Effectiveness of Household Water Treatment Technologies based on WHO Guidelines

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Declaration of Candidate

We hereby declare that this thesis is our original work and it has been written by us in its entirety. We have duly acknowledged all the sources of information which have been used in the thesis.

This thesis has also not been submitted for any degree in any university previously.

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APPROVAL

The dissertation entitled ***"Effectiveness of Household Water Treatment Technologies based on WHO Guidelines"*** by Md. Redowan Rashid Niloy and Omar Sadab Chowdhury has been approved fulfilling the requirements for the Bachelor of Science Degree in Civil Engineering.

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Abstract

This thesis examines the bacteriological removal efficiency of different Household Water Treatment (HWT) technologies. Tests were conducted according to guidelines laid out by World Health Organization (WHO). Bacterial removal efficiencies of Ceramic Filters, Chlorination, Ultra-violet disinfection and Coagulation and Sedimentation were tested in a controlled environment by using two types of Test Water as per WHO requirement. Each of these options were tested using the two types of test water. The tests were conducted in the IUT Environmental Lab. *E.Coli bacteria* was used as the test organism to determine the removal efficiencies of these HWT methods before and after treating the test waters. Physicochemical parameters of the water samples were also measured along with the bacterial removal efficiencies.

For all the methods of household water treatment systems, two types of test waters were used as per WHO guideline for household water treatment systems (HWTS)

Ceramic Water Filters (CWF) have gained immense popularity over the recent years especially in developing countries. CWF implements porous ceramic and activated carbon to treat water at households. They have been identified as one of the most promising and accessible technologies for treating water at the household level. (Thomas F. Clasen). 8 filters of different companies were set up in the laboratory for control experiment to determine the efficiency of CWF in removing bacteria (E.Coli). A total of 1000 liters of water were passed and the bacteria removal efficiencies at 0%, 25%, 50%, 75% and 100% of water passage was measured. A total of at least 20 liters of water were passed per filter each day in order to replicate the water requirement of an average household size of approximately 5 people in Bangladesh. (Health Bulletin 2012). The physicochemical parameters of the water samples before and after filtration were recorded on a weekly basis. It was found that the effectiveness of the filters slowly declined with time. Laboratory results showed that after every cleaning process the efficiency of the filters increased.

Chlorination is a chemical disinfection method that uses various types of chlorine or chlorine-containing substances for the oxidation and disinfection of what will be the potable water source. Test waters were subjected to treatment by chlorination and it was found that this method had a

very high bacteria removal efficiency. Physicochemical data were also recorded for every experiment. A chlorine solution of 0.1N was used as the chemical disinfectant.

Coagulation and sedimentation is the process in which a coagulant is added to water and mixed thoroughly to cause sedimentation. In this experiment 0.1N alum solution was used. The coagulant produces positive charges to neutralize the negative charges on the particles. Then the particles can stick together, forming larger particles which are more easily removed. Alum concentration was varied and for each concentration the bacteria removal was measured. For lower concentrations the removal efficiency was very poor but showed gradual improvement with increasing concentration. However the increased alum dosage rendered several unwanted physicochemical properties to the water which caused the water to lose its drinking water characteristics. Though this method yielded favorable results in removing bacteria, it showed unsatisfying results in physic-chemical studies. It was found that the dosage that is needed to remove E. coli completely from the sample water, creates acidic condition in the water. The pH level was found to be 3.85. So the method can't be used to remove E. coli from water.

Ultra Violet Radiation has been found to have disinfecting abilities and recent studies show that they may implemented as an effective method of disinfecting contaminated water. UV Water Purification systems use special lamps that emit UV light of a particular wavelength that have the ability, based on their length, to disrupt the DNA of micro-organisms. These UV light waves are also referred to as the Germicidal Spectrum or Frequency. The frequency used in killing micro-organisms is 254 nanometers (nm). As water passes through a UV water treatment system, living organisms in water are exposed to UV light which attacks the genetic code of the microorganism and rearranges the DNA /RNA, eliminating the microorganism's ability to function and reproduce. According to studies it has been found that this process removes 99.99% of harmful microorganisms. From laboratory experiment it has been found that all the E. coli was removed from the sample water within 30 minutes for both type 1 and type 2 water.

All the physic-chemical behavior was satisfactory. So the method can be used to remove E. coli in household level.

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Chapter 1: Introduction

1.1. General

Contaminated drinking water, along with inadequate supplies of water for personal hygiene and poor sanitation are the main contributors to an estimated four billion cases of diarrhea each year, causing 2.5 million deaths. Access to safe drinking water is a challenge in developing countries due to increasing population and lack of technology access. According to a study conducted by World Health Organization (WHO) it has been found that 884 million people do not have access to safe drinking water and in most cases the households are located 1 km or further from the source (WHO 2008). Among children under less than five years old in developing countries, diarrheal disease accounts for 21% of all deaths. Around 289,000 children under five die every year from diarrheal diseases caused by poor water and sanitation. In Bangladesh deaths due to diarrhea is a common issue with the most effected group being children under the age of five years old. According to a report by WHO/UNICEF, 2006, diarrhea, cholera, enteric fever and hepatitis cause 1.6 million deaths annually, a greater proportion being children. By inhibiting normal consumption of foods and adsorption of nutrients, diarrheal diseases are also an important cause of malnutrition, leading to impaired physical growth and cognitive development, reduced resistance to infection, and potentially long-term gastrointestinal disorders.

For domestic uses urban dwellers are dependent on piped water supply. However, recent studies have shown that the water arriving at end points is prone to contamination rendering the water unsafe for drinking. Source water and treatment process changes in water plants, flow of aged water from a storage reservoir, water demand variation, and quality deterioration in water distribution are examples of non-contaminant events (e.g., Harding and Walski, 2000; Powell et al., 2000; Kroll and King, 2006),. A recent study in Bangladesh revealed microbial contamination of pipe water supply in Khulna and Jessore (Karim et al. 2016). There are several other factors that contribute to contamination of pipe water including cross contamination with sewerage lines, old pipes and leakage of pipes causing intrusion of surrounding contaminated water. Household water treatment

(HWT) interventions may play an important role in protecting public health where existing water sources, including those delivered via a piped network or other improved sources, are untreated, are not treated properly or become contaminated during distribution or storage (UNICEF & WHO, 2009). Therefore it is important to implement an effective point-of-use water treatment.

There are several HWT technologies that are being used for treating water. The available technologies are boiling, coagulation, sedimentation, chlorination, filtration, solar disinfection, uv-radiation or a combined form of one or more of these methods. Commonly these apparatuses are compiled and assembled in the country or imported from neighboring countries. In this experiment four of these technologies were tested for their bacterial removal efficiencies. i) Ceramic Water Filters ii) Chlorination iii) Coagulation and Sedimentation iv) UV Radiation. There are growing number of literatures on ceramic water filters (Elliot et al., 2011) chlorination (M.D. Sobshey. et al.) and UV Radiation (A. Hamamoto.,). Greater focus is being given to HWT as a means of providing safe drinking water to consumers. Hence it is important to determine the most efficient means of point-of-use water treatment method. The bacteria removal efficiencies were analyzed by calculating the *Log Reduction Value (LRV)* of each option.

This study was performed to evaluate the bacterial removal efficiencies of different HWT technologies by means of laboratory controlled experiments according to WHO Guideline for drinking water. Long term evaluation was done on Ceramic Filters in order to determine variations in flow rates, physicochemical parameters and bacteria removal efficiencies. The other methods were also tested as per the requirements of WHO guideline for drinking water.

1.2. Objective

The objectives of this study is listed below:

1. To determine the efficiency of commonly used household drinking water treatment technologies according to WHO guideline.
2. Comparing the efficiency of different treatment methods.
3. Evaluating the performance with respect to recently published references and recommendations for microbial performance by the World Health Organization.

1.3. Scope of the study

There were several tasks that were required to be performed in order to accomplish the aforementioned objectives which are outlined below:

1. Setting up the necessary equipment for conducting study according to WHO guideline for all of the treatment options.
2. Measurement of bacterial removal and physicochemical parameters of all test waters.
3. Comparing the results between different treatment options.

1.4. Thesis Layout

Chapter 1: This chapter includes a general introduction, background, objectives and scope of the study.

Chapter 2: This chapter consists of the literature review which covers water quality aspects and water borne diseases and problems of Bangladesh. Different household water treatment technologies and related research studies are also discussed.

Chapter 3: Detailed methodology of all the experiments performed is discussed here. It includes the process by which the guideline had been followed while performing the relevant experiments. Details of scheduling, laboratory set up, spiking, taking measurements, sampling and analysis of the test samples from different options of water treatment.

Chapter 4: Results of the experiments that were performed are analyzed in this chapter. The microbiological and physicochemical parameters are also presented with relevant analysis. Comparison between different types of treatment options is done.

Chapter 5: This chapter includes the conclusion from the experiments conducted for different HWT technology options. It includes findings, recommendations and limitations of the experiment.

CHAPTER 2: LITERATURE REVIEW

2.1. General

Several water supply treatment options of Bangladesh have been outlined in this chapter. Different types of water borne diseases, their causes and facts, WHO drinking water quality guideline and different household water treatment options have also been presented in this chapter. Ceramic Water Filter (CWF), Chlorination, Coagulation and Sedimentation and UV disinfection have been described with functional elements.

2.2 Overview

2.2.1 Water borne diseases

Water contributes to health directly within households through food and nutrition and indirectly as a means of maintaining a healthy, diverse environment. Lack of adequate supplies of safe water and safe methods of preservation; create ideal conditions under which fecal oral diseases thrive. Water-borne disease is transmitted or spread through contaminated water. Pathogenic microbes and some parasitic organisms are responsible for 12 various diseases. Such infectious pathogens survive and spread in the environment using various strategies. The main source of pathogenic spread is through water. Infectious diseases caused by pathogenic bacteria, viruses and parasites (e.g. protozoa and helminths) are the most common and wide spread health risk associated with drinking water. The pathogens which transmit through drinking water are diverse in quality, characteristics and resistance (WHO, 2011a). Between 1972 and 1999, 35 new agents of disease were discovered, and many more have reemerged after long periods of inactivity or are expanding into areas where they have not previously been reported (WHO, 2003) Bangladesh is considered the world's one of the most densely populated countries with 2,639 people per square mile. The most common cause of illness and deaths in the developing countries like Bangladesh is a watery diarrhoea called cholera (Clasen et al., 2006) caused by a bacterial pathogen classified as Vibrio cholerae (Shultz et al., 2009). Among the 50 prevalent diseases in Bangladesh, 40 of them are water borne including diarrhoea, dysentery, typhoid, parasitic worm infections etc. Water borne diseases in Bangladesh cause 5 billion taka (US$ 80 million) each year for treatment in hospitals alone. A total of 1,106,000 deaths can be attributed to water, sanitation and hygiene issues in Bangladesh. Among them 109,000 deaths are directly caused by water related diseases. Diarrhoeal diseases in particular are carried through the medium of

water. These diseases account for about 12% of all illnesses in Bangladesh which are alone the major causes of death from water related diseases in Bangladesh. Hence, water borne disease in Bangladesh cost numerous lives each year based on their severity. WHO Guidelines for drinking-water quality mentions a list of pathogens transmitted through drinking water. Table 2.1 shows different types of organisms which are responsible for important water related diseases globally based on their severity.

Table 2.1. Pathogens transmitted through drinking water (WHO, 2011b)

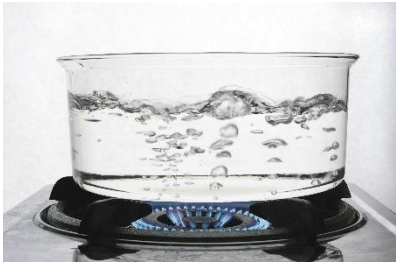
Pathogen	Health significance	Persistence in water supplies	Resistance to chlorine	Relative infectivity	Important animal source
Burkholderia pseudomallei	High	May multiply	Low	Low	No
Campylobacter jejuni, *C. coli*	High	Moderate	Low	Moderate	Yes
*Escherichia coli*pathogenic	High	Moderate	Low	Low	Yes
E. coli-Enterohaemorrahgic	High	Moderate	Low	High	Yes
Francisella tularensis	High	Long	Moderate	High	Yes
Leginoella spp.	High	May multiply	Low	Moderate	No
Leptospira	High	Long	Low	High	Yes
Mycoacteria (nontuberculous)	Low	May multiply	High	Low	No
Salmonella Typhi	High	Moderate	Low	Low	No
Other *salmonellae*	High	May multiply	Low	Low	Yes
Shigella spp.	High	Short	Low	High	No
Vibrio cholerae	High	Short to long	Low	Low	No

Table 2.2. Total annual deaths and water borne disease in different age groups (WSP, 2007)

Cause of death	Children under age 5	Children ages 5-14	Persons ages 15+	Total persons
Diarrhoea (direct)	43,126	121	5,415	48,661
ALRI	12,597			12,597
Measles	4,137			4,137
Malaria	199			199
Other causes*	18,647			18,647
Helminthes (direct)	49	259	20	328
Total mortality	78,755	380	5,435	84,569
*Excluding diarrhoea, malaria, ALRI, measles, intestinal helminthes, and all perinatal causes.				

2.2.2 Household Water Treatment (HWT) Options

Since the quality of drinking water is hard to control for millions of inhabitants of the developing world, water from unimproved sources is often supplied to communities. This problem is further amplified by the fact that water frequently becomes contaminated after collection but before consumption (Wright et al., 2004). This is a particular problem for households who must travel long distances to collect water (Mellor et al., 2012 b). In both rural and urban areas, household based treatment has been shown to be about twice as effective in reducing endemic diarrhoea as the conventional treatment at the source or point of distribution (Clasen & Cairncross, 2004; Fewtrell et al., 2005). The point-of-use (POU) water treatment devices or HWT devices are encouraged to apply as a means of improving health by achieving clean water (Clasen et al., 2010). Therefore, the implementation of POU water treatments (Figure 2.1) has been proposed as an alternative solution where improving the feed water quality is a challenge for drinking purpose. In contrast to centralized, larger capacity systems that treat water for a whole community, POU systems are decentralized and treat water at the household level. These POU technologies offer the advantages of being easily maintained and simple to use. The POU interventions have demonstrated reduced bacterial contamination in water which leads to human health improvements (Clasen et al., 2004; Sobsey et al., 2002). 15 Chlorination seems to be effective against bacterial agents since the median reduction in endemic diarrhoeal disease is 46%. Filtration technologies provide a median reduction of 40%, followed by flocculation and combination of flocculation/disinfection with 38% in median reduction. Somewhat less efficient are solar radiation and heating methods accounting for a median reduction of 35% (Clasen & Cairncross, 2004).

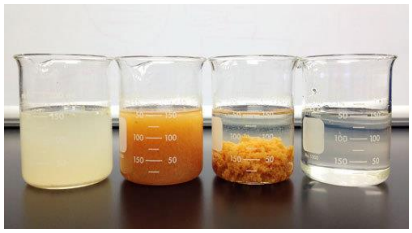


Boiling

Ceramic Filters

UV Radiation

Solar Disinfection (SoDis)



Coagulation and Flocculation

Chlorination

Along with these options, combination of these methods simultaneously or sequentially (e.g. coagulation combined with disinfection) often yield more effective results as "multi-barrier" technologies (Souter et al., 2003). Other combination or multiple barriers are media filtration followed by chemical disinfection, media filtration followed Figure 2.1. Different Household Water Treatment (HWT) options 16 by membrane filtration or composite filtration combined with chemical disinfection. The above mentioned reviews as well as other reviews of technologies have suggested that the success of interventions is highly context specific, with no one technology or method representing a universal best solution (Clasen et al., 2007). The availability of materials, the quality of feed water available, cultural factors and user preferences or cost may determine which technology is most suited to HWT applications in resource-limited settings, such as technologically less developed countries. Mwabi et al. (2011) mentions that the most appropriate technology will depend on the following issues: a. the situation, b. the quality of the feed water, c. the availability of the required materials and equipment, d. the time frame in which it is to be used, e. the customs, preferences and education levels of the local population and f. the availability of personnel to provide the necessary training and monitoring for the technology to be successfully implemented.

Some of the important treatment options have been briefly discussed below:

2.2.2(a) Boiling

Boiling is the most common and probably one of the oldest method for treating small quantities of water globally, with an estimated 1.2 billion people using it as a means of household water treatment (HWT) (Rosa et al., 2010 a; Yang et al., 2012; Rosa et al., 2012). It is such a technique that is being widely accessible and effective against all classes of pathogens if properly done (Sobsey et al., 2002), although it may be locally expensive, energy-intensive, and more environmentally costly than other options for water treatment. It is also, in many places, an ingrained cultural practice. Boiling is now being proposed to evaluate as the standard HWT method against which other methods can be evaluated (Clasen et al., 2008a). 17 Boiling water is a widespread practice despite its cost in both fuel and time. A temperature of 55°C or above over a period of several hours will inactivate most bacteria. Because of monitoring issues raised during the thermal process, householders are usually recommended to heat to a vigorous or rolling boil. In theory, the heat treated water should be stored in the same container it was boiled in, but in practice, householders stores treated water in comparatively smaller containers. The main drawback of handling large volumes of boiling water is a hazard and time consuming process to cool the water and disperse it into appropriate suitable containers. As a technology, boiling has the effectiveness of reducing thermotolerant coliforms (TTC) by 86–99% (Clasen et al., 2008a; Clasen et al., 2008b; Psutka et al., 2011; Rosa et al., 2010b). A mean E. coli reduction of 98.5% in stored boiled water samples was observed in a study (Brown et al., 2012) where there is also some reports of negative LRV (log10 reduction) in treated water (Desmarais et al., 2002; Wright et al., 2004;Jensen et al., 2002).

2.2.2(b) SODIS

SODIS (Solar Disinfection) is a technique which was introduced by the American University in Beirut, Lebanon and the Swiss institute EAWAG (Swiss Federal Institute of Aquatic Science and Technology) has improved solar disinfection by adding steps using settlement or filtration to remove turbidity and increasing the effectiveness of UV inactivation by aeration, for instance, by shaking the container to aerate the water (Kehoe et al., 2001). PET bottles (Polyethylene Tetrapthalete) are recently being used in SODIS as it is easier to handle and less likely to release dangerous chemical products. The formation of free radicals derived from oxygen under the influence of UV radiation may play a significant part in removing pathogens through oxidation process. Sometimes, even with an adequate educational programme, people would not use the technology. This was the case for a successful field study undertaken in Nepal which reduced the fecal coliform count by 90% using SODIS as water treatment but the study 18 revealed that the method was subsequently adopted by only 10% of the households, despite the fact that the implementation was followed by an educational programme (Rainey & Harding, 2005). In another study in the coastal areas of Bangladesh shows that the median health risk reduction by SODIS was more than 96 and 90% for pond and RWHS,

respectively. Also turbidity has reduced to 5NTU, except pond water. In this case only 34% of the participating households routinely adopted SODIS during the study (Islam et al., 2015).

2.2.2(c) Chlorination

Chlorination was one of the oldest of the disinfection mechanism at the household level. It was first used to disinfect public water supplies in the early 1900s, and helped drastically reduce waterborne disease in cities in Europe and the United States (Gordon et al., 1987). It is available to a broad range of forms (e.g. pills, solution). It has the potential to kill bacteria and viral water borne pathogens. However, at low concentrations normally used for water treatment, chlorine lacks activity against protozoal cysts. The production of chlorinated disinfection by-products was for long considered as a threat to human health at high concentrations but according to report WHO, (2004), the "risk to health from these products are extremely small in comparison to the risks associated with inadequate disinfection. In association with Pan American Health Organization (PAHO) and US Centers for Disease Control (CDC), Safe Water System (SWS) implemented a trial project where, in four randomized controlled trials, the SWS reduced the risk of diarrhoeal disease by 44– 84% using chlorination (Luby et al., 2004; Semenza et al., 1998). Studies showed a lot of prevention potential of diarrhoeal disease in developing countries using chlorination. E. coli level has reduced to < 1/100mL when using 1-5mg/L dose of hypochlorite. Also Clostridium perfringens and heterotrophic plate count have been reduced a lot in chlorine interventions. This resulted into 43% less diarrhoea in 19 communities where using this treatment in Bolivia and 24% less potential of diarrhoea in Bangladesh (Sobsey et al., 2003).

