off during firing according to Clair, (2006). Therefore, filters with a higher percentage of sawdust in their composition left behind more pores after firing and hence greater porosity.

The flow rate of water through the filter decreased with a decrease in saw dust proportion. The candle filter with 16.7% saw dust (5:1) produced the lowest volume of water (196.43ml h^{-1}) and the filter with highest saw dust proportion had the highest percolation rate (916.67 ml h^{-1}). The average flow rates obtained for each filter unit during the study period were not within the recommended limit. For good performance by the filters according to Brown et al, (2006) recommend flow rates ranging between 1 and 11 lh^{-1} for Ceramic Candle Filters (CCF). These varying flow rates were as a result of different porosities of the filters due to their different clay to saw dust compositions. This was evidenced by the fact that filters with high percentage of sawdust in their composition exhibited a higher rate of water filtration. The porosity of the Ceramic Candle Filters (CCF) is therefore the major factor that determines the rate of water filtration through the filters. In addition, other factors like filter thickness, filter surface area, water turbidity and water pressure also contribute to the rate at which water percolates through the filters. However, in this study, filter thickness, filter surface area and water pressured were kept constant. This means that in this study the rate of water filtration through the filters was mainly dependent on the porosity of the filters and the turbidity of the water being filtered. The measured flow rates are unacceptable; it is a basic requirement that Ceramic Candle Filters (CCF) provides sufficientreliable water for a family. Although this is a major weakness, it should not be forgotten thatthe positive impact of Ceramic Candle Filters (CCF) in the field will be enormous. This ceramic candle filter (CCF) research underlines theconclusion that the major deficiency of ceramic candle filter (CCF) is the low discharge. At this stage it must be again noted that the reduction in discharge depends on the raw water quality. The pores may be blocked by organic matter or particles.

The highest turbidity removal performanceof <1 NTU was noted with the ceramic candle filter (CCF) having the lowestsaw dust (5:1). Although, the levels of turbidity in filteredwater exceeded the recommended limit (which is <1 NTU)according to DWAF et al, (1996), the turbidity removal efficiency of the filter units was at <5 NTU. Turbidity is caused by the presence of suspended matter such as solid particles and organic matter. High turbidity in filtered water therefore indicates the presence of suspended organicmaterial, which contains contaminants according to Momba et al, (2003).

All the ceramic candle filter (CCF) samples were able to decreasethe concentrations of pathogens from lake water samples. However, this bacterial reductionwas characterised by variations in the performance of the filter samples. The percentage removalof E-coli by the ceramic candle filter (CCF) ranged between 92.4% and 99.9%, which was within the removal rates of 81–

100% stated by previousinvestigators according to Baumgartner et al, (2007). However according to World Health Organization, which recommends that drinking water should have zero e-coli colony forming units (CFU) at any time [http://water.epa.gov/drink/contaminant/index.cfm; accessed on 9/04/2012] not all the filter samples achieved this. The filters with the least percentage composition by volume of sawdust in their texture (5:1) had the highest E-coli removal efficiency (99.9%), this is because, after firing they had fewer numbers of voids according to Dies, (2003) for the e-coli to pass through. Filters with composition ratio 1:1exhibited the lowest performance with regard to e-coli removal, e-coli removal efficiency of 92.4% was observed. The poor performance of these filters can be attributed to the fact that they had a high percentage of sawdust in their composition and thus, after firing, they had a high number of voids, Dies (2003). The high number of voids meant that many suspended particles and other organisms could easily pass through the filters.

5.3 Conclusions

It can therefore be concluded that, porosity is directly proportional to the proportion of saw dust in clay to saw dust ratio. This porosity in turn determines the flow rate, turbidity removal and E-Coli removal efficiency in the filtered water.