2.2.2(d) Sedimentation, Coagulation and Flocculation

Sedimentation is one of the most used techniques among the household treatments as it requires only settling down the water in a container to allow the floating and suspended solids to sediment. The main use of this method is as a pre-treatment or first stage of treatment of the water to remove large inorganic materials. A few hours is needed to settle larger particles. Different pathogens also settle down unless those which are too small are in need of a settlement with coagulation. The main down sides of this technique are the vessels that are used, need to be frequently cleaned and sediments need to be removed. Microbial films growing on the vessel walls need to be removed by scrubbing or by chemical disinfection. Nath et al. (2006) found that as a pre-treatment process, sedimentation is "very cost effective requiring only a suitable vessel, labor and time". Coagulation and flocculation processes are important methods for water treatment. In

household level, sachets or tablets are being used to combine both coagulation and flocculation. It involves adding a coagulant to vessel of water, mixing rapidly to spread the coagulant followed by stirring to enable the formation of large flocs. These flocs are responsible to charge the particles which attract the colloidal particles and micro-organisms among themselves. The advantage of the method is that it makes significant improvements in terms of turbidity and removes until 90-99% of pathogenic bacteria and viruses under optimum conditions. However the drawback is that the bacteria can be accumulated on flocs and to cause recontamination of the water. Therefore settlement or filtration is needed after the process. Studies show that this technology can reduce fecal coliforms of 280 – 500 MPN/ 100 mL to 5 – 10MPN /100 mL (Babu & Chaudhuri, 2005). 20

2.2.2(e) Filtration

Among the Point of Use (POU) processes, filtration is one of the most promising approaches because, the main advantage of filters are, they are easy to use and are made of local materials such as sand, gravels and ceramic which are familiar to many communities. Filtration covers a wide range of technologies from simple removal of large particles (including cloth or plastic gauze) to sophisticated membrane systems operating under high pressure capable of removal of particles down to the nanometer size. It is becoming more popular in developing countries where chemical disinfection or boiling may not always be practical or effective (Colwell et al., 2003). Filtration is a way to remove particles and at least some microbes from water. Several processes take place simultaneously during filtration • Mechanical trapping • Adsorption of suspended matter, chemical, microorganisms • Biochemical processes (biodegradation, grazing by protozoan etc.) For domestic filtration treatment, two general principles are used: • Straining: This is used when the size of the pores in the filter medium is smaller than the particle being removed. This can occur on the filter surface or within the depth of the filter wherever the water flow channels narrow to a size smaller than the particles. This refers to ceramics and granular media filtration. • Depth filtration: when particles passing through the channels become trapped on the surface of the channel wall by a variety of physical mechanisms. This refers to granular media filtration. A number of studies (Table 2.3) show that this HWT or POU technique is very effective in a large variation of water sources against disease burden specifically diarrhoeal diseases(Clasen et al., 2007; Sobsey et al., 2002). In addition to that, WHO has emphasized 21 this treatment option constitutes simple, socially acceptable and low cost interventions with significant potential to reduce global waterborne disease and death (Clasen et al., 2006). Studies shows a good reduction potential of different filtration techniques. In some cases, 48% reduction of cholera was seen in the verification study of filtration. (Colwell et al., 2003). Other study of ceramic water filter shows up to 6 log10 reduction of E. coli and 3 log10 reduction of MS-2 virus (Brown et al., 2012). In a follow up meta-analysis done by Clasen et al. (2007) showed that, POU technologies at individual household level are

more protective in improving water quality and substantially reducing diarrhoeal illness than those interventions implemented in sources to protect water up to consumption.

2.2.2(f) Ultraviolet radiation

Ultraviolet (UV) technology has gained a lot of attention and popularity due to its effectiveness in disinfection applications (Crawford et al. 2005, Bowker et al. 2011). UV disinfection system has a simple design which usually consists of a very few components, UV lamp, reaction chamber and a control box and is very easy to operate and maintain (Ibrahim et al. 2013). Installing or replacement of parts of the UV system in new or existing water treatment plant is relatively easy and requires a few modifications to the plant. UV light is divided into UV-C (100-280 nm), UV-B (280-315 nm) and UV-A (315-400 nm). UV wavelengths between 200-300 nm are considered to be directly absorbed by DNA and therefore considered to be germicidal (Beck et al. 2014). UV-B and UV-C are the common UV classes in inactivating microorganisms but germicidal UV-C irradiation at 254 nm is widely used to inactivate chlorine resistance pathogens within a relative short contact time without producing undesirable disinfection by-products (Ibrahim et al. 2013). 24 Inactivation of microbial pathogens using UV radiation has been demonstrated in many studies (Hinjinen et al. 2006, Eischeid et al. 2009, Schwarzenbach et al. 2011) through oxidation application processes known as photolysis which has resulted in bond cleavage of organic molecules (Blanksby and Ellison 1993). The efficiency of UV systems is due to the fact that DNA molecules absorb UV light. These processes can occur directly by inducing lysis in the target compounds due to the absorption of highly energetic photons, or indirectly, in which an intermediary compound transfers the absorbed photon energy to the target molecule (Schwarzenbach et al. 2003). Thus, leading to the breakage and damage of DNA, preventing replication, transcription and translation that often prompt the fast destruction of bacteria (Soloshenko et al. 2006, Cheveremont et al. 2012). Wavelengths 254 nm and 280 nm may be potentially the most efficient to eliminate microorganisms since they are close to the DNA maximum absorption rate and responsible for the formation of pyrimidine dimers. Thus, this wavelength range has been proven to cause damage on both DNA and proteins of adenoviruses (Eischeid et al. 2009). Measuring the nucleic acid damage has been established to give adequate insight into the mechanism involved in the UV inactivation. Kuluncsics et al. (1999) found that the induced cyclobutane pyrimidine dimers (CPDs) which is a dominant form of UV-induced DNA damage, is more effectively induced by UV-C than the UV-A. Besaratinia et al. (2011) established that the formation of CPDs and other photodimeric lesions is wavelength dependent.

Table 2.3. Technology-specific parameters, variables or conditions that may affect performance according to WHO guideline (WHO, 2011b)

Technology	Testing parameters, variables or conditions potentially affecting performance
Chemical disinfection	Concentration and type of disinfectant, type of treatment reactor, reaction (contact) time, pH, temperature, dissolved solids (organic and inorganic) and suspended constituents (e.g. turbidity or suspended particles) that can interfere with microbial inactivation by disinfectant consumption or physical protection of the target microbes.
Membrane, porous ceramic or composite filters	Turbidity or suspended matter, dissolved solids (organic or inorganic), temperature, pH, contact time or flow rate, filter surface chemistry, filter media pore size distribution, filter geometry; operational parameters include flow rate, flux, intermittent or continuous flow, length of filter run, factors influencing fouling or clogging, filter media cleaning procedures and cycles, and vulnerability to by passing filter medium (faulty filter element seals and other failures of filter element integrity)
Granular media filters	Turbidity, temperature, pH, contact time, filter surface chemistry, dissolved and colloidal constituents, filter bed geometry, hydraulic residence time and flow profile (e.g. extent of plug flow or short circuiting), and extent of biological activity on filter media particles or on filter bed surface; operational parameters include flow rate, flux, intermittent or continuous flow, length of filter run, filter media cleaning procedures and cycles
Solar disinfection	Incident solar radiation, aids to solar energy capture (e.g. solar reflectors), temperature, time, dissolved oxygen in water, turbidity or suspended matter; UV absorbing dissolved constituents in water and UV penetrability of container walls, soluble constituents subject to sunlight-induced chemical changes that modulate antimicrobial activity (e.g. photo-Fenton reactions) and metallic oxide or other particulate additives or coatings intended to increase disinfection efficiency.
UV light (lamp/ light-emitting diode) technologies	Intensity of incident radiation (mW/cm2) and delivered UV fluence or dose (mW·s/cm2), UV wavelengths in the germicidal range, exposure time, dissolved oxygen, turbidity or suspended matter (measured as transmittance or absorbance), dissolved constituents or solutes (that absorb UV energy or alter its reactivity with target microbes)
Thermal technologies	Temperature, exposure time, dissolved or suspended constituents that protect or physically stabilize or chemically protect microbes (e.g. clays and proteins)

Coagulation, precipitation and/or sedimentation	Type (chemical properties) of coagulant or precipitant, chemical dose, contact time, pH, mixing (conditions for coagulation flocculation or precipitation), settling conditions for sedimentation (static; no mixing), turbidity or suspended matter, dissolved solutes (organic and inorganic), particle sizes and vessel geometry
Combination (multibarrier) approaches or other emerging technologies	Combinations of the above variables and conditions, depending on which chemical and physical treatment methods are used together or in series

2.3 Performance Evaluation Guidelines for Household Water Treatment Options

Quality of drinking water depends mainly on the microbial safety. From the source to the consumer, the pathogenic contamination can be happen at multistage and affects the quality of the water. So there should have some combined approaches to treat the pathogenic contamination and increase the safety by reducing the entry of pathogens. In general terms, the greatest microbial risks are associated with ingestion of water that is contaminated with pathogenic bacteria, viruses, protozoa and helminthes.

To ensure safe water, World Health Organization (WHO) proposes different treatment mechanisms based on country specific settings. Organizations and NGOs developed their own mechanisms and techniques to purify drinking water against pathogenic threat. Different source water including pipe water and other supply water are no longer safe due to various contamination in intermediary stages; household water treatment (HWT) is becoming a point of concern for public health safety (UNICEF & WHO, 2009). For household level treatment, point of use (POU) treatment is very effective against contaminated source water. WHO has specified HWT and POU as synonymous mechanisms. It has stated that- for the purposes of treating water at the household level or at the point of use in other settings, such as schools, health-care facilities and other community locations, a range of technologies, devices or methods can be employed which will be termed as household water treatment (HWT) or point of use (POU) treatment (WHO, 2011b).

2.3.1. Log Reduction Value (LRV)

In evaluating microbial effectiveness of any technology, Log Reduction Value (LRV) or log10 reduction is used to define the reduction potential of the technology. LRV is a simple logarithmic mathematical tool which is evaluated in microbe concentration in comparison to the source water quality. Generally LRV means the logarithmic reduction of microbes used to show the relative number of live microbes eliminated from a surface by disinfection or cleaning.

The determination of LRV is simply noted as follows: log10 reduction (LRV) = (C untreated water / C treated water), where C = microbe concentration in water.

All the standards and guidelines mention performance evaluation of any water treatment technology through LRV. So in performance testing, until epidemiological data are obtained and/or where epidemiological studies may not be practical or appropriate, experimental options must be used to verify through control measures in a wide variety of settings based on log10 reduction (LRVs) (WHO, 2011b). So it can be exemplified as follows:

1. 1 log10 reduction (LRV) is equal to 90 % reduction; 2- log10 reduction equals 99 %; 3-log reduction equals 99.9 % and so forth. A requirement of 5- log10 reduction, or 99.999 %, is a much stricter than 2- log10 reduction or 99%.

2. A technology which can be effective against bacteria by 5 log10 reduction, that means lowering the number of microorganisms by 100,000-fold, or

3. If water contains 100,000 pathogenic microbes in it, a 5- log10 reduction would reduce the number of microorganisms to one.

To evaluate any technology, it should demonstrate the reduction potential against three important organisms of disease that is bacteria, virus and protozoa. So for evaluation, LRV has to be calculated based on the reduction of specific organisms.

Globally different countries and organizations developed their own set of guidelines or standards to accommodate the evaluation of treatment facility based on their preferences and demands. Table 2.6 provides a list of different standards and their recommended LRV for water treatment technologies.

2.3.2. Targeted Pathogens

In practice, there are two basic criteria for evaluation of any technology against organisms. First, those technologies which can show efficiency against bacteria only. Second, those technologies which is efficient against all three kinds of pathogens: bacteria, viruses and protozoan cysts or spore forming bacteria.

The selection of organisms were based on some of the following criteria mentioned in WHO guideline (WHO, 2011b) which states-

- The reference pathogens for bacteria, viruses and spore forming bacteria or cysts were selected based on their relative characteristic, high public health importance and conservativeness with respect to dose response and infectivity. In other words, if treatment options were in place to control these reference pathogens, there would be the expectation that other important pathogens within each class of pathogen would also be controlled.

- Separate individual treatment units should be used for effectiveness testing against each separate microbe (e.g. Escherichia coli, coliphages, Clostridium perfringens spores) to prevent any interaction between these microbes that could potentially influence the validity of the treatment performance and test microbe assays.

- The choice of target microbes is an important consideration in technology verification studies. It is preferable to do such studies with the microbes that are known to be present in the source water and pose the highest waterborne disease burden. If the important waterborne pathogens are not known or studies with the known, relevant pathogens are not possible, it is recommended that test challenge waters be spiked with sufficient concentrations of indicator bacteria, viruses and spore forming bacteria to follow the extent and possibly the kinetics of inactivation over time.

The WHO recommended indicator bacteria, viruses and spore forming bacteria are, respectively, Escherichia coli, bacteriophages of E. coli and spores of either Clostridium perfringens or Bacillus spp. to document log10 reductions of treatment technologies. Different performance evaluation studies were done using these indicator organisms to understand the potential of microbial effectiveness of those technologies against contamination in India, Cambodia and other countries. (Brown et al., 2012; Bhathena et al., 2013; Bhathena et al., 2014)

2.3.3. Specific Performance Target for Each Organism

WHO (2011b) has mentioned three recommended levels of performance for the technologies to reduce bacteria, viruses and protozoa or spores are illustrated in Table 2.7.

Table 2.4. Criteria of Log10 reduction for technologies to establish health-based HWT performance targets

TARGET	Log_{10} reduction required: Bacteria	Log_{10} reduction required: Virus	Log_{10} reduction required: Protozoa
Highly protective	**≥ 4**	**≥ 5**	**≥ 4**
protective	**≥ 2**	**≥ 3**	**≥ 2**
Interim*	**Achieves "protective" target for two classes of pathogens and results in health gains**		
* Treatment options classified as "interim" should be recommended only when credible epidemiological evidence indicates that use of such devices results in reductions in waterborne disease.			

These range from a top tier target "highly protective" reference level of risk of 10−6 DALY per person per year to a bottom tier, "interim" target relevant to the performance of currently available, low cost technologies that have demonstrated health improvements.

The top tier standard of "highly protective" represents those technologies that, if used correctly and consistently over an entire year, will limit drinking-water disease burden to 10−6 DALY per person. This is an extremely conservative health based target and from a health perspective, such technologies should be unequivocally recommended for use.

The second tier, "protective", has been established to allow for a less stringent level of tolerable disease excess, yet is still consistent with the goal of providing high-quality, safer water. The "protective" target defines pathogen removals that achieve a health-based target of 10−4 DALY per person per year. In areas with a suspected high burden of waterborne disease, technologies that meet the log removal standards in the second tier would still result in significant health benefits. Both the "highly protective" and "protective" targets are based on the removal of all three classes of pathogens.

Highly protective and to a lesser extent, protective targets are conservative and that achievement of these targets may not be the most cost effective or achievable option in some situations, an "interim" target has been set. The "interim" target applies to those technologies that achieve "protective" removal targets for two classes of pathogens and have a proven impact on reducing diarrhoeal and waterborne infections. Achievement of this lower tier target should be seen as an initial step in an effort to incrementally improve towards the ultimate target of "highly protective".

CHAPTER 3: METHODOLOGY

3.1. General.

The experiments conducted for testing different HWT technologies were conducted over a span of ten weeks in the IUT Environmental Laboratory. Each of the experiments were conducted according to World Health Organization guideline for drinking water. This chapter describes in details the different procedures and methodologies implemented to perform the experiments.

3.2. Preparation of Escherichia Coli (E.Coli) and Spiking

E.Coli was prepared in the same way for determining efficiencies of different HWT technologies tested in the experiment. The *E.Coli* used throughout the experiment was obtained from Environmental Microbiology Laboratory of International Centre for Dirrheal Disease Research, Bangladesh (icddr,b), Dhaka. The sample strain was sub-cultured using MacConkey agar. The prepared culture was incubated at 37°C for 24 hours. Colonies were isolated and sub-cultured in mTEC agar medium. Then it was incubated at 37°C for 2 hours and followed by 44°C for 18 – 24 hours. One step and one medium method using modified mTEC agar was used for differentiation and enumeration of E.Coli. This method was recommended by method 1603 published by the EPA in 2002. [dll version method 1603:E.Coli].

A fresh culture of E.Coli ATCC 25922 that were grown on mTEC agar over night was used to prepare a suspension of E.Coli in normal saline. Using drop plate technique 100 µl of diluted suspension was cultured. The E.Coli was measured and found to be in the range of 10^6-10^7 CFU/100 ml. The saline was stored at around -15°C and before spiking they were placed in water bath in order to lower the temperature of the saline to room temperature.

3.3. Ceramic Water Filters (CWF)

Market survey and Filter Selection:

Popular markets in the Gazipur region were surveyed for popular CWFs. Three of the most widely used filters were chosen based on popularity, filtration capacity and ease of set-up. The brands selected were 1) Miyako 2) Nova and 3) JCL. Basic properties of the three selected brand of filters are shown in the table below (as per manufacturers claim):

Table 3.1. Information of selected brands for Lab Testing

Brand Name	Pore size	Effective lifetime	Claimed Capacity
Miyako	0.2-0.5 micron	2 years	Upper compartment – 11 liters Lower compartment – 21 liters
Nova	0.6-1 micron	No mention	Upper compartment – 11 liters Lower compartment – 21 liters
JCL	0.5-1 micron	No mention	Upper compartment – 11 liters Lower compartment – 20 liters

3.3.1. Filter installation and set-up

At least two filters should be used for the same challenge water in order to determine performance reproducibility and identify any variations in results (WHO 2011). The favorable filters were purchased and transported to the laboratory. Before handling the filters hands were rinsed with alcohol in order to reduce chances of secondary contamination. The filters were at first thoroughly washed with tap water to remove any dust particle. Two setup of filters were arranged corresponding to two types of test water. All of the filters were to be tested for bacteria removal efficiency. In addition the physicochemical parameters of both influent and effluent waters were also to be measured.

Two additional filters were assigned as negative control filters for the two different types of test waters. Spiking was not performed in these filters, instead were seeded with

Figure 3.1. Laboratory setup of Filters

autoclaved wastewater in type 2 test water. This setup will enable us to determine the possibility of secondary contamination in the occasion that results yield bacterial counts in test waters from the negative control filters. The filters were arranged as shown in order to enable ease of sampling and performing the experiments.

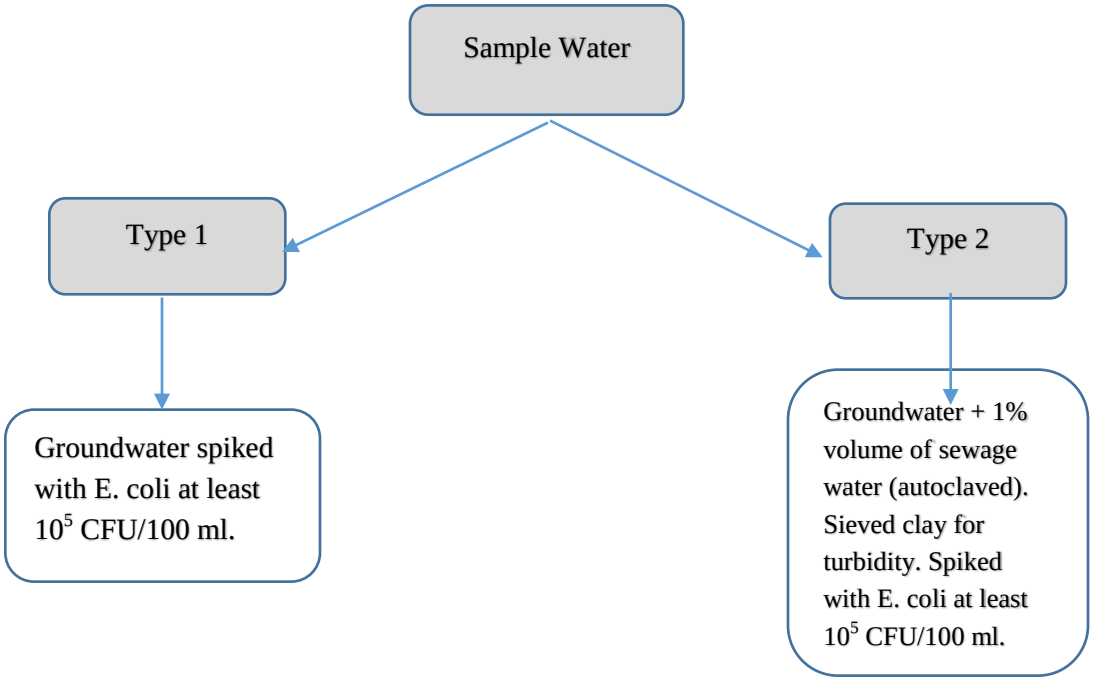
3.3.2. Test Waters

According to WHO guideline for drinking water two types of water should be used for control experiments of HWT technologies.

Table3.2. Types of water to be tested according to WHO guideline (WHO, 2011b)

	Test Water 1	**Test Water 2**
Description	High-quality groundwater, surface water, caught (newly harvested) rainwater or other water free of disinfectant residual	High-quality groundwater, surface water, rainwater or other water free of disinfectant residual with 20% by volume primary wastewater effluent or 1% by volume untreated raw sewage, sterilized or pasteurized.
Turbidity	< 5 NTU	> 30 NTU
pH	7.0-9.0	6.0-10.0
Temperature	20°C ± 5°C	4°C ± 1°C

Figure3.2. Preparation of test water.



3.3.3. Steps of preparation of the two types of test waters.

Type 1 water:

Water is supplied in IUT by means of a piped system with groundwater as the source. For the experiment, water was collected from taps in the laboratory and then they were spiked with E.Coli bacteria by ensuring a count of 10^5 CFU/100 ml.

Type 2 water:

Tap water is mixed with 1% by volume of autoclaved sewage water according to WHO guideline for drinking water. Type 2 water requires a turbidity of more than 30 NTU which is incorporated into the water by adding sieved clay. It is then spiked with 10^5 CFU/100 ml of E.Coli bacteria.