The flow rate of water through the filter decreased with a decrease in saw dust proportion in the mixture. The candle filter with 23% saw dust (5:1) produced the lowest volume of water (196.43ml h^{-1}) and the filter with highest saw dust ratio had the highest filtration rate (916.67 ml h^{-1}). From this research, it can be concluded that filters with higher initial filtration ratesare more porous than those with low filtration rates.

Although the ceramic candle filter (CCF) with dust proportion of (5:1) wasmore effective in reducing turbidity, at a rate of<1 NTU, only two ofthe filter samples achieved the limits set by the SANS 241 (<1 NTU).However all the filters met the standard (<5 NTU) for World Health Organisation itcan therefore be concluded that the filters were capable of filtering the turbidity of the water and therefore making the water safe for consumption.

The outcomes of this investigation showed that all filter samples decreased the concentrations of microbial contaminantsfrom test water sources. Higher removal efficiencies ofcontaminants were observed in filter samples with small saw dust to clay mixture (5:1) comparedto the higher saw dust to clay mixture (1:1). Its evidence enough that ceramic candle filter (CCF) can safely filter un clean water into safe clean drinking water.

5.4 Recommendations

The performance of a ceramic candle filter depends on many parameters some of which were not considered in this study. It was also visibly evident that the flow rate was low; therefore the following recommendations are here by suggested

(i) The effect of grog on cohesive nature of the filter, flow rate of the water, turbidity of water, and total coliform removal of the filter should be further studied

(ii) The patterns in contaminant removal efficiency of each filter sample with short-term and long-term use was not catered for in the results therefore, there is need to study it as well.

(iii) The effect of the application of colloidal silver on the adsorptive properties of the filter material and consequently on the quality of water should equally be explored.

(iv) The main deficiency of ceramic candle filter (CCF) is the low filter discharge. This means that the filters produce insufficient drinking water to provide for an average sized family. Therefore the possibilities of increasing the discharge should be carried out without losing effectiveness of the removal of pathogenic micro organisms.

REFERENCES

Azoru-ra C. A. (1994). *"A Study of the Composition and Mechanical Strengthof Ugandan Clays"*,MSc Dissertation, Makerere University

Brown, J., Sobsey, M. (2006).*"Independent Appraisal of Ceramic Water Filtration Interventions in Cambodia"*: Final Report, Department of Environmental Sciences and Engineering, School of Public Health, University of North Carolina, USA.

Clasen, T., Roberts, I., Rabie, T., Schmidt, W., Cairncross, S., (2006). *"Interventions to improve water quality for preventing diarrhoea"*, (A Cochrane Review), no. 3. The Cochrane Library, Oxford.

DWAF, (1996).*"South African Water Quality Guideline, Domestic use, 2nd ed"*.pp.1Earwaker, P., 2006.Evaluation of Household BioSand Filters in Ethiopia.Master of Science in Water Management (Community Water Supply) Thesis, Institute of Water and Environmental Management.Cranfield University, Silsoe, United Kingdom.

GrimShaw R.W. (1971). *"The Chemistry and Physics of Clays and allied Ceramic Materials, 4th edition"*, Wiley Interscience, New York, pg 421,538

Heijman, S.G.J. (1993) *"Oxide Pigments in Water: The Colloidal chemical Point of View"*,Eindhoven University of Technology, The Netherlands

Jawetz, Melnick, &Adelberg, (2010).*"Medical Microbiology, 24th Edition"* by Vishal.The McGraw-Hill Companies.

Jones, J. T. and M. F. Berard,(1972).*"CERAMICS Industrial Processing and Testing"*.The Iowa StateUniversity Press, Ames, Iowa.

Kabagambe Musa, (2010). *"Performance of ceramic water filters made from selected Ugandan clays for point-of-use"*. Masters dissertation, MUK.

Katherine L.C, Lauren E. F, Krause C.F, Manto P.J, Dara J. P and Brooke L. Y. (2000). *"Implementation of an appropriate house-hold water purification system in Tourou, Cameroon"*.www.sys.virginia,edu accessed 14th /July/2008.