Figure 3.3.1. Autoclaved waste water for preparing type 2 water

Figure 3.3.2. Clay preparation for obtaining turbidity in Type 2 water

Table 3.3. Volume of waste water added to different brands of filter

Brand Name	Claimed Capacity	1% by volume wastewater
Miyako	Upper compartment – 11 liters	110 ml
Nova	Upper compartment – 11 liters	110 ml
JCL	Upper compartment – 11 liters	110ml

3.3.4. Sample Preparation

- ***Turbidity:*** Clay is used to instill turbidity in the water sample. This clay taken from a sample of undisturbed soil sample of Dhaka-Chittagong highway in the

Geotechnical Laboratory. The sample was obtained from below 30 m. This sample was sieved in a 200 mm sieve [ASTM. *ASTM D 6913 – 04 (2009)]* to obtain clay.

- ***Sewage water:*** Water was collected from raw sewage line and then autoclaved for 24 hours for sterilization. One percent by volume was then used for different filters during the experiment. (WHO)
- ***E. coli:*** The E. coli strain was obtained from the International Centre for Diarrheal Disease Research Bangladesh (ICDDRB) which was cultured on mTEC medium by streak plate procedure. One loop of E. coli was mixed in sterilized .85% normal saline (pH: 7.8-8.0) of 500 ml and well shaken in order to obtain the initial concentration that were spiked into the sample water. Then the E. coli solution was stored under 4^0 C. The concentration of E. coli in this solution is 2.2 X 10^7 CFU/100 ml.

3.3.5. Flow Rate Measurement

The rate of water flow from the upper to lower compartment is measured everyday on an hourly basis. Measurements were taken for all of the filters. Nova and Miyako can accommodate 11 liters while JCL can accommodate 8 liters (Table). Each of the filters were calibrated to facilitate the measurement of water level. (Figure) The flow rate was measured by the formula:

Flow Rate = Volume passed from upper to lower compartment (L)/ Time taken (hrs)

This measurement was taken on a regular basis to determine the change in flow rate with the passage of time and also identify any relationship between bacteria removal and flow rate of filters. The data obtained were recorded for further analysis.

3.3.6. Sampling

The samples were analyzed on a weekly basis by taking samples from both the upper and lower compartments. According to guideline samples for determining E.Coli removal was collected at 0%, 25%, 50%, 75% and 100% of total water passage. We had anticipated a total of 1000 liters of water to be passed. The samples were carefully collected and analyzed following the recommendations of EPA 2002. The physicochemical parameters were also measured for each water sample collected from upper and lower compartments of all of the filters. Two additional filters were introduced for water type 1 and water type 2 as negative control filters to check for secondary contamination. Water samples were collected and various tests were performed within 2 hours of collection. Physicochemical parameters were measured and recorded for all the samples (pH, turbidity, electric conductivity and color) by standard procedure. In order to facilitate data collection and analysis all of the filters were labelled. (Table)

Table 3.4. Filter and Sample ID

Water Type	Brand Name	Filter ID	Sample ID
Type 1	JCL	J-1	J-1-1, J-1-2
Type 2	JCL	J-2	J-2-1, J-2-2
Type 1	NOVA	N-1	N-1-1, N-1-2
Type 2	NOVA	N-2	N-2-1, N-2-2
Type 1	MIYAKO	M-1	M-1-1, M-1-2
Type 2	MIYAKO	M-2	M-2-1, M-2-2

Each of the filters is assigned an ID. JCL, MIYAKO and NOVA were assigned IDs of J, M and N respectively. They were further subdivided with respect to the compartment from which the water was taken. For instance N-1 indicates water from NOVA upper compartment and N-2 indicates water from NOVA lower compartment. Again further categorization was done based on test water type. Hence N-1-1 indicates water from NOVA upper compartment and of water type 1.

3.4. Chlorination

Chlorination was performed in the laboratory under controlled conditions. According to WHO guideline chlorination should be tested with type 1 water. A chlorine stock solution was prepared by administering 2 mL of standard 0.1N chlorine solution to 500 mL of water to yield 86 mg/L Total Chlorine. This stock solution was used to administer varying concentrations of chlorine for testing. The formula $S_1\ V_1 = S_2 V_2$ was used to determine the volume requirements to produce desired concentration of chlorine solution. 500 ml distilled water is taken in a beaker, 1.40 ml E.Coli solution was added to it. Initial bacterial count was taken before adding chlorine. A total of 5 readings were taken within a period of 20 minutes. The chlorine dose was varied for every experiment (0.05, 0.1, 0.2-1.0 mg/L). 20 ml of sample water was collected at every determined time points for each chorine dosage. 10 ml was used to measure residual chlorine and other physicochemical parameters. 10 ml was used for filtering in order to test for bacteria. (Discussed in) Residual chlorine had to be measured continuously during the span of the experiment. The residual chlorine and bacterial counts for t = 0, 2, 5, 10, 15 and 20 mins were measured. According to WHO guideline**,** after treatment water may have a residual chlorine of 0.2 – 1 mg/L. It also requires several parameters to be monitored: water quality, chemical dose, contact time, temperature and type of mixing.

3.5. Coagulation and Sedimentation

In water treatment, coagulation is a process that occurs when a coagulant is added to water to “destabilize” colloidal suspensions. It is a chemical process that involves neutralization of charge. However its effectiveness in removing bacteria from water meant for drinking

Figure 3.4. Coagulation and Sedimentation experiment in Laboratory

in households needs to be evaluated. In testing this option of HWT technology standard 500 ml beakers were used. Six 500 ml beakers were labelled at first according to the amount of coagulant dosage being administered. They were filled up to 500 ml with type waters 1 and 2 in separate experiments. For each water type varying volumes of the coagulant was used to detect changes in microbiological and physicochemical properties of the water. Each sample was spiked with 1.4ml of E.coli stock solution. 0.1 N of standard alum solution was used as the coagulant throughout the experiment. Different volumes were added in different beakers according to labelling. The dosage were 0.5, 1, 1.5, 2, 2.5, 3, 4, 5, 6, 7, 8 ml. Then the beakers were placed in the coagulator and were stirred at a certain rpm. At first they were mixed at 100 rpm for 2 minutes and followed by 40 rpm for 10 minutes. After being thoroughly stirred they were allowed to settle for 20 minutes. Samples were taken from each of the beakers after the experiment. These samples were tested for bacterial removal (E.coli) and physiochemical parameters (turbidity, pH, temperature) were measured and recorded.

3.6. Ultraviolet Radiation

Ultraviolet (UV) technology has gained a lot of attention and popularity due to its effectiveness in disinfection applications (Crawford et al. 2005, Bowker et al. 2011). We conducted our experiment by considering two types of water according to WHO guideline (WHO, 2011b). Both the water were taken in two separate water container with water tape. Then they were spiked with 7x10^5 cfu/100ml of E. coli. After spiking we contacted them

Figure 3.5. UV experiments and the electric ballast of UV lamps

with a 6W UV (254 nm) lamp each. They were given UV radiation for 40 minutes. The sample were taken in every 5 minutes interval. Then the microbiological and physic-chemical tests were conducted.

3.7. Bacteria Testing

For all of the HWT technologies tested the same bacteria testing method was implemented. Sample waters of 250 ml were taken from each source and subjected to the membrane filtration technique (Figure). 10 ml of each sample was filtered through filter papers having pores of 0.45 µm (Sartorious Stedim, Gottingen, Germany). After filtration the filter paper was placed in a broth made from Bactoagar and Emendo produced in a petri dish. This was then placed in an incubator at 37°C for 24 hours. *E.Coli* colonies

have a characteristic magenta color which makes it possible to count the total number of colonies with the naked eye. Following the incubation period total number of colonies of *E.Coli* is counted and recorded for each of the samples. At certain instances the number of bacteria colony was too large to be counted. To avoid such cases serial dilution was carried out before conducting the membrane filtration technique for counting bacteria. The bacteria was recorded as CFU/100ml and it was maintained at greater than 10^5CFU/100 ml. (Mwabi et., al 2011)

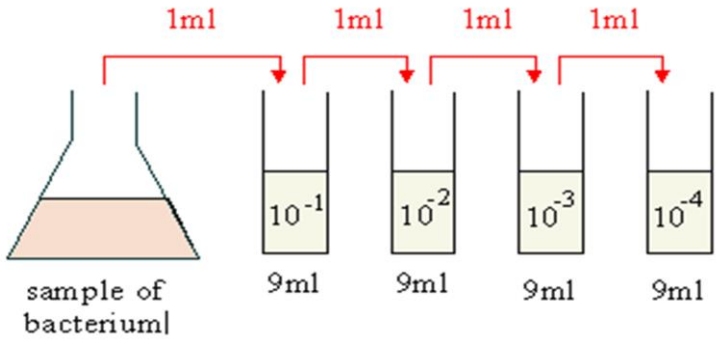


Figure 3.6. Serial dilution process

A minimum of five serial dilutions were required to obtain colonies that could be counted.

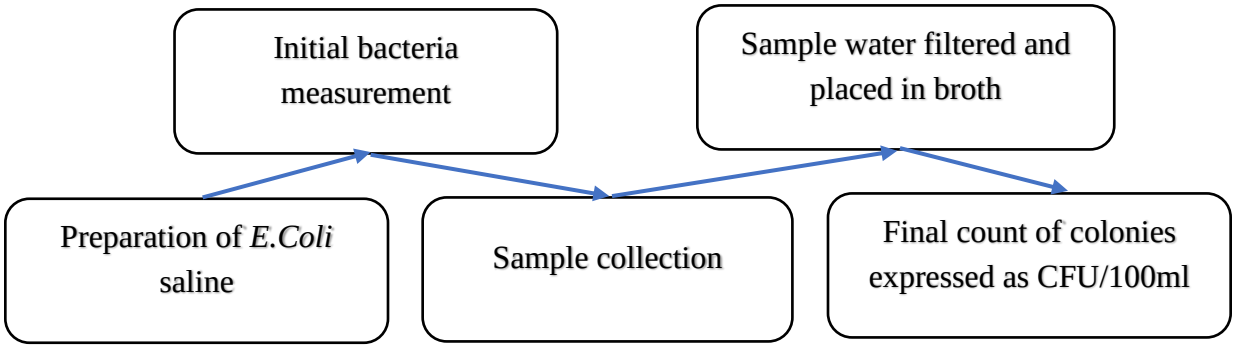


Figure : 3.7. Flow diagram of *E.Coli* measurement.

Figure 3.8. E. coli measurement

3.8. Physic-Chemical Testing

Four physic-chemical parameters namely pH, turbidity, color and electric conductivity were measured for both feed and filtered water. Also the temperature of the laboratory was tried to maintain according to the field condition. The following methods were used to evaluate these parameters.

3.8.1. pH

pH was measured by a calibrated HACH® pH meter (HACH sensION+ PH31).

3.8.2. Turbidity

Turbidity measurement was performed using proprietary nephelometric instrument. Turbidity is expressed as Nephelometric Turbidity Units (NTU). The apparatus used for turbidity evaluation is HACH® series portable turbidimeter (HACH 2100Q).

3.8.3. Color

Laboratory based apparatus HACH® Spectrophotometer (HACH DR2800) was used to determine color concentration. Color is usually expressed in platinum-cobalt (pt.co units) which is based on the intensity of color.

3.8.4. Electric Conductivity

Electric conductivity was tested using a calibrated HACH® conductivity probe (HACH CDC40101). Electric conductivity is expressed as micro-siemens/cm

Figure 3.9. Different instruments for physic-chemical testing

Chapter 4: Performance of the HWT technologies under laboratory tests.

4.1. General

The laboratory tests were performed by abiding by the WHO guideline for HWT technologies. In the experiments three different brands of filters were used for testing the ceramic water filters. Standard procedures were followed for testing coagulation, chlorination and UV radiation methods. The results of these experiments are outlined in this section followed by conclusion based on WHO protocol.

4.2. Ceramic Water Filter

4.2.1. Flow Rate Analysis

Experiments on the chosen filters were conducted over a span of twelve weeks with the aim to pass a total volume of 1000 liters by each of the eight filters. Filtration data obtained for all of the filters have been reported in Appendix. A total of five points (0%, 25%, 50%, 75% and 100%) were determined to collect bacteriological data for analysis. Table shows the average filtration volume of each sample. The percentage of water passed is also shown. The average values were taken for both type 1 and type 2 water together.

Table4.1. Volume of water flowing for Type 1 water through different filters.

Sampling (days)	JCL (L)	NOVA (L)	MIYAKO (L)	NEGATIVE (L)
0	0	0	0	0
12	248 (24.8%)	252 (25.2%)	240 (24%)	236 (23.6%)
23	464.6 (46.4%)	473.8 (47.4%)	460 (46%)	460 (46%)
34	689.7 (68.97%)	689.7 (68.97%)	670.3 (67.03%)	675.14 (67.51%)
46	935.33 (93.53%)	925.1 (92.51%)	908 (90.8%)	904.67 (90.5%)

Table.4.2. Volume of water flowing for Type 2 water through different filters.

Sampling (days)	JCL (L)	NOVA (L)	MIYAKO (L)	NEGATIVE (L)
0	0	0	0	0
12	244 (24.4%)	240 (24%)	236 (23.6%)	244 (24.4%)
23	473.8 (47.4%)	460 (46%)	455.4 (45.54%)	450.8 (45.1%)
34	684.85 (68.5%)	660.57 (66%)	669.3 (66.93%)	646 (64.6%)
46	920 (92%)	874 (87.4%)	904 (90.4%)	858.67 (85.7%)

Initially it was determined that measurements would be taken at 0%, 25%, 50%, 75% and 100% of volume of water passage. It was planned to pass a total of 22 liters of water every day and dates for obtaining readings were calculated with respect to this plan. Readings were taken at 0, 12, 23, 34 and 46 days from the beginning of the experiment respectively. However due to variations in flow rate the total volume of 1000 liters could not be filtered in the experiment duration as shown in the tables above. It can be observed that total water volume passing through for Type 1 water is greater than that of the Type 2 water. This due to difference in water qualities of Type 1 and Type 2 with Type 2 water containing clay for turbidity. This may be due to blocking of pore spaces by the suspended particles that caused the pore space of filters to be reduced ultimately resulting in a reduction of flow rate as compared to Type 1 water. Filters that were set up for Negative Control experiment also showed similar behavior for the two types of test water with 90.5% of water volume flowing for Type 1 and 85.7% of water volume flowing for Type 2 water.

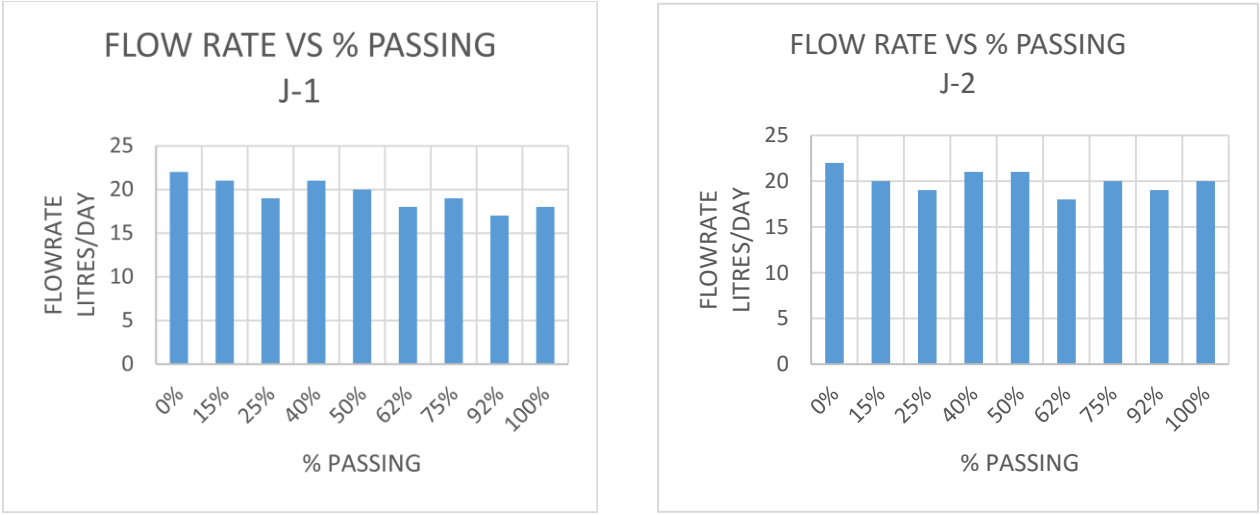
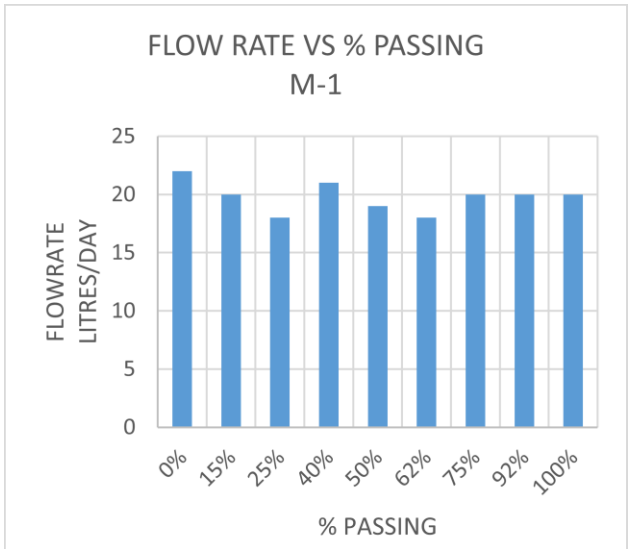
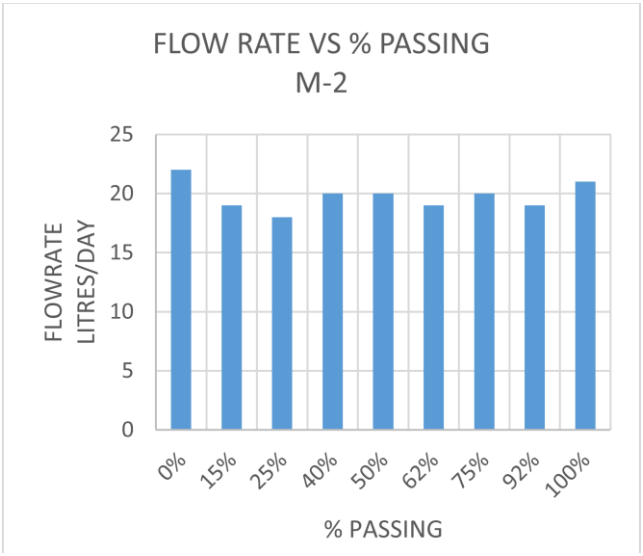
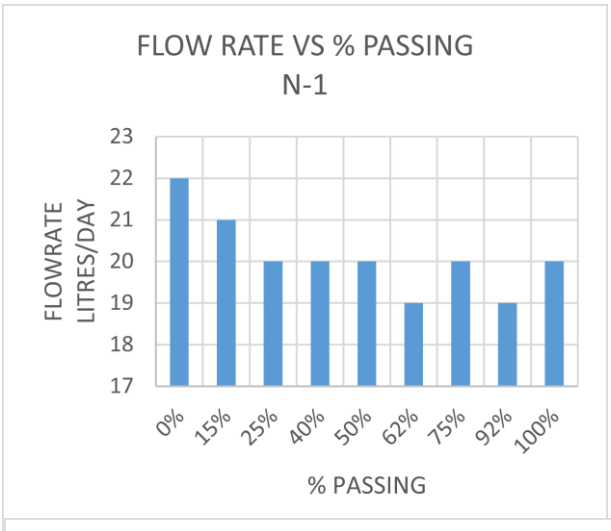
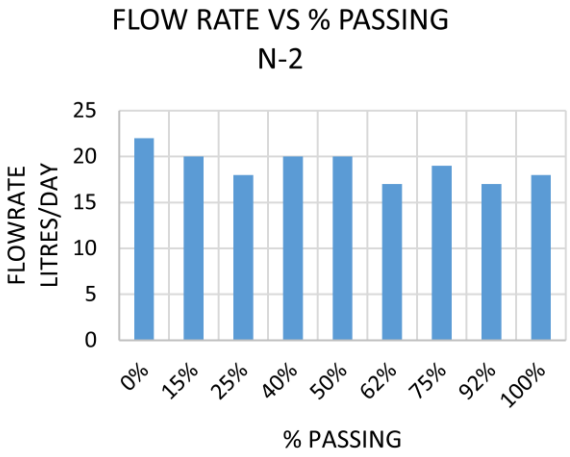


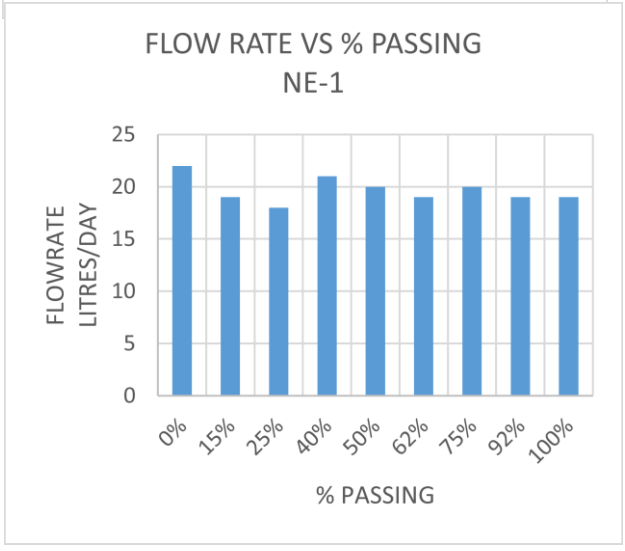
Figure 4.1. Flow rate VS % passing











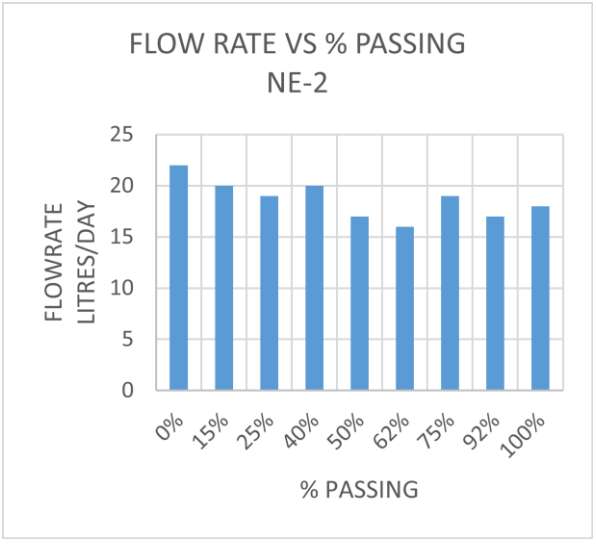


Figure 4.1. Flow rate VS % passing

The graphs represent flow rate (L/day) vs. different percent volumes of water passing through the filters. All of the filters follow a common trend in the filtration rate. It has been observed that the filtration rate is maximum at first which then decreases till 25% of total water volume. The flow rate rises again but the value is lower than the initial rate. It decreases again till 62% of water volume and rises again to value lower than the reading obtained at 40% flow of water. The value decreases again till 92% of water which then rises during the last reading taken at 100% of water flow.

The decrease in flow rate occurs due to shrinking of pore sizes of ceramic filters over time as more suspended particles accumulate in the pore spaces. Cleaning of the filters were done after measurements were taken at 25%, 62% and 92%. Due to cleaning the pore spaces were cleaned which caused an increase in the filtration. However the original filtration rate was not obtained showing an effect on the filters. This is due to permanent block of several pore spaces by the suspended water particles present in both Type 1 and Type 2 water. Similar patterns were observed for each time the filters were cleaned. The initial filtration rate could not be retained showing a gradual decline in filtration rates over time.

4.2.2. Physic-Chemical Outcome

Several physic-chemical parameters like pH, color, turbidity and EC were examined of the feed and filtered water during the experiment period. shows the physic-chemical data of the water obtained from this control experiment.

Groundwater was used as a source of the water which we used throughout the experiment as feed water. It is a good source of mineral content with low organic content. However the added wastewater can add colloidal and organic substance which causes variations in the physic-chemical parameters. When Type 1 water was used in JCL (J-1) it had a mean pH of 7.68 and after filtration the mean pH was 8.12. There was an increase in pH of the water which may have been due to materialistic properties of the minerals and stones which rendered the water alkaline upon contact. The same pattern was observed for Myako (M1) (mean pH 7.36 for feed water and pH 7.99 for the filtered water), Nova (N1) (mean pH 7.57 and pH 8.10 of feed water and filtered water respectively), Negative (Ne1) (mean pH 7.64 and pH 8.07 of feed water and filtered water respectively). The trend was true also for the negative control which indicated that the increase in

pH was a phenomenon induced by the materials of the filter. The mean pH of feed water was 7.56 and the mean pH of filtered water was 8.07. In Type 2 water a similar pattern was observed. The mean pH was 7.57 for feed water and for filtered water it was 8.09. When JCL (J-2) was tested with Type 2 water the mean pH of feed water was 7.46 and filtered water was 8.07. Similarly for Myako (M-2) (mean pH of feed water was 7.67 and filtered water was 8.07), Nova (N-2) (mean pH of feed water was 7.54 and pH 8.11 of filtered water), Negative (Ne-2) (mean pH of feed water was 7.61 and for filtered water pH was 8.09).

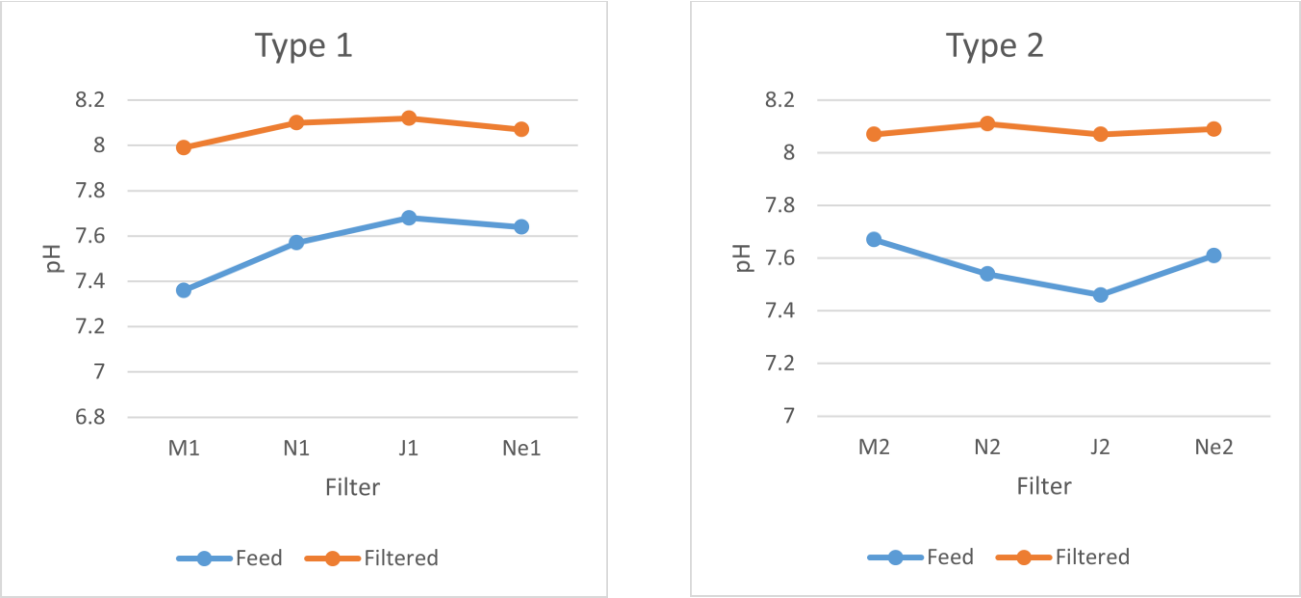


Figure 4.2. Mean pH in different filters

In terms of color it was observed that it decreased after filtration. For Type 1 water JCL (J1) (mean color 55 pt-co for feed water and 41.88 pt-co for the filtered water), Myako (M1) (mean color 43.44 pt-co and 34.55 pt-co of feed water and filtered water respectively), Nova (N1) (mean color 134.33 pt-co and 30.77 pt-co of feed water and filtered water respectively). The trend was true also for the negative control which indicated that the decrease in color was a phenomenon induced by the materials of the filter. The mean color of feed water was 77.59 pt-co and the mean color of filtered water was 35.73 pt-co. In Type 2

water a similar pattern was observed. The mean color was 309.83 pt-co for feed water and for filtered water it was 40.55 pt-co.

When JCL (J-2) was tested with Type 2 water the mean color of feed water was 294.89 pt-co and filtered water was 52.67 pt-co. Similarly for Myako (M-2) (mean color of feed water was 404.22 pt-co and filtered water was 40.11 pt-co), Nova (N-2) (mean color of feed water was 434.22 pt-co and 17.88 pt-co of filtered water), Negative (Ne-2) (mean color of feed water was 106 pt-co and for filtered water color was 51.55 pt-co).

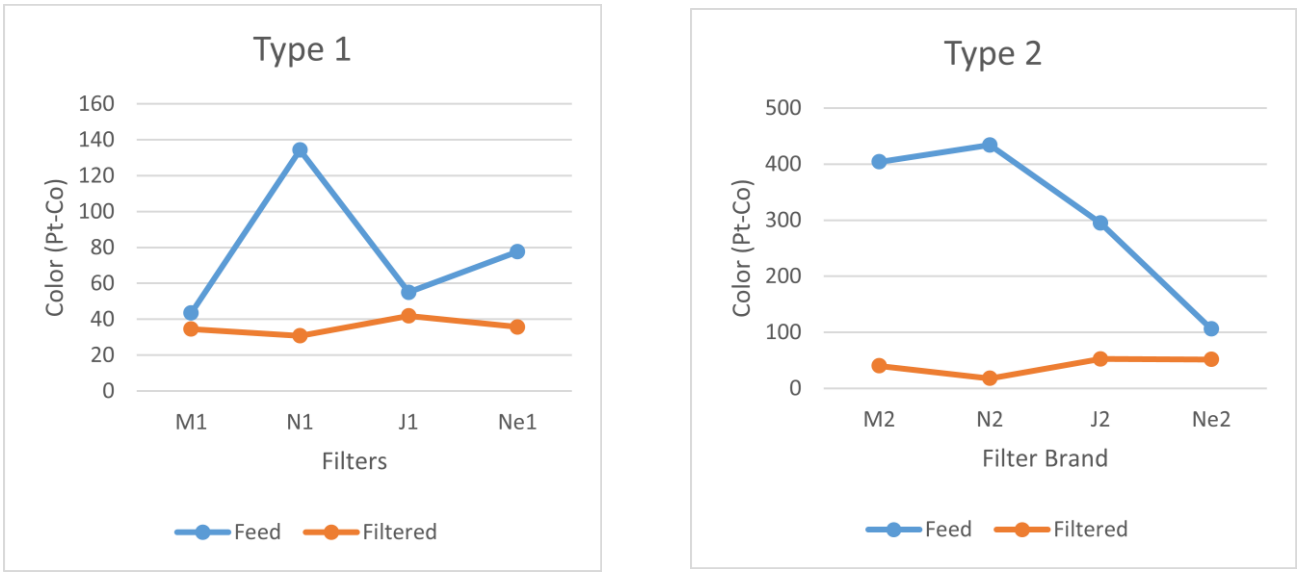


Figure 4.3. Mean color in different filters

In terms of turbidity it was observed that it also decreased after filtration. For Type 1 water JCL (J1) (mean turbidity 1.95 NTU for feed water and .534 NTU for the filtered water), Myako (M1) (mean turbidity 2.51 NTU and .76 NTU of feed water and filtered water respectively), Nova (N1) (mean turbidity 4.51 NTU and 1.29 NTU of feed water and filtered water respectively). Negative (Ne1) (mean Turbidity 5.21 NTU and .761 NTU of feed water and filtered water respectively) For Negative control The trend was true also for the negative

control which indicated that the decrease in turbidity was a phenomenon induced by the materials of the filter. The mean turbidity of feed water was 3.545 NTU and the mean turbidity of filtered water was .845 NTU.

In Type 2 water a similar pattern was observed. The mean turbidity was 43.41 NTU for feed water and for filtered water it was 1.001 NTU. When JCL (J-2) was tested with Type 2 water the mean turbidity of feed water was 48.03 NTU and filtered water was 1.597 NTU. Similarly for Myako (M-2) (mean turbidity of feed water was 46.02 NTU and filtered water was .969 NTU), Nova (N-2) (mean turbidity of feed water was 41.48 NTU and .698 NTU of filtered water), Negative (Ne-2) (mean turbidity of feed water was 38.11 NTU and for filtered water turbidity was .743 NTU).

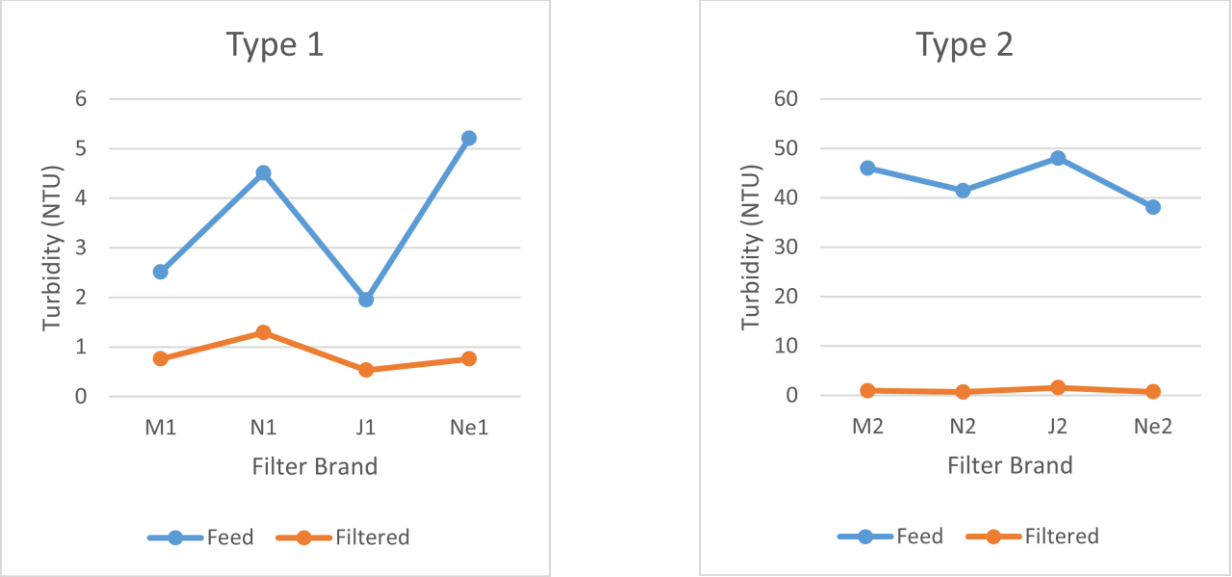


Figure 4.4. Mean turbidity in different filters

In terms of Electric Conductivity it was observed that it also decreased after filtration. For Type 1 water JCL (J1) (mean EC 1.95 NTU for feed water and

.534 NTU for the filtered water), Myako (M1) (mean EC 2.51 NTU and .76 NTU of feed water and filtered water respectively), Nova (N1) (mean EC 4.51 NTU and 1.29 NTU of feed water and filtered water respectively). Negative (Ne1) (mean EC 5.21 NTU and .761 NTU of feed water and filtered water respectively). The mean EC of feed water was 3.545 NTU and the mean EC of filtered water was 0.845 NTU.

In Type 2 water a similar pattern was observed. The mean EC was 43.41 NTU for feed water and for filtered water it was 1.001 NTU. When JCL (J-2) was tested with Type 2 water the mean EC of feed water was 48.03 NTU and filtered water was 1.597 NTU. Similarly for Myako (M-2) (mean EC of feed water was 46.02 NTU and filtered water was 0.969 NTU), Nova (N-2) (mean EC of feed water was 41.48 NTU and 0.698 NTU of filtered water), Negative (Ne-2) (mean EC of feed water was 38.11 NTU and for filtered water EC was .743 NTU).

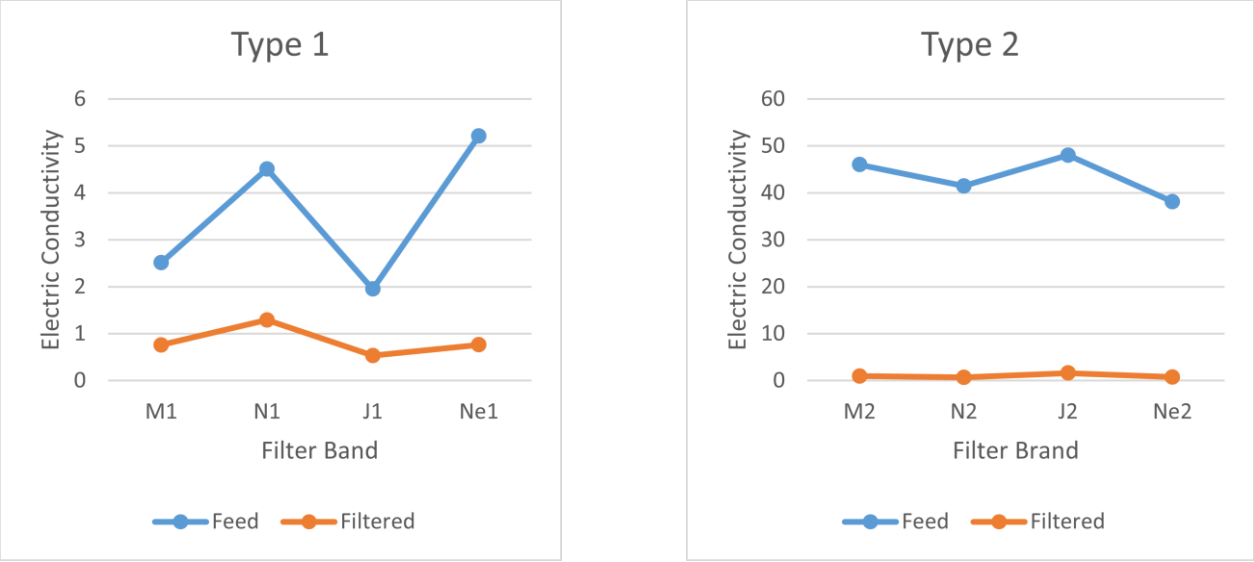


Figure 4.5. Mean electric conductivity in different filters

Avg. Color *(Pt-Co)*	**Feed**	**Filtered**	**% Reduction**
M1	43.44	34.55	20.46500921
N1	134.33	30.77	77.09372441
J1	55	41.88	23.85454545
Ne1	77.59	35.73	53.95025132
Avg. Turbidity *(NTU)*	**Feed**	**Filtered**	**% Reduction**
M1	2.51	0.76	69.72111554
N1	4.51	1.29	71.39689579
J1	1.95	0.534	72.61538462
Ne1	5.21	0.761	85.39347409
Avg. EC	**Feed**	**Filtered**	**% Reduction**
M1	2.51	0.76	69.72111554
N1	4.51	1.29	71.39689579
J1	1.95	0.534	72.61538462
Ne1	5.21	0.761	85.39347409

Table 4.3. Percentage reduction of various parameters for Type 1 water.

Color (Pt-Co)	Feed	Filtered	% Reduction
M2	404.22	40.11	90.07718569
N2	434.22	17.88	95.88227166
J2	294.89	52.67	82.13910272
Ne2	106	51.55	51.36792453
Turbidity (NTU)	**Feed**	**Filtered**	**% Reduction**
M2	46.02	0.969	97.89439374
N2	41.48	0.698	98.31726133
J2	48.03	1.597	96.67499479
Ne2	38.11	0.743	98.05038048
EC	**Feed**	**Filtered**	**% Reduction**
M2	46.02	0.969	97.89439374
N2	41.48	0.698	98.31726133
J2	48.03	1.597	96.67499479
Ne2	38.11	0.743	98.05038048

Table 4.4 Percentage reduction of various parameters for Type 2 water.

4.2.3 Log Reduction Values (LRV) and percentage removal of bacteria.

For calculating the log reduction values of all of the filters samples were taken at 0%, 25%, 50%, 75% and 100% of the duration of the experiment. Since the filters had different rates of filtration samples were taken based on time and not on volume of water flowing. It was observed that for both types of test water the LRV value was greater than 4. According to WHO guideline, **for a LRV value of greater than 4 the technology is considered to be highly protective** in terms of bacteria removal. Hence it may be concluded that the filters are highly protective.

NOVA had the highest average LRV value of 4.35, JCL had a value of 4.312 and MYAKO had a value of 4.042. These values were obtained when Type 1 water was used.

When Type 2 water used the values were 4.09, 4.04 and 4.006 for JCL, MYAKO and NOVA respectively.

LRV and percentage removals of the filters used in the experiment are illustrated in Table 4.5 and 4.6.

For the Negative Controls that were set up no counts of bacteria were observed for both Type 1 and Type 2 water. Hence it can be concluded that there were no secondary contamination during the performance of this experiment.

Table 4.5. LRV and % removal for Type 1 water.

Type 1	Sample	1	2	3	4	5	Average
M	**LRV**	4.5	4.12	4.3	3.12	4.17	**4.042**
	% Removal	99.998	99.993	99.995	99.925	99.993	**99.9808**
N	**LRV**	5.02	4	4.65	3.64	4.44	**4.35**
	% Removal	99.9999	99.99	99.998	99.977	99.996	**99.99218**
J	**LRV**	4.78	4.12	4.54	4	4.12	**4.312**
	% Removal	99.998	99.993	99.995	99.99	99.992	**99.9936**

Table 4.6. LRV and % removal for Type 2 water.