Kosek M, Bern C, Guerrant R. L., (2003).*"The global burden of diarrhoeal disease"*, Bull World Health Organ81: 197–204.

Lantagne, D.S., (2001). *"Investigation of the Potters for Peace Colloidal Silverimpregnated Ceramic Filter"*: Intrinsic Effectiveness and Field Performance in Rural Nicaragua, Alethia Environmental, Allston, Massachusetts.

Lantagne, D.S., Clasen, T., (2009).*"Point of Use Water Treatment in Emergency Response"*, London School of Hygiene and Tropical Medicine 80(5)

Lechevallier M.W., Evas T.M. and Sadler R.J. (1981*). "Effect Turbidity on chlorination Efficiency and Bacterial efficiency in drinking water"*.Applied Microbiology No.1, Vol.42, 159-167.

Matsumoto, M., Inoue, K., (2011).*"Editorial: earthquake, tsunami,radiation leak, and crisis in rural health in Japan"*. Rural andRemote Health

Mcallister S. (2005). *"Analysis and comparison of sustainable water filters"*.EPD397 Technical report.http://pottersforpeace.org accessed 8th/July/2008

Momba, M.N.B., Notshe, T.L., (2003). *"The microbiological quality of groundwaterderived drinking water after long storage in household containers in a rural community of South Africa"*. J. Water Supply: Res. Technol.

Momba, M.N.B., Malakate, V.K., Theron, J., (2006). *"Abundance of pathogenic Escherichia coli, Salmonella typhimuriumand Vibrio cholerae in Nkonkobedrinking water sources"*. J. Water Health 04 (3), 289–296.

Murcott, S., (2006).*"Implementation, critical factors and challenges to scale-up of household drinking water treatment and safe storage systems"*. In: Background Paper on Household Water Treatment and Safe Storage (HWTS) for the Electronic Conference Hosted by USAID/Hygiene Improvement Project (HIP),pp. 1–39.

Nederstigt, J., S. Lam (2005) *'Flow rate testing equipment design'*, Practica Foundation, SriLanka

Obwoya K. S (2003*)."Effects of Microstructure on Mechanical Strength of Selected Clays from Uganda*", PhdThesis Makerere University

Pritchard, M., Mkandawire, T., Edmondson, A., O'Neill, J.G., Kululanga, G.,(2009). *"Potential of using plant extracts for purification of shallow well water in Malawi*". Phys. Chem. Earth, Parts A/B/C 34 (13–16), 799–805.

Robert W. Dies, (2003). *"Development of a ceramic water filter for Nepal"*.Dissertation for Master in Civil and Environmental Engineering, MIT.

Sagara J.,(2000). *"Study of filtration for Point-of-Use Drinking Water in Nepal"*.Master of Engineering in Civil and Environmental Engineering, Massachusetts Institute of Technology.

Sakka Y, Fengqw T, Hiroshi F and Tetsuo U.K (2003) *"Fabricationof porous ceramics with controlled Pore size by colloidal processing*", National Institute for Material sciences.

Schwartz, J., Levin, R.R., Goldstein, R.R., (2000.)*"Drinking water turbidity and gastrointestinal illness in the elderly of Philadelphia*". J. Epidemiol. Community Health 54, 45–51.

Shepard, Anna. (1968), *"Ceramics for the Archaeologist"*.Carnegie Institution of Washington. Washington, DC. Publication 609.

Sobsey, M.D., Stauber, C.E., Casanova, L.M., Brown, J.M., Elliott, M.A., (2008). *"Point of use household drinking water filtration":* a practical, effective solution for providing sustained access to safe drinking water in the developing world. Environ. Sci. Technol. 42, 4261–4267.

Thomas F. C, Brown J, Collin S, Suutura O and Sandary C. C.(2004). *"Reducing Diarrhoea through the use of household ceramic water Filters":* Arandomised controlled trial in Rural Bolivia.

Violette, S., Boulicot, G., Gorelick, S.M., (2009). *"Tsunami-inducedgroundwater salinization in southeastern India"*.ComptesRendus Geosciences 341, 339-346.

Vinka A, Oyanedel C, and James A.S. (2008).*"Sustainable Colloidal-Silver-Impregnated Ceramic Filter for Point-of-usewater treatment"*. Environmental Science and Technology, 42,927-933

Washburn, E.W. (1921) *'Note on a method of determining the distribution of pore sizes inporous material'*. Proceedings of the National Academy of Science

WHO, (2007).*"Combating Waterborne Disease at the Household Level"*: The International Network to Promote Household Water Treatment a Safe Storage.World Health Organization, Geneva, Switzerland.

WHO/UNICEF, (2006). *"Meeting the MDG Drinking Water and Sanitation Target":* The Urban and Rural Challenge of the Decade. World Health Organization/UNICEF Joint Monitoring Programme for Water Supply and Sanitation, Geneva,Switzerland.

Young, S., Balluz, L., Malilay, J., (2004). *"Natural and technologic hazardous material releases during and after natural disasters"*: a review. Science of the Total Environment 322, 3-20.

APPENDIX A: Data forPorosity Determination

For each of the clay to saw dust ratio, five filters were produced and labelled A,B,C,D,and E. Raw data for porosity was then collected and tabulated.

	A	B	C	D	E
1:1	47.52	46.73	48.39	48.72	48.90
5:4	43.63	42.58	44.78	45.69	44.98
5:3	41.65	43.28	42.30	41.58	42.76
5:2	40.24	38.35	37.54	36.46	39.43
5:1	36.71	35.32	34.57	35.67	33.32

APPENDIX B: Data for Water Filtration Determination

For each of the clay to saw dust ratio, five filters were produced and labelled A,B,C,D, and E. Raw data for water filtration was then collected and tabulated.

APPENDIX B 1: Data for Water Filtration through the 1:1 Filter

	Time /hr				
Volume/ ml	A	B	C	D	E
50	0.031	0.034	0.039	0.041	0.043
60	0.035	0.042	0.044	0.048	0.052
70	0.045	0.049	0.056	0.061	0.065
80	0.053	0.058	0.066	0.072	0.078
90	0.062	0.068	0.074	0.089	0.091
100	0.071	0.076	0.084	0.095	0.122
110	0.077	0.086	0.089	0.114	0.124
120	0.088	0.093	0.099	0.126	0.128
130	0.110	0.125	0.129	0.136	0.146
140	0.128	0.130	0.138	0.142	0.148
150	0.132	0.139	0.143	0.146	0.150

APPENDIXB2: Data for Water Filtration through the 5:4 Filter

	Time /hr				
Volume/ ml	A	B	C	D	E
50	0.050	0.060	0.043	0.045	0.048
60	0.086	0.075	0.080	0.078	0.068
70	0.090	0.120	0.120	0.121	0.078
80	0.110	0.123	0.125	0.126	0.085
90	0.121	0.129	0.130	0.131	0.135
100	0.142	0.156	0.158	0.165	0.168
110	0.156	0.161	0.169	0.171	0.178
120	0.180	0.192	0.194	0.178	0.220
130	0.184	0.196	0.215	0.220	0.252
140	0.193	0.221	0.233	0.245	0.259
150	0.231	0.236	0.241	0.247	0.260

APPENDIXB3: Data for Water Filtration through the 5:3 Filter

	Time /hr				
Volume/ ml	A	B	C	D	E
50	0.22	0.24	0.26	0.28	0.30
60	0.23	0.25	0.27	0.29	0.31
70	0.26	0.28	0.32	0.33	0.35
80	0.29	0.31	0.34	0.36	0.38
90	0.32	0.34	0.36	0.38	0.41
100	0.34	0.37	0.39	0.42	0.45
110	0.35	0.38	0.43	0.46	0.49
120	0.37	0.39	0.44	0.47	0.51
130	0.39	0.42	0.45	0.49	0.53
140	0.41	0.44	0.47	0.52	0.54
150	0.43	0.46	0.49	0.53	0.56