Type 2	Sample	1	2	3	4	5	Average
M	**LRV**	4.48	3.74	4.18	3.8	4	**4.04**
	% Removal	99.997	99.98	99.993	99.984	99.99	**99.9888**
N	**LRV**	4.35	3.84	4.2	3.64	4	**4.006**
	% Removal	9.995	99.986	99.994	99.977	99.99	**81.9884**
J	**LRV**	4.48	3.9	4.3	3.87	3.9	**4.09**
	% Removal	99.997	99.987	99.995	99.986	99.987	**99.9904**

4.3. Chlorination

4.3.1. Physic-Chemical Outcome

Chlorination was performed for Type 1 water only as per the guidelines of WHO for drinking water. Three different concentrations (0.02, 0.05, 0.08 mg/L) were used to test the bacteria removal efficiency. Readings were taken for a total of twenty minutes with five minute intervals (0, 5, 10, 15, 20 mins). pH, Total Dissolved Solids (TDS) and Total Suspended Solids (TSS) were measured. It was observed that the pH decreased with passage of time for every experiment. The results are represented in the Tables 4.7 and 4.8.

Table 4.7. Different values of physic-chemical parameters in chlorination for .02 mg/L concentration in different time

0.02				
TIME	PH	TEMPERATURE	TDS(20 mints)	TSS(20 mints)
2	7.35	26.5	0.217	0.248
5	7.25	26.5		
10	7.19	26.1		
15	7.1	26.6		
20	7.03	26.7		

Table 4.8. Different values of physic-chemical parameters in chlorination for .05 mg/L concentration in different time

0.05				
TIME	**PH**	**TEMPERATURE**	**TDS(20 mints)**	**TSS(20 mints)**
2	7.37	26.5	0.567	0.047
5	7.14	26		
10	7.1	26.1		
15	7.08	26.3		
20	7.05	26.7		

Table 4.9. Different values of physic-chemical parameters in chlorination for .08 mg/L concentration in different time

0.08				
TIME	**PH**	**TEMPERATURE**	**TDS**	**TSS**
2	7.2	26.5	0.619	0.043
5	7.19	26.3		
10	7.11	26.2		
15	7.09	26.3		
20	7.05	26.8		

4.3.2. Microbiological outcome

LRV of Chlorination for different dosage was calculated. The percentage removal was also measured. The results are illustrated in the Tables 4.10, 4.11 and 4.12.

Table 4.10. LRV and % removal in chlorination for .02 mg/L concentration in different time

Dose	**0.02 mg/L**	**Temperature (24.6 °C)**				
Time (min)	0	2	5	10	15	20
Bacteria (cfu/100 mL)	12x10^5	120	80	40	16	0
Residual Chlorine (mg/L)	0.02	0.015	0.014	0.013	0.012	0.012
% removal	0%	99.99%	99.993%	99.997%	99.999%	100%
LRV		4	4.2	4.47	4.9	

Table 4.11. LRV and % removal in chlorination for .05 mg/L concentration in different time

Dose	**0.05 mg/L**	**Temperature (25 °C)**				
Time (min)	0	2	5	10	15	20
Bacteria (cfu/100 mL)	9x10^5	100	50	30	0	0
Residual Chlorine (mg/L)	0.05	0.031	0.029	0.027	0.024	0.024
% removal	0%	99.98%	99.990%	99.996%	100%	100%
LRV		3.7	4	4.22		

Table 4.12. LRV and % removal in chlorination for .08 mg/L concentration in different time

Dose	**0.08 mg/L**	**Temperature (26 °C)**				
Time (min)	0	2	5	10	15	20
Bacteria (cfu/100 mL)	12x10^5	60	40	0	0	0
Residual Chlorine (mg/L)	0.08	0.073	0.07	0.07	0.07	0.07
% removal	N.C	99.995%	99.996 %	100.000%	100.000%	100.000%
LRV	N.C	4.3	4.48	N.C	N.C	N.C

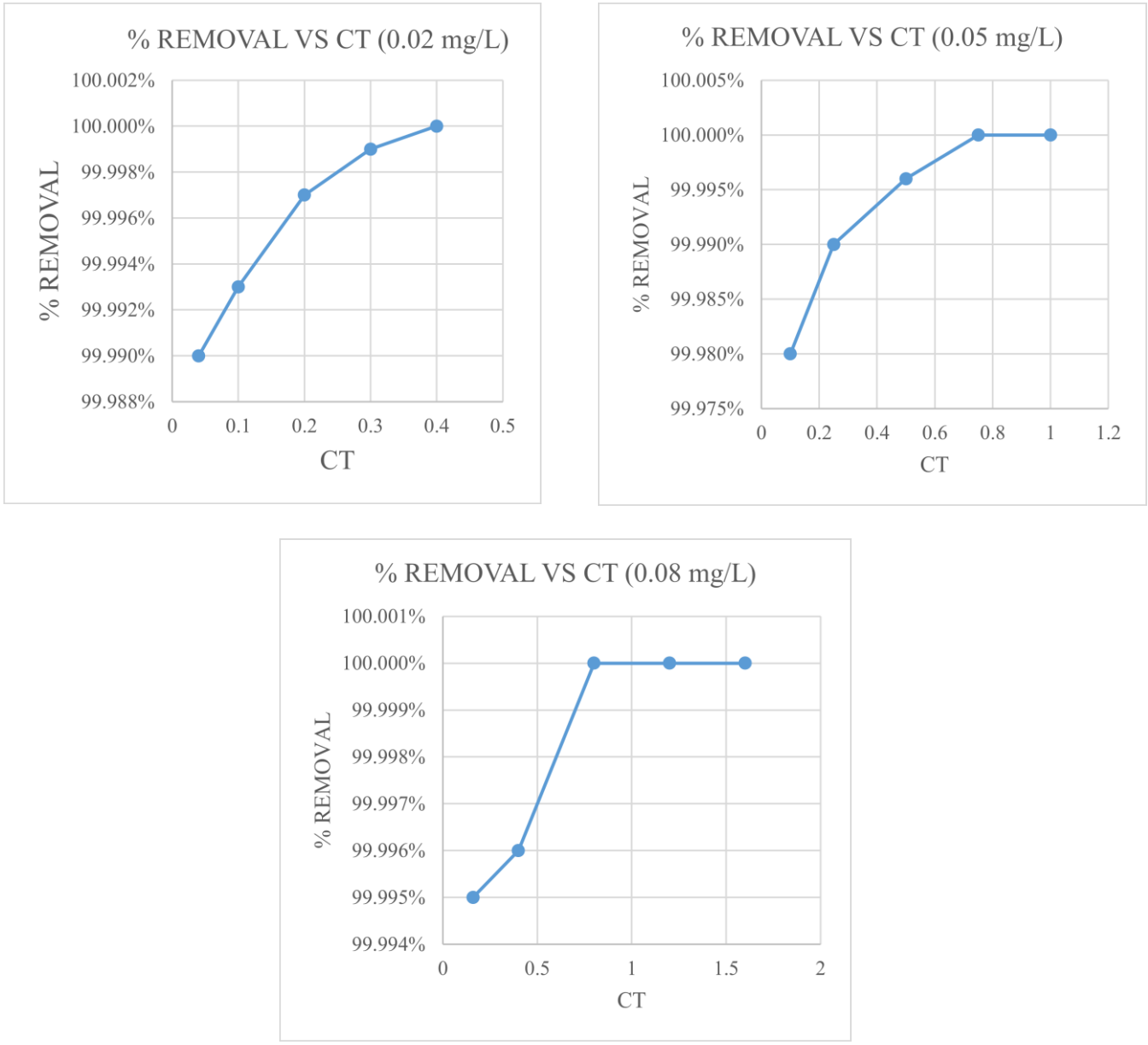


Figure 4.6. % removal VS CT

The removal efficiency increased with time and concentration for all the dosage used for chlorination. The graph of percentage removal VS CT shows that this phenomenon is true for all concentrations of chlorine solution used for the experiment.

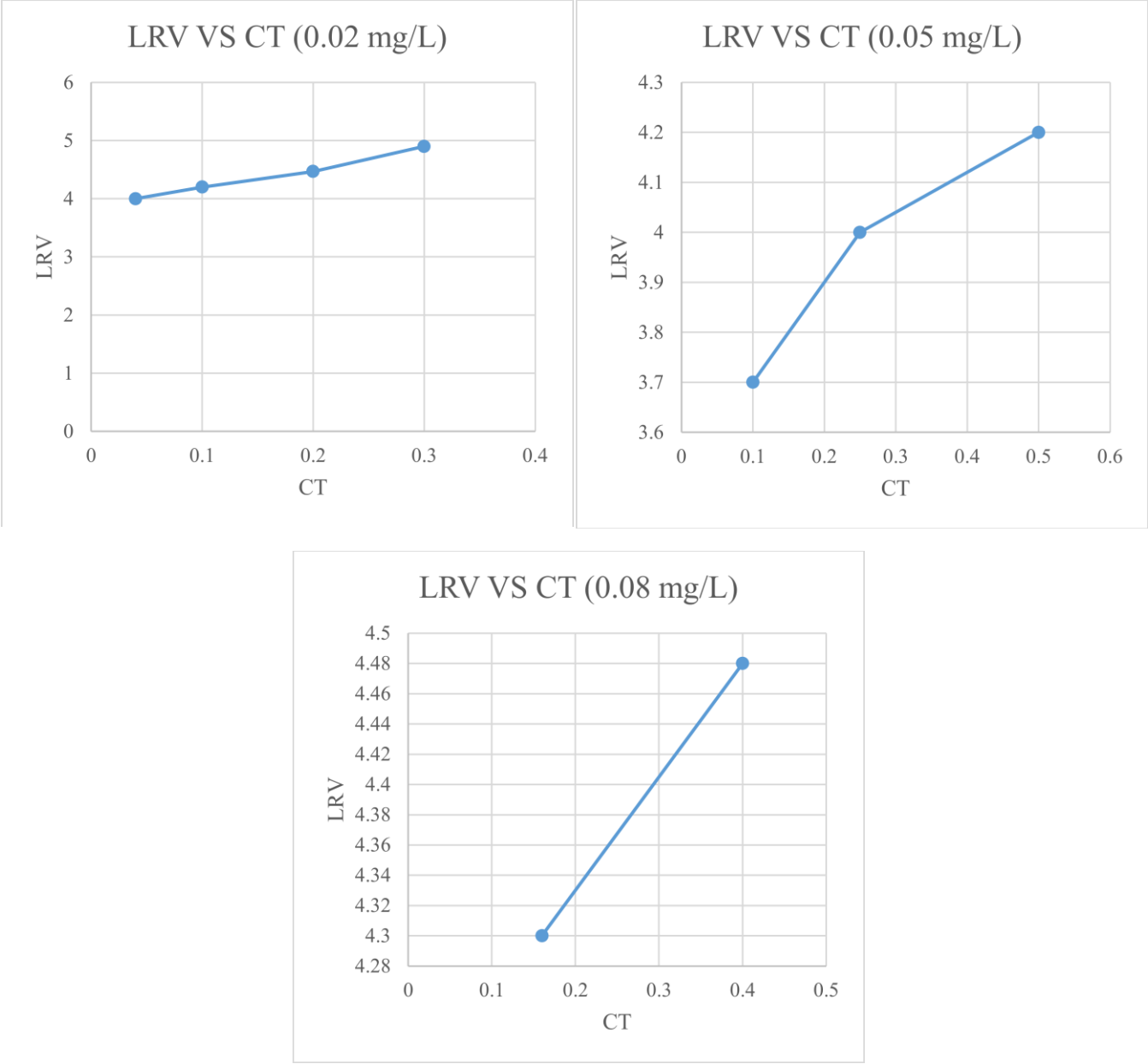


Figure 4.7. LRV VS CT

It was observed that with passage of time the LRV increased for all three dosages that were tested in the experiment. For 0.02 mg/L dosage minimum LRV was 4 when CT was 0.04. Maximum LRV was 4.9 when CT was 0.3. For 0.05 mg/L dosage the minimum LRV was 3.7 at CT 0.1. Maximum LRV was 4.2 when CT was 0.5. For 0.08 mg/L dosage the minimum LRV was 4.3 at CT 0.16. Maximum LRV was 4.48 when CT was 0.4.

4.4. Coagulation and Sedimentation

4.4.1. Physic-Chemical Outcome

Different physic-chemical parameters were measured during the experiment. A minimum dosage of 1 mg/L was tested and a maximum of 26 mg/L was used. For each experiment pH, Turbidity, TDS and color were measured. It was observed that the pH decreased with increasing dosage of alum. Turbidity, TDS and color increased with increasing dosage of alum.

DOSAGE (mg/L)	PH	TURBIDITY(NTU)	TOTAL DISSOLVED SOLIDS(mg/L)	COLOR(Pt-Co)
1	7.4	8	0.354	22
1.5	6.92	9.2	0.412	26
2	6.23	10.6	0.498	31
2.5	5.88	11.4	0.543	33
3	5.21	12.1	0.627	36
4	4.92	14.7	0.731	41
5	4.55	15.9	0.845	46
6	4.13	17	0.930	50
7	4.09	19.4	1.114	77
8	4.04	21.5	1.432	99
9	4.01	23.4	1.641	134
10	3.98	27.5	1.978	170
11	3.95	29.6	2.235	186
12	3.93	31.8	2.744	210
13	3.93	34.2	3.213	274
14	3.92	37.3	3.749	315
15	3.92	40.1	4.130	380
16	3.92	45.9	4.985	486
18	3.9	48.7	5.850	550
20	3.88	52.3	6.761	631
22	3.87	59.5	7.860	680
24	3.87	68.7	8.592	783
26	3.85	75.1	10.154	810

Table 4.13. Physic-Chemical Outcome of coagulation and sedimentation

Table 4.14. LRV of coagulation and sedimentation with different dosage

Dosage (mg/L)	LRV
0.5	2.19
1	2.22
1.5	2.23
2	2.28
2.5	2.32
3	2.4
4	2.41
5	2.42
6	2.45
7	2.62
8	2.68
9	2.8
10	2.82
11	2.92
12	2.97
13	2.99
14	3.04
15	3.12
16	3.16
18	3.22
20	3.44
22	3.6
24	3.74
26	4.1

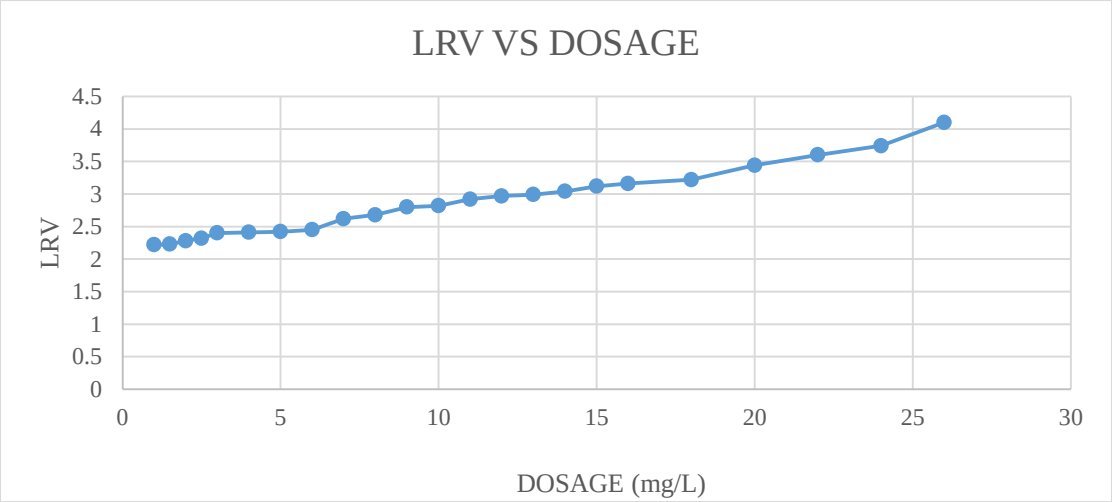


Figure 4.8. LRV VS dosage

4.4.2. Microbiological outcome

From figure 4.8 it can be seen that the LRV value increases with increasing dosage. For dosage below 25.5 mg/L it can be seen that LRV values are less than 4. For dosage of less than 13 mg/L the LRV value obtained was less than 3. The minimum LRV value obtained was 2.22. Hence it can be deduced that for alum concentrations of less or equal to 25.5 mg/L coagulation and sedimentation method is 'Protective' and for dosages greater than 25.5 mg/L it is 'Highly Protective' according to WHO guideline for Household Water Treatment Technologies. However it was observed that various physic-chemical parameters of water changed drastically with administration of increasing alum dosage on the test waters. These changes render water non-drinkable as per the National and WHO guideline for drinking water quality.

4.5. UV Disinfection

4.5.1. Physic-Chemical Outcome

According to WHO guideline Dissolved Oxygen and turbidity are the main physic-chemical parameters that need to be considered in UV disinfection (WHO 2011b).In our experiment we have tested two type of waters. We have found that both type of water showed same behavior in both Dissolved Oxygen and turbidity value. The are shown in figure 4.9 and 4.10.

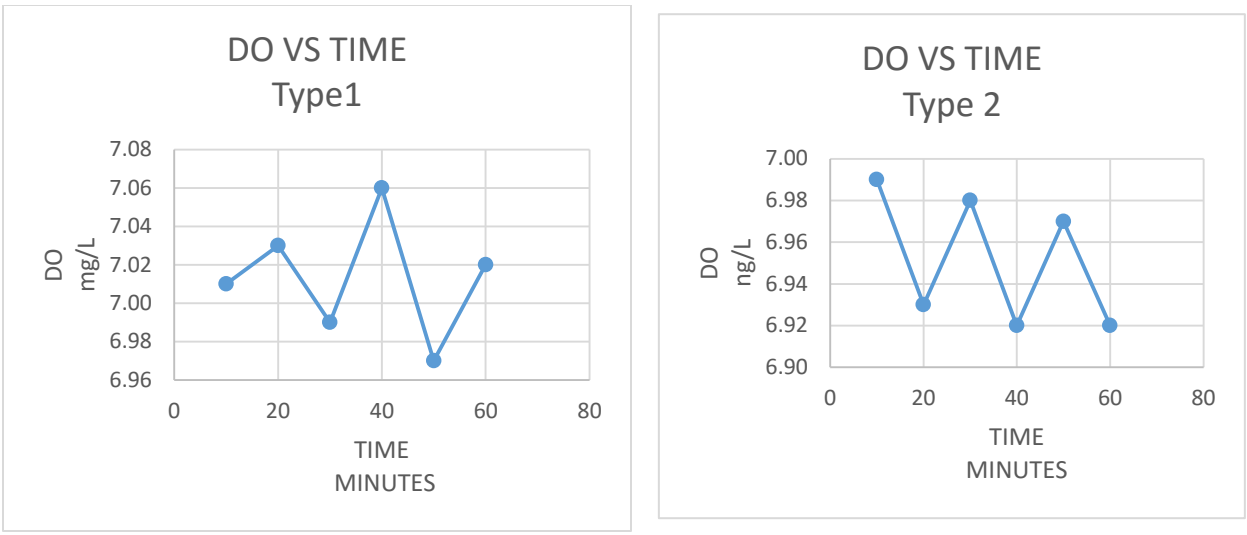


Figure 4.9. DO VS time

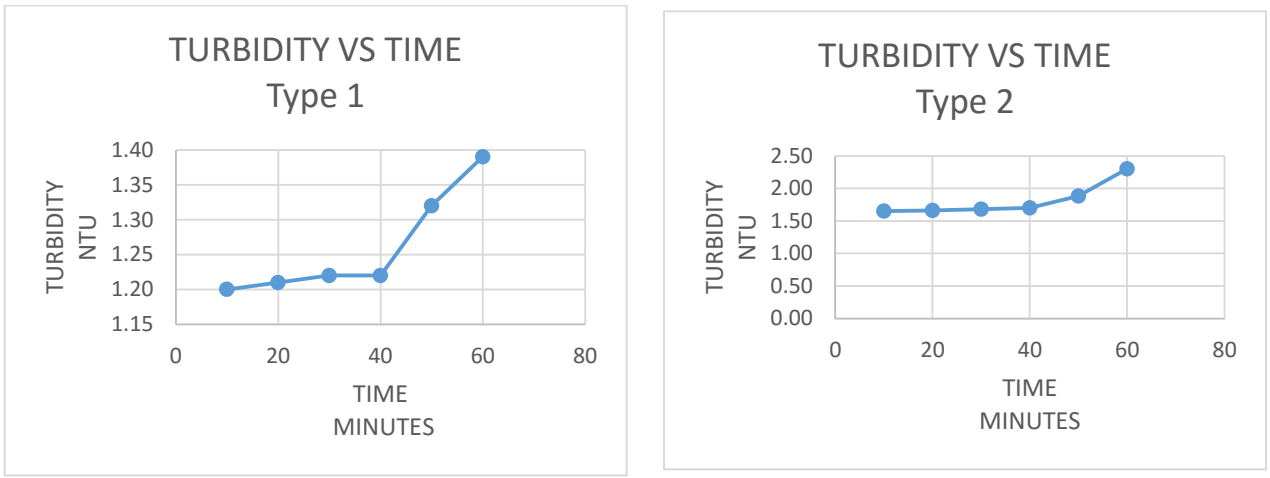


Figure 4.10.Turbidity VS time

4.5.2. Microbiological outcome

We have found that for both type of water E. coli was removed completely after 30 minutes. Both LRV and % removal was increased with time. It is shown is figure 4.11. and 4.12.

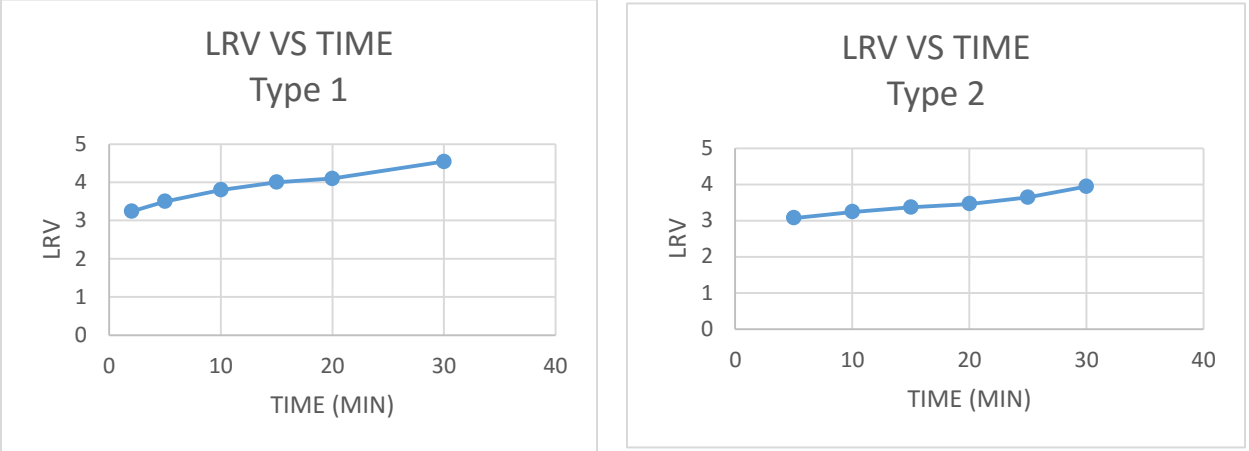


Figure 4.11. LRV VS time

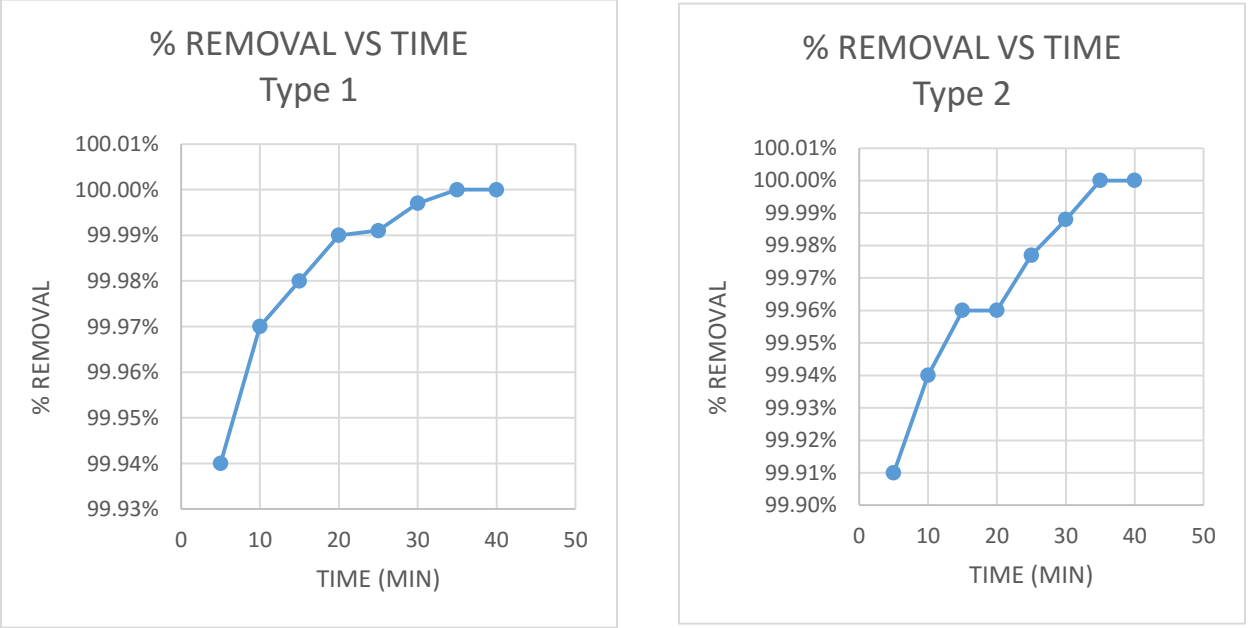


Figure 4.11. % removal VS time

Chapter 5: Conclusion and Limitations

5.1. Conclusion

In this chapter the results and observations are summarized in order to derive a conclusion from the experiments conducted. Future scope of study and recommendations are also outlined.

1. It was found that the filters had varying filtration rates but in terms of bacteria removal they exhibited similar properties with a log reduction value of greater than 4 for all the filters. This indicates a good performance of filters for removing bacteria from feed water.

2. The filtration rates decreased gradually with time. After periodic cleaning the filtration rate improved but did not retain the initial filtration. For best performance the filters should be periodically cleaned.

3. All filters showed good removal efficiency in terms of different physic-chemical parameters. Color, pH, turbidity, TSS and TDS were reduced to acceptable range according WHO guideline for drinking water parameters. They also exhibited decrease in performance over time due to clogging.

4. The study showed that, source water was groundwater which is of low nutrient source for pathogenic multiplication and thereby the overall microbial removal potential was very low in terms of other studies where the source water is surface water or other nutrient rich water. Also the field study showed more consistent reduction potential against bacteria where the source water was either surface water or rain water.

5. Filters are ‘Highly Protective’ according to WHO guidelines for HWT.

6. When chlorination was performed the pH of water decreased with time showing that the water was becoming acidic. This is due to free chlorine in the water after addition of disinfectant. However the pH and other physic-chemical parameters were within acceptable limits for drinking.

7. The LRV values increased with time indicating progressive bacteria removal. A minimum of 10 minutes of contact time is required for all concentration of disinfectant used to ensure sufficient treatment before drinking.

8. Chlorination had an average LRV greater than 4. Hence it is also 'Highly Protective' when a minimum of 10 minutes contact time is maintained. Residual chlorines were also found after disinfection. A concentration of 0.015 mg/L is sufficient as residual chlorine in the household drinking water to disinfect bacteria.

9. For coagulation and sedimentation 'Highly Protective' behavior was observed for concentrations of alum greater than 25.5 mg/L.

10. The pH of water decreased drastically with increasing dosage of alum. At 26 mg/L of alum the pH dropped as low as 3.85. The turbidity was 59.5 NTU, TDS was 7.86 mg/L and color was 680 Pt-Co.

11. LRV for coagulation and sedimentation was 2-4 for concentrations till 25.5 mg/L. Hence it is only 'Protective' in terms of bacteria removal for concentrations less than 25.5 mg/L. For concentration greater than 25.5 mg/L it is 'Highly Protective' but the physic-chemical parameters are not within the acceptable limits of drinking water quality.
12. For UV disinfection 'Highly Protective' behavior was observed for 6W (254nm). All the E. coli was removed after 30 minutes of contact time.

13. The dissolved oxygen and turbidity level was also satisfactory according to WHO guideline.

5.2. Limitations

The studied filters had been chosen based on market price and maximum demand among different users. Most of these filters were imported and assembled locally. Some manufacturer brings different parts of the filter from different countries. Thus the quality of filter material is unknown.

In WHO (2011) guideline, the minimum water to be filtered by any HWT technology in laboratory verification is 20 liters. But in Chlorination it was not possible due to limitation of chemicals. Measuring the Physic-chemical parameters in exact time was not possible due to preparation time of the instrument.

In coagulation and sedimentation WHO verification for 20 litres cant be maintained due to limitation of coagulants.

During UV disinfection Time maintaining was difficult as we had to measure several parameters at a time.

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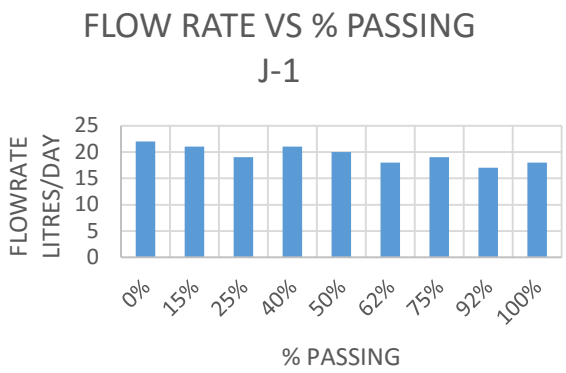
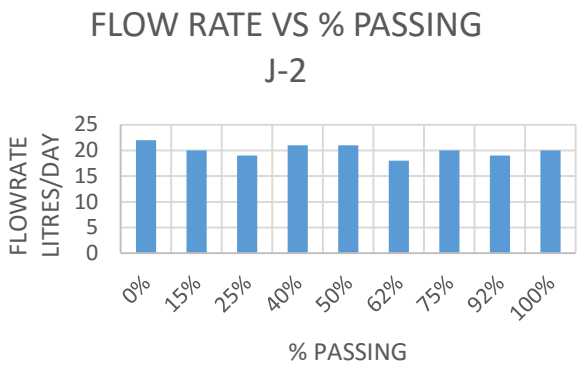
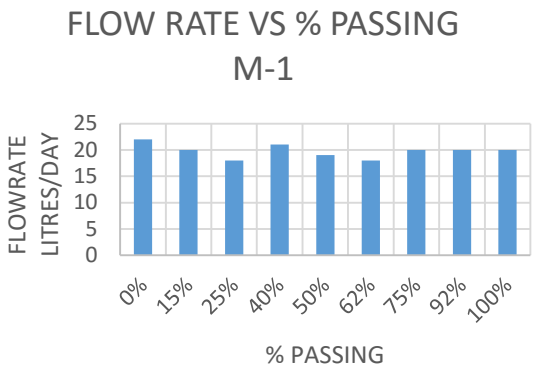
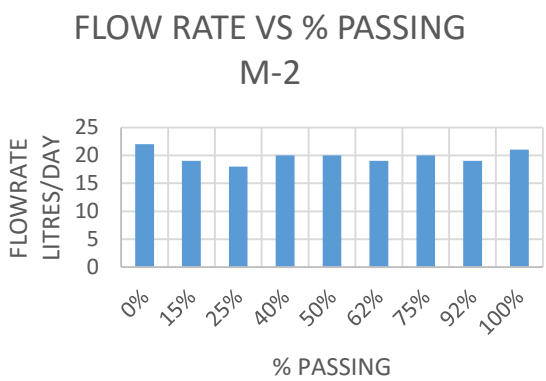
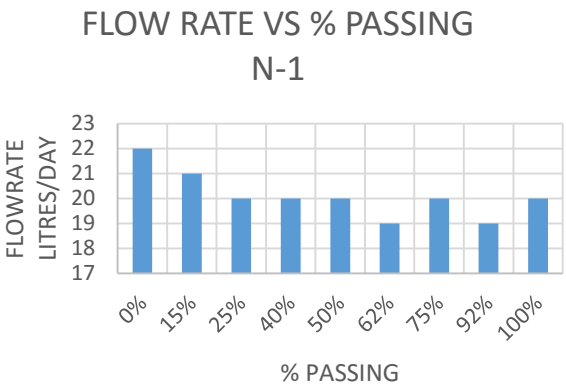
Appendix: Control Experiment FIGURES
F1: Filtration Method by Ceramic Filter
F1.1: Flow rate VS % Passing

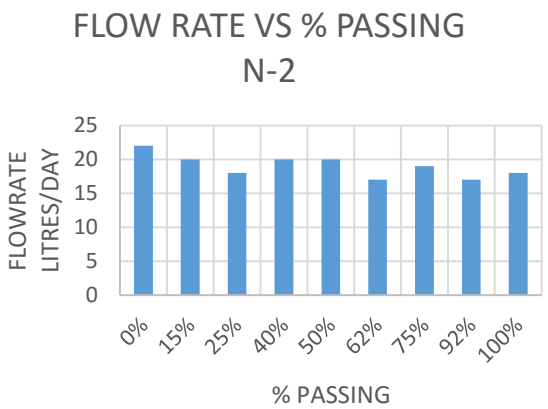


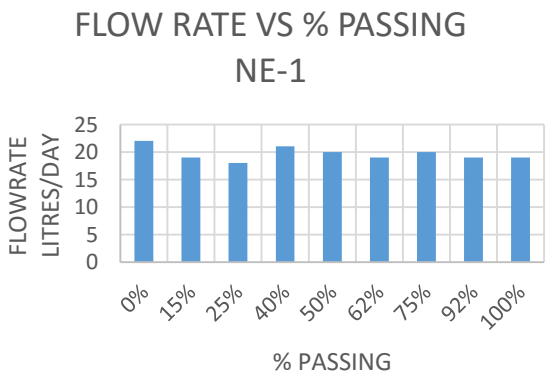


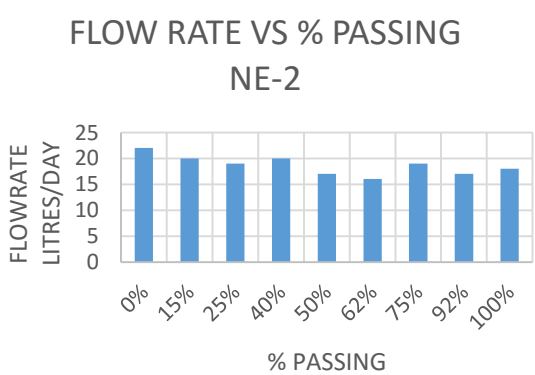












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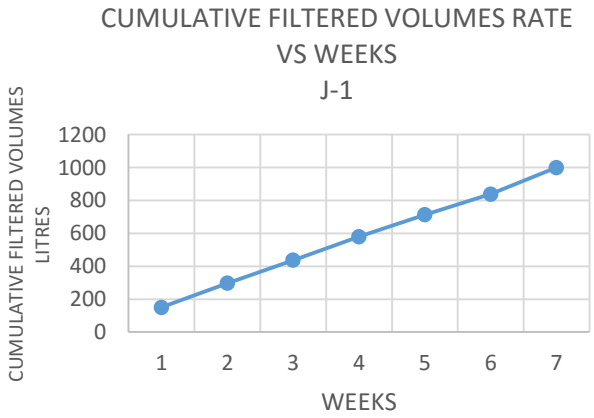

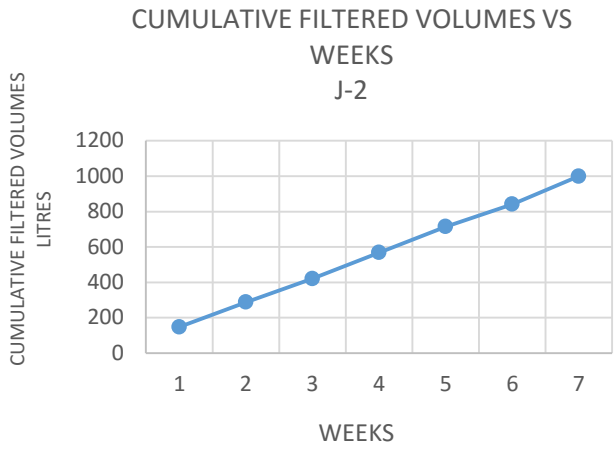

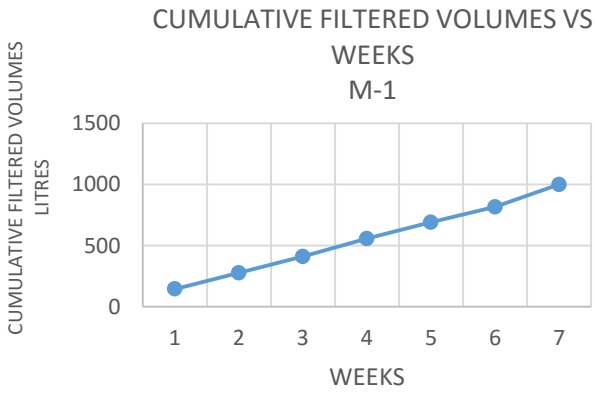

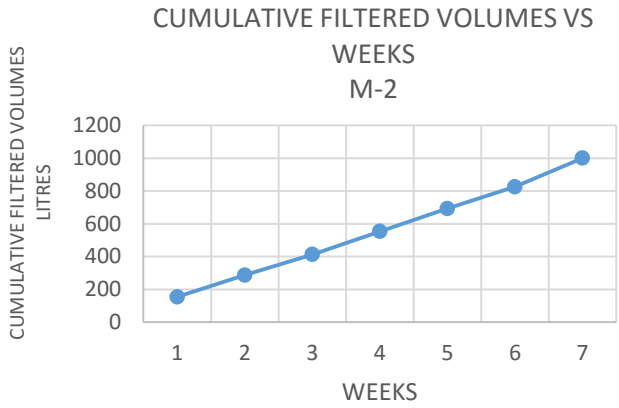

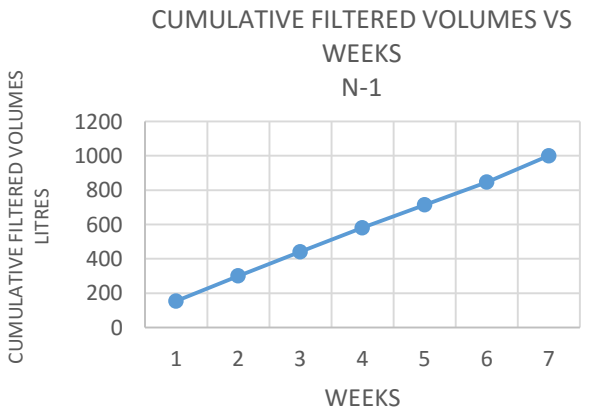

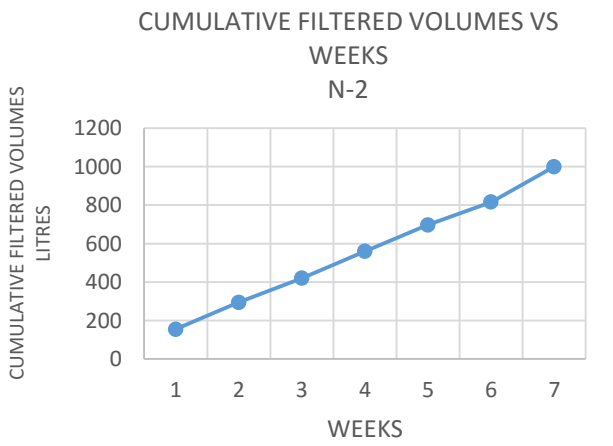

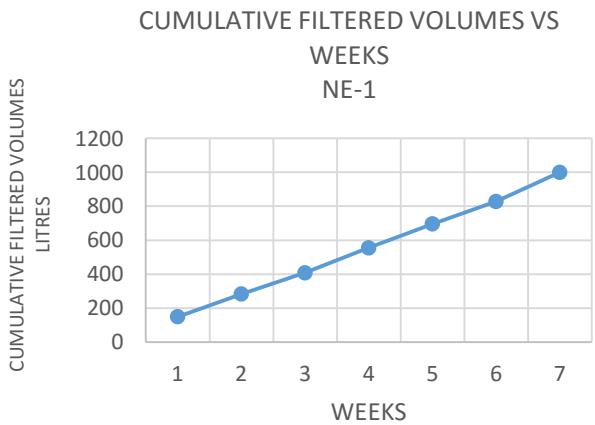

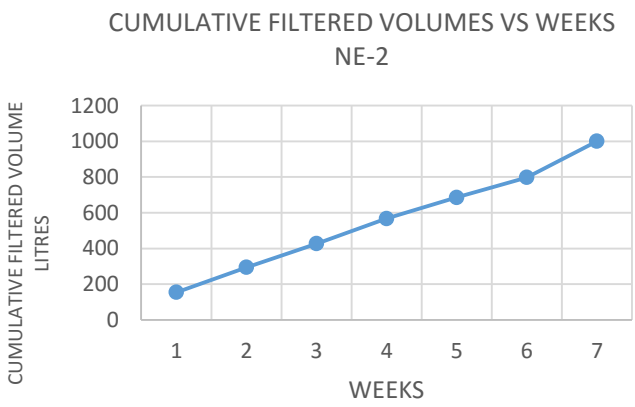

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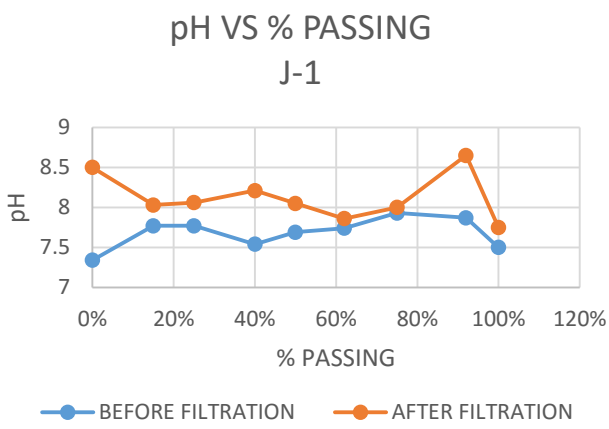

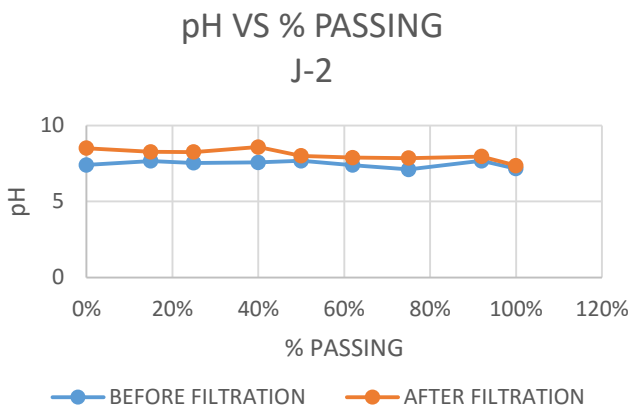

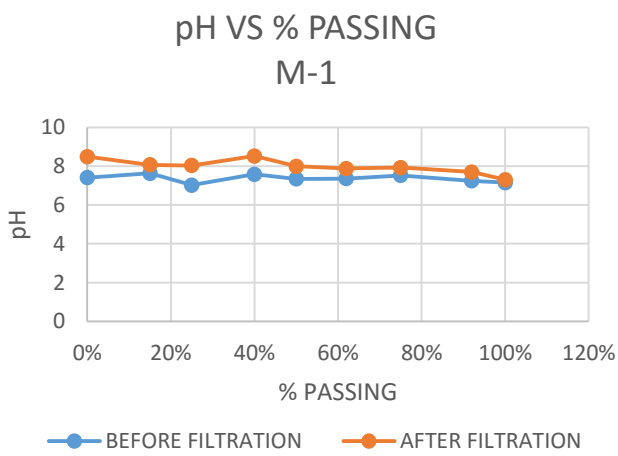

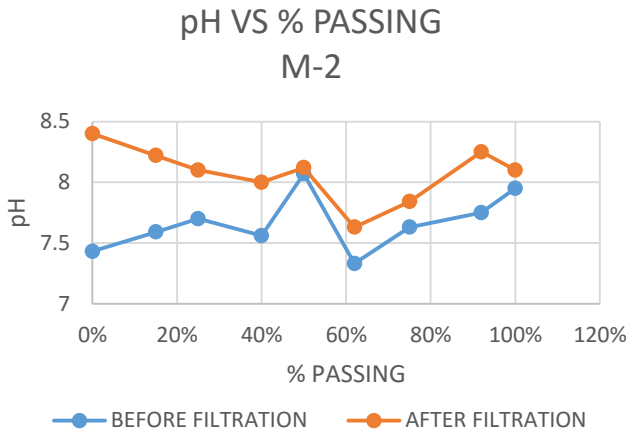

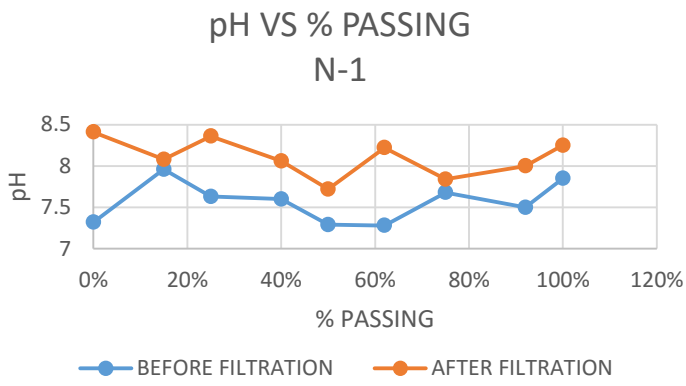

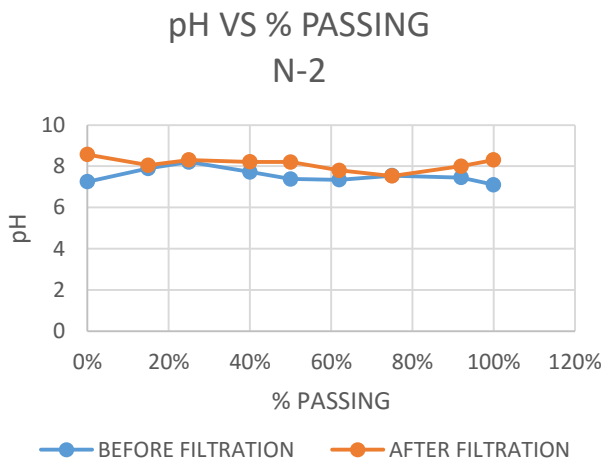

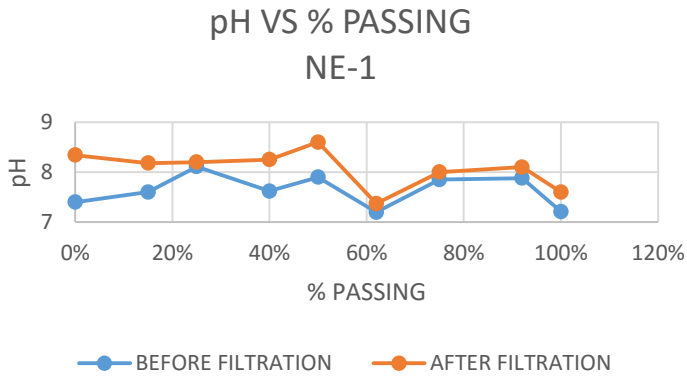

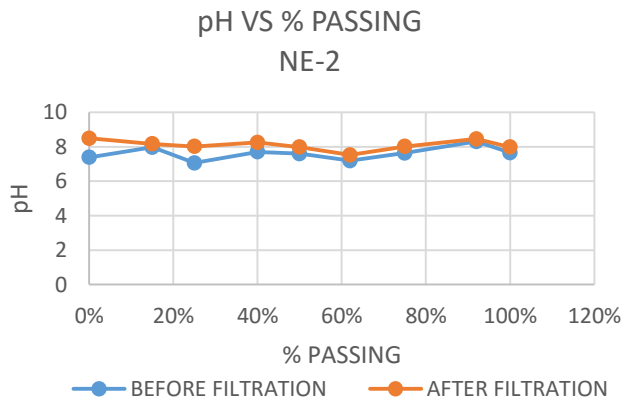

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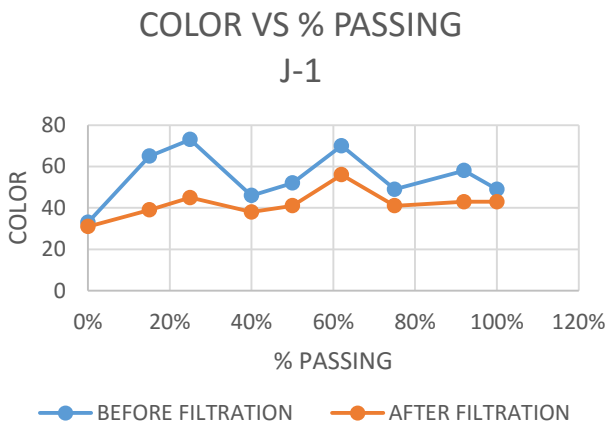
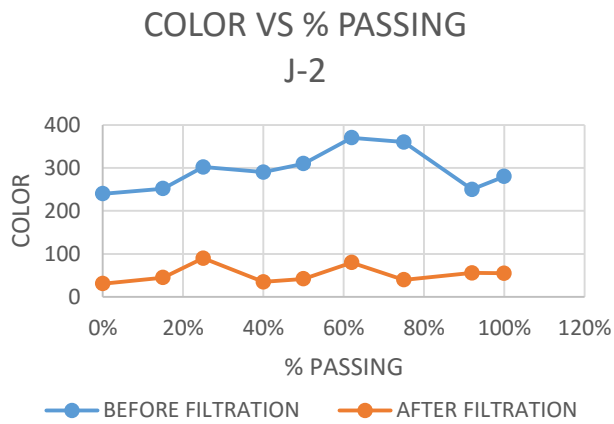
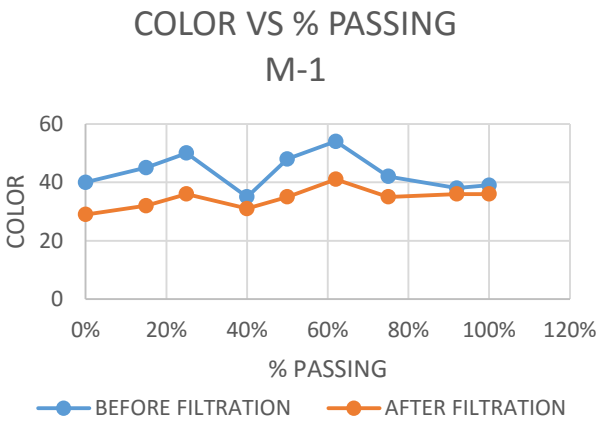
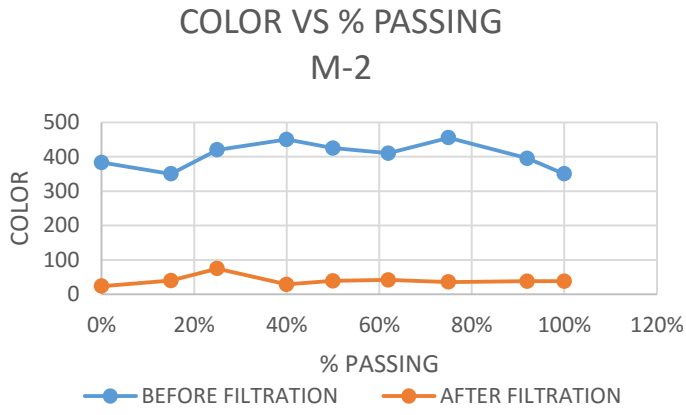
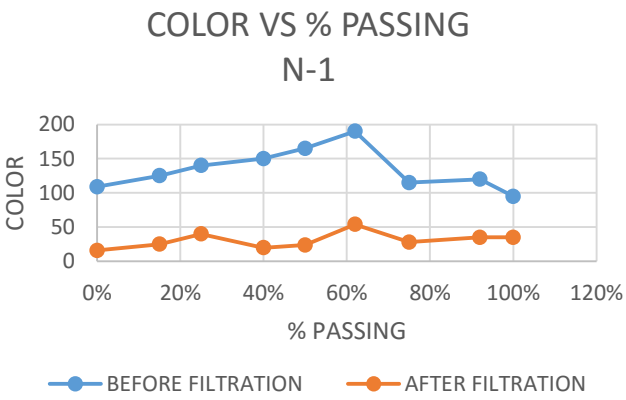
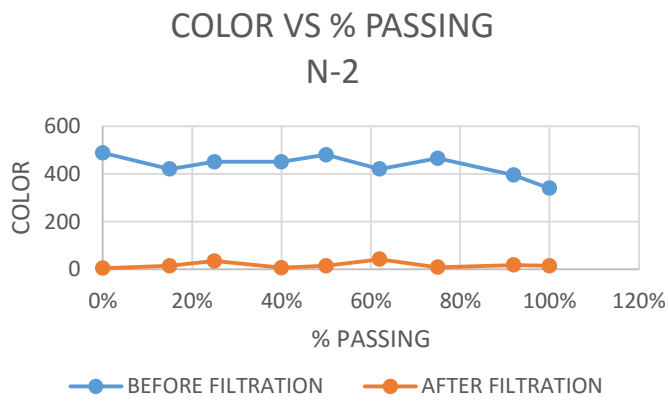


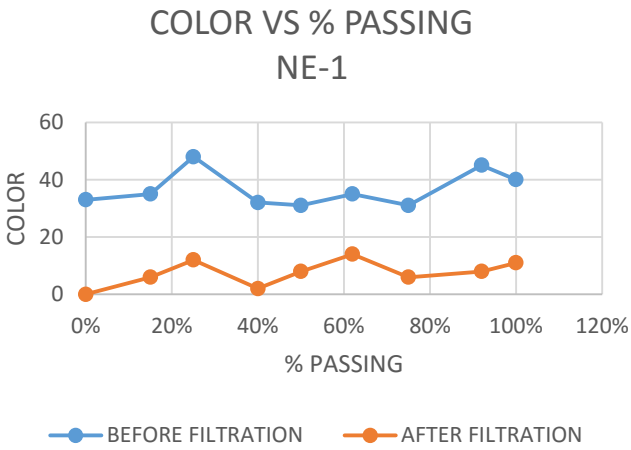


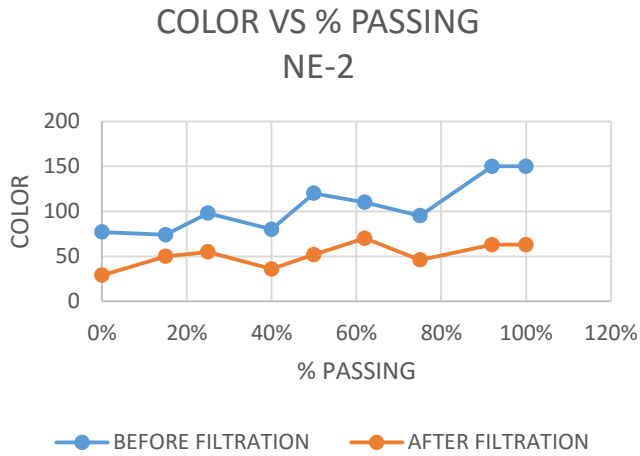




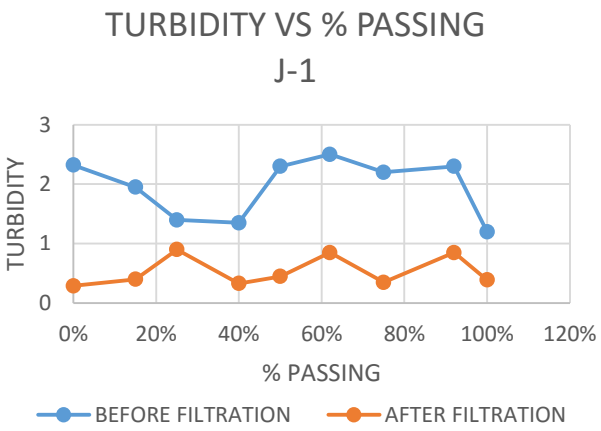


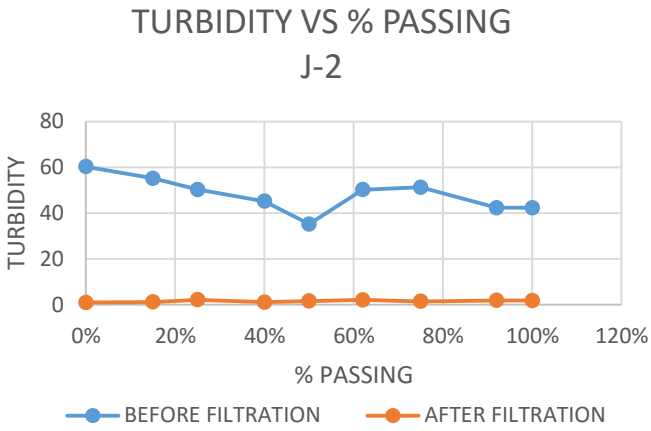


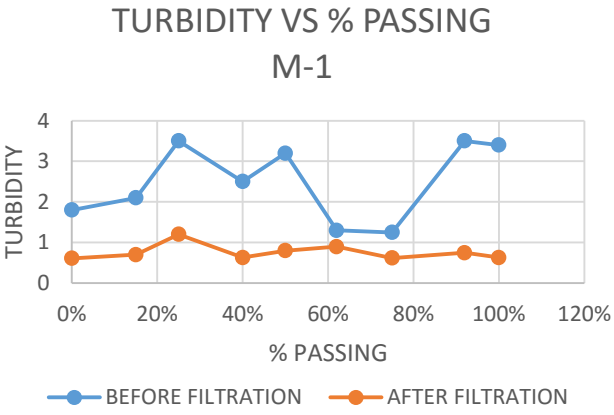


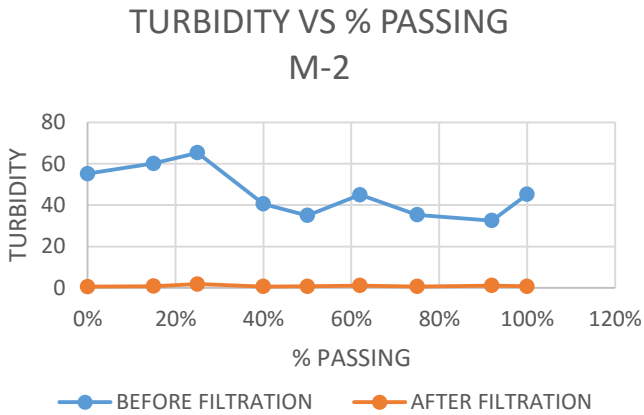


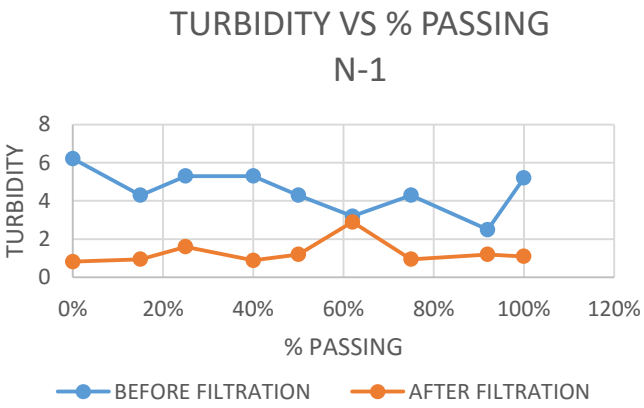
F1.4: TURBIDITY VS % Passing

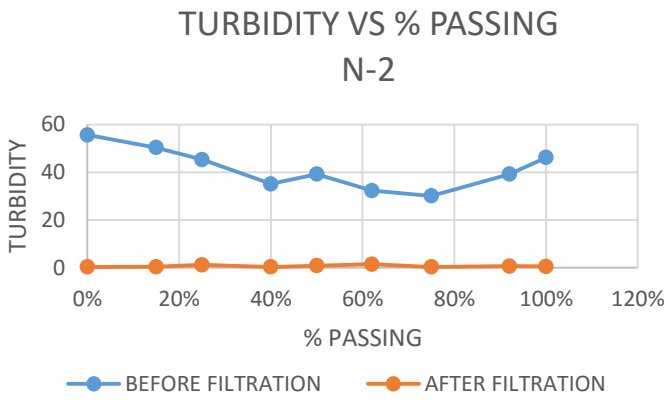


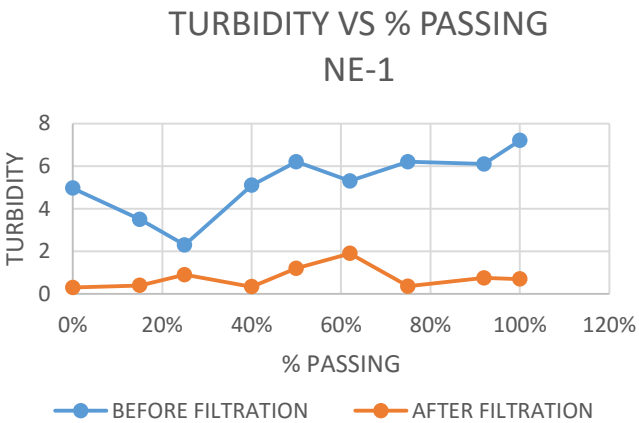


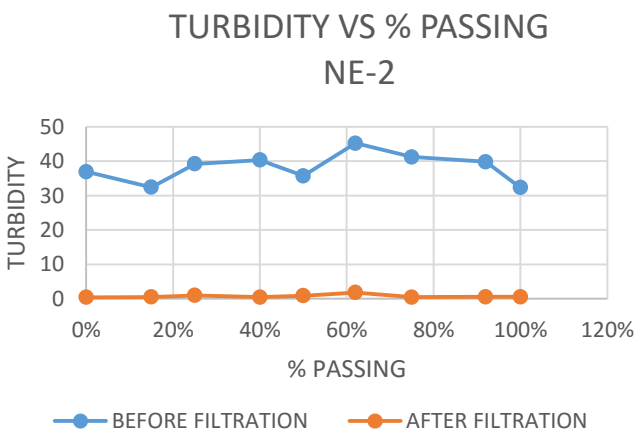




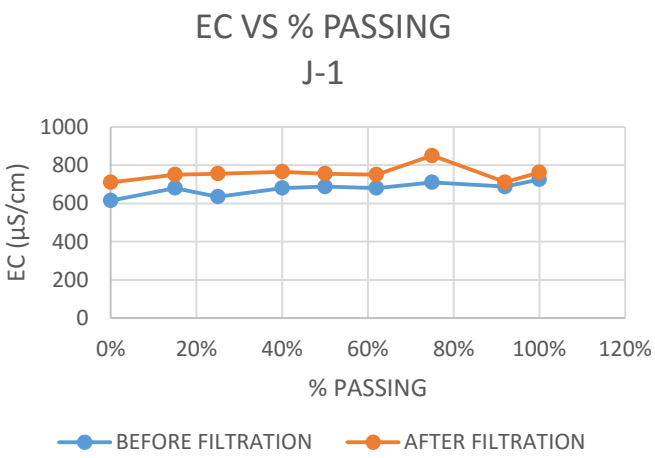


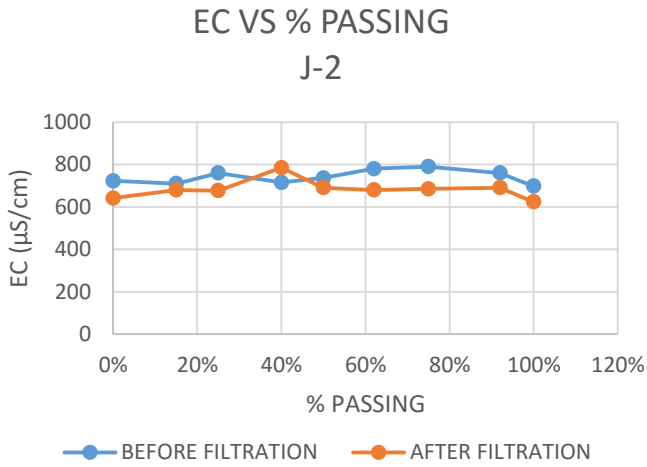


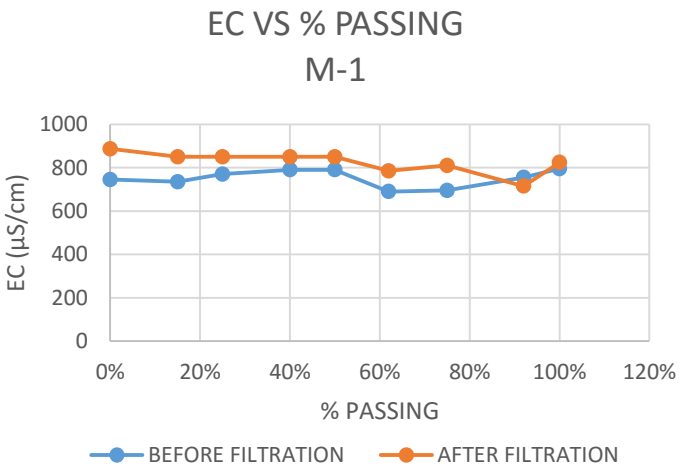


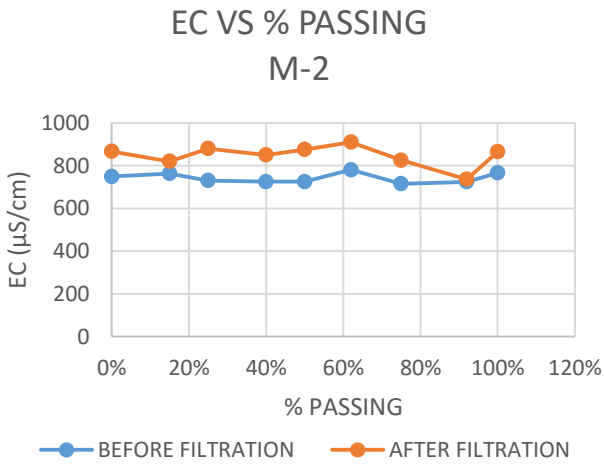


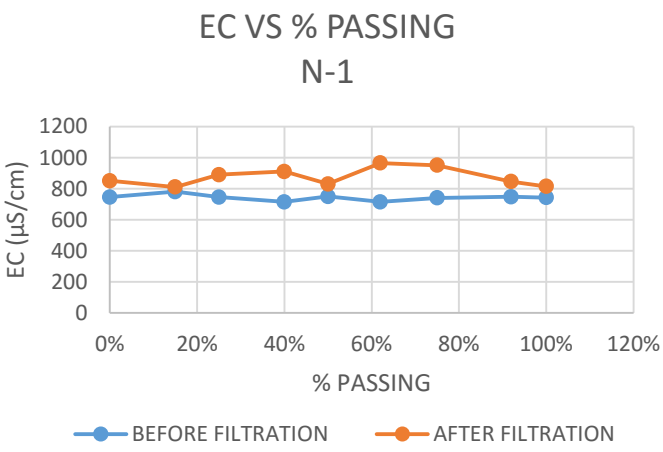
F1.5: Electric Conductivity VS % Passing

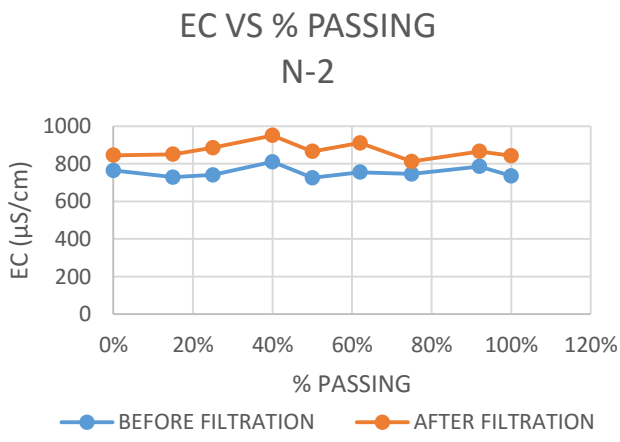


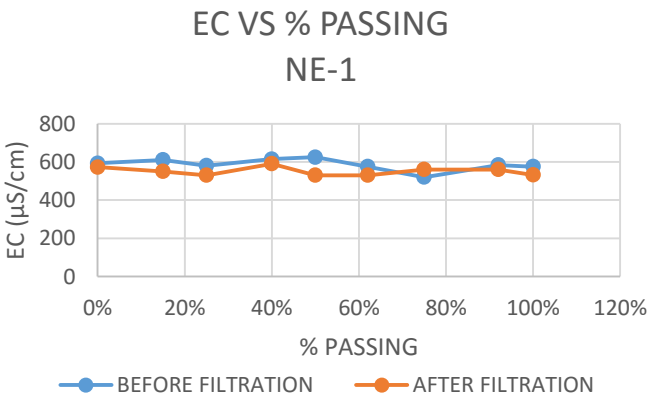


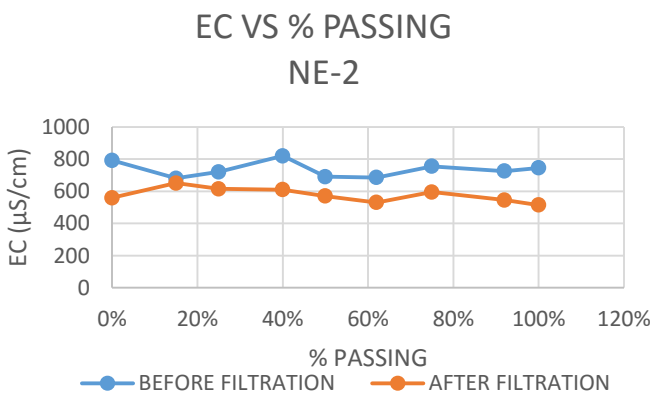












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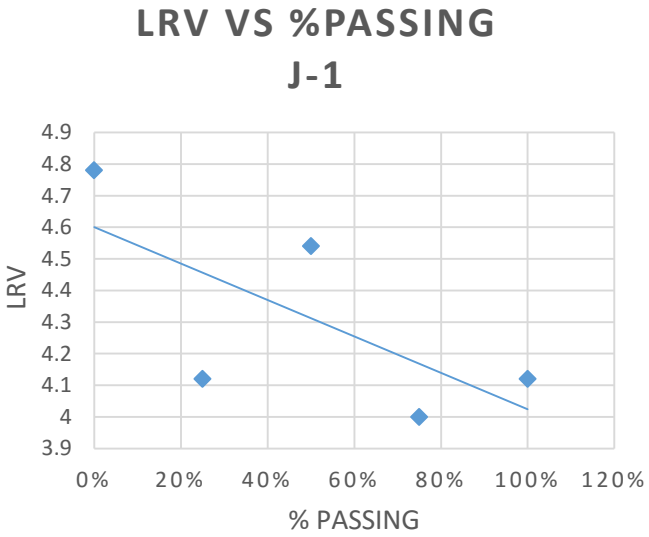
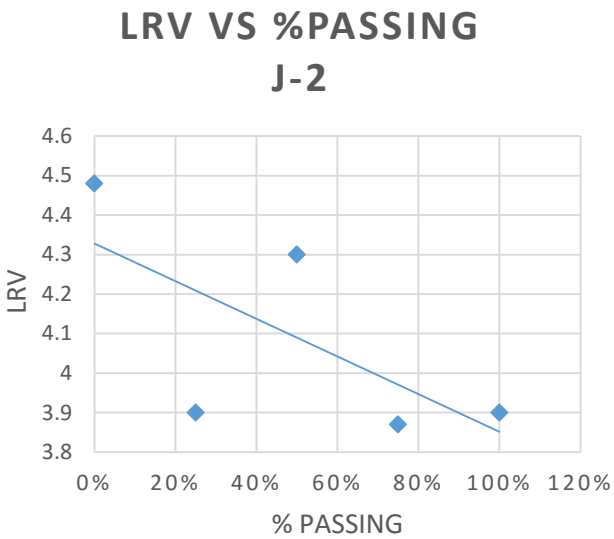
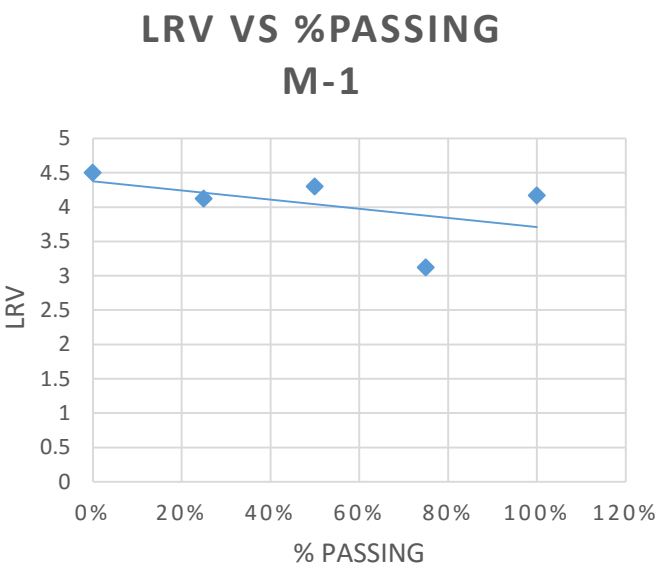
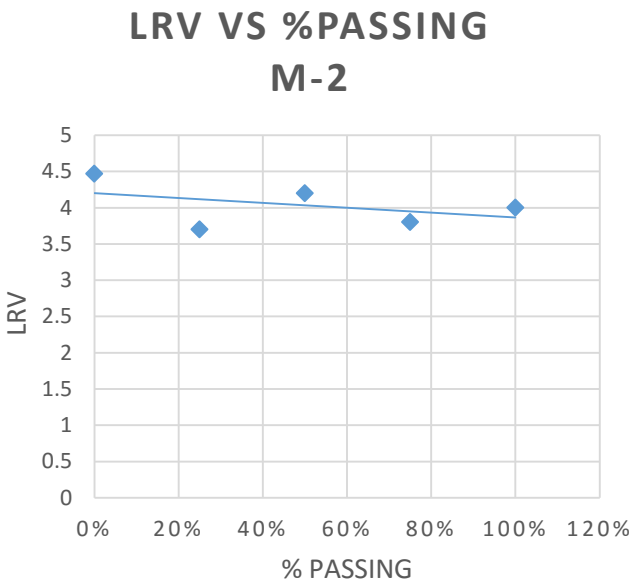
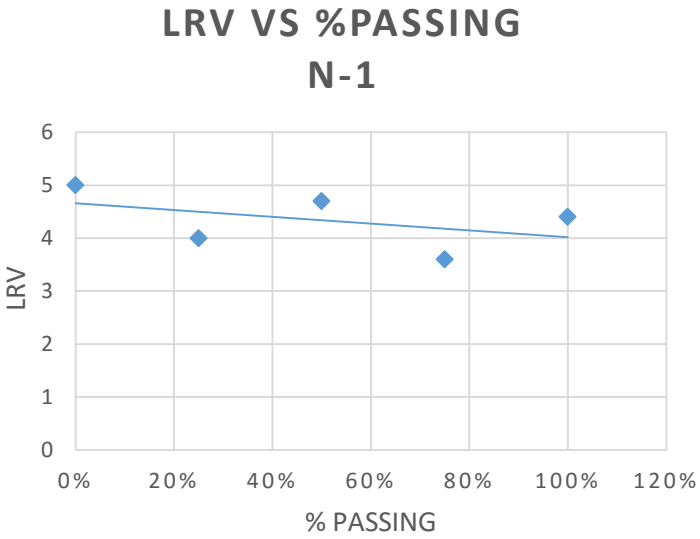
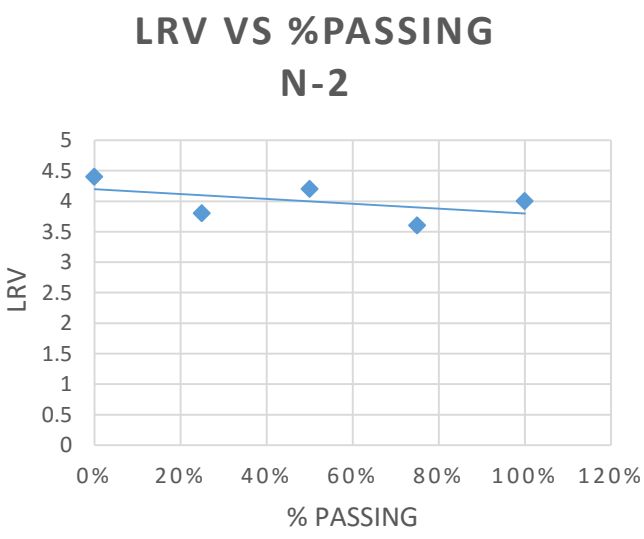




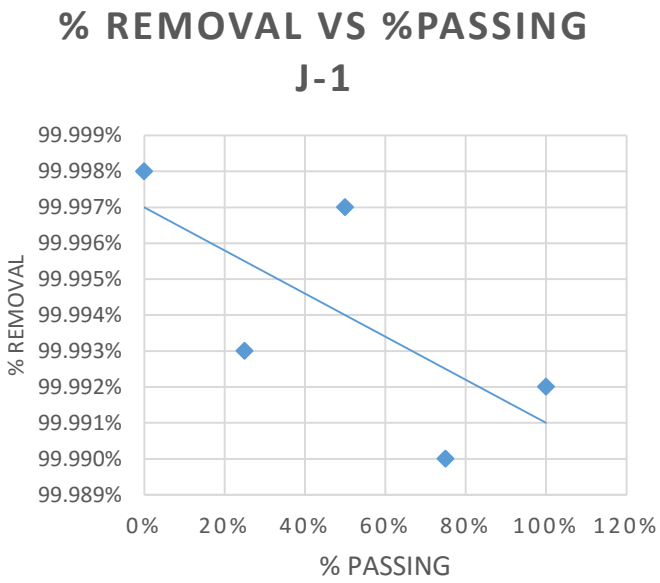


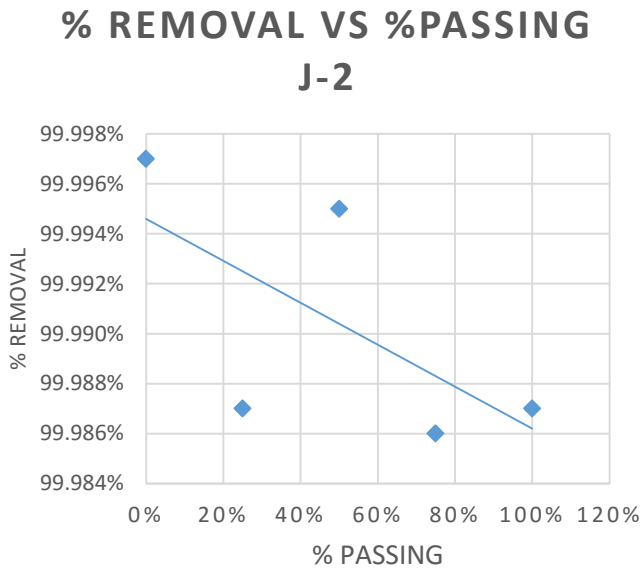


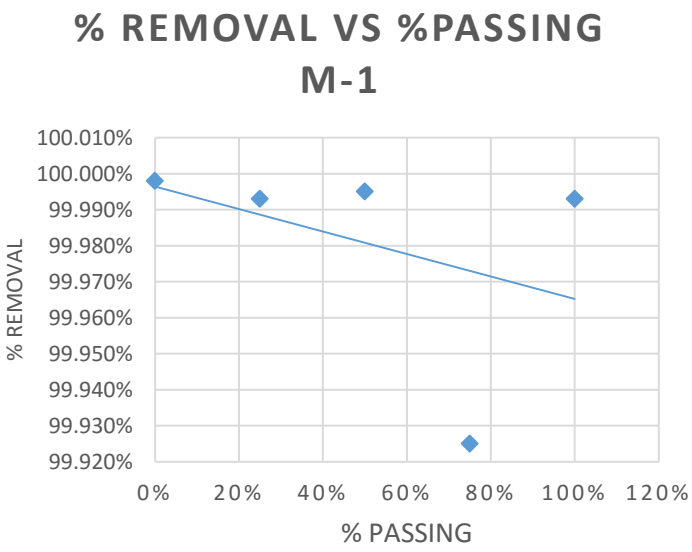


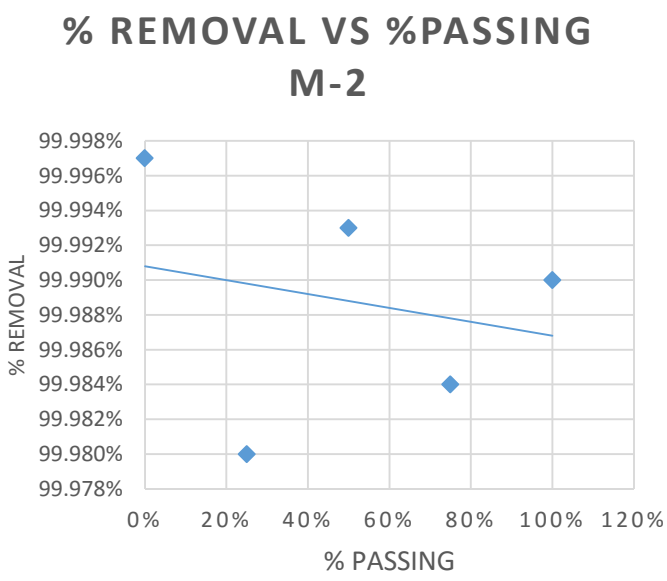


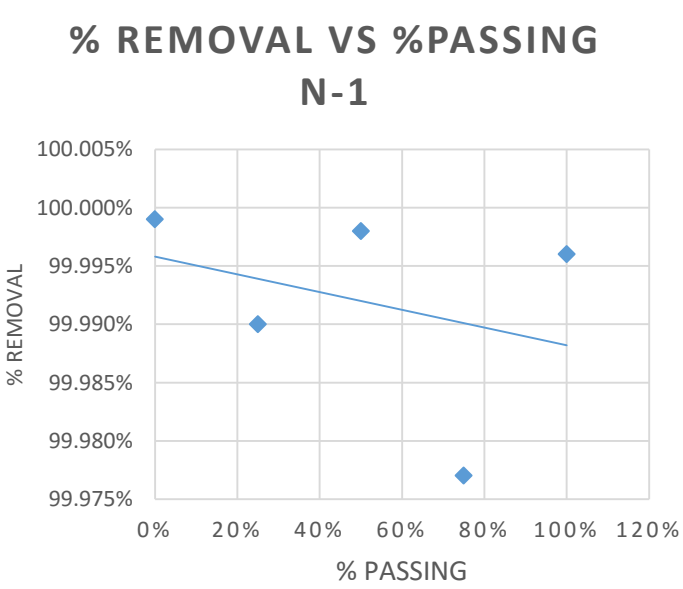
F1.7: % Removal VS % Passing

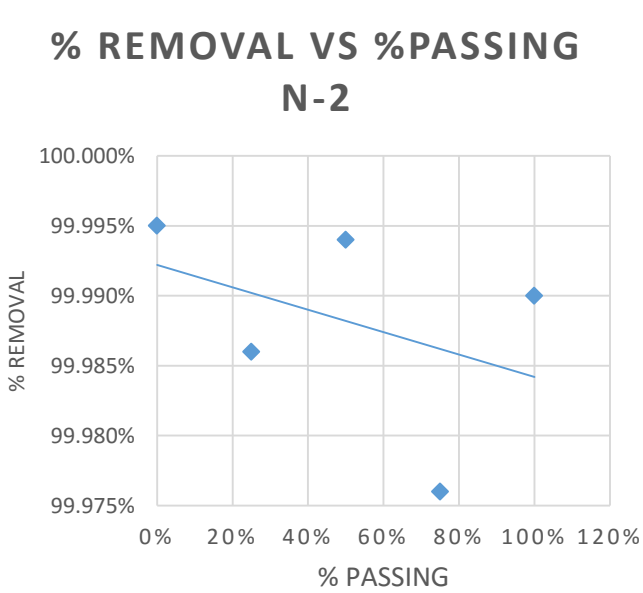