APPENDIXB 4: Data for Water Filtration through the 5:2 Filter

	Time /hr				
Volume/ ml	A	B	C	D	E
50	0.26	0.28	0.31	0.34	0.37
60	0.27	0.29	0.32	0.35	0.38
70	0.31	0.33	0.36	0.40	0.42
80	0.34	0.37	0.41	0.43	0.45
90	0.36	0.39	0.44	0.46	0.49
100	0.43	0.46	0.49	0.52	0.54
110	0.47	0.53	0.55	0.57	0.63
120	0.54	0.56	0.59	0.64	0.67
130	0.57	0.60	0.62	0.65	0.69
140	0.62	0.65	0.68	0.71	0.74
150	0.67	0.69	0.73	0.75	0.77

APPENDIXB 5: Data for Water Filtration through the 5:1 Filter

	Time /hr				
Volume/ ml	A	B	C	D	E
50	0.23	0.25	0.28	0.31	0.35
60	0.27	0.29	0.32	0.36	0.39
70	0.31	0.34	0.38	0.41	0.44
80	0.35	0.39	0.42	0.46	0.49
90	0.41	0.43	0.47	0.51	0.56
100	0.44	0.48	0.52	0.57	0.61
110	0.49	0.53	0.58	0.64	0.68
120	0.59	0.62	0.66	0.72	0.75
130	0.63	0.65	0.68	0.74	0.78
140	0.67	0.69	0.73	0.79	0.81
150	0.75	0.76	0.83	0.81	0.83

APPENDIXC: Data for Water Turbidity after Filtration

	A	B	C	D	E
1:1	4.242	4.363	3.991	4.763	3.664
5:4	3.399	2.351	2.359	2.281	1.436
5:3	2.254	2.245	1.499	1.253	1.135
5:2	0.385	0.373	0.270	0.268	0.245
5:1	0.209	0.271	0.267	0.214	0.225

APPENDIXD: DataE-ColiCount in Filtered Water

	A	B	C	D	E
1:1	145	165	165	145	145
5:4	74	50	32	50	32
5:3	11	11	6	3	6
5:2	6	3	2	1	1
5:1	0	0	0	1	1

APPENDIXE: Data forSignificance of the Results

When the common population variance, σ^2, is unknown, then an unbiased estimate,$\tilde{\sigma}^2$, is used. This is sometimes known as a pooled two- sample estimate, where

$$\tilde{\sigma}^2 = \frac{n_1 {s_1}^2 + n_2 {s_2}^2}{n_1 + n_2 - 2}$$

Where,

$s_1$and$s_2$are sample variances

For small samples the standardised form of the distribution of $\overline{x}_1 - \overline{x}_2$ follows a t −distribution.

$$t = \frac{\bar{x}_1 - \bar{x}_2}{\tilde{\sigma}\sqrt{\frac{1}{n_1} + \frac{1}{n_2}}}$$

APPENDIX E 1: Data for Significance of Porosity

The mean and the variance of the porosity was calculate and tabulated

Clay: saw dust	Mean	Variance
1:1	48.05	0.663
5:4	44.33	1.206
5:3	42.31	0.423
5:2	38.40	1.790
5:1	35.12	1.284

The t–value calculated from the above results is 18.53

APPENDIX E 2: Data for Significance of turbidity

The mean and the variance of the turbidity was calculate and tabulated

Clay: saw dust	Mean	Variance
1:1	4.205	0.135
5:4	2.365	0.388
5:3	1.677	0.232
5:2	0.308	0.003
5:1	0.237	0.001

The t–value calculated from the above results is 21.486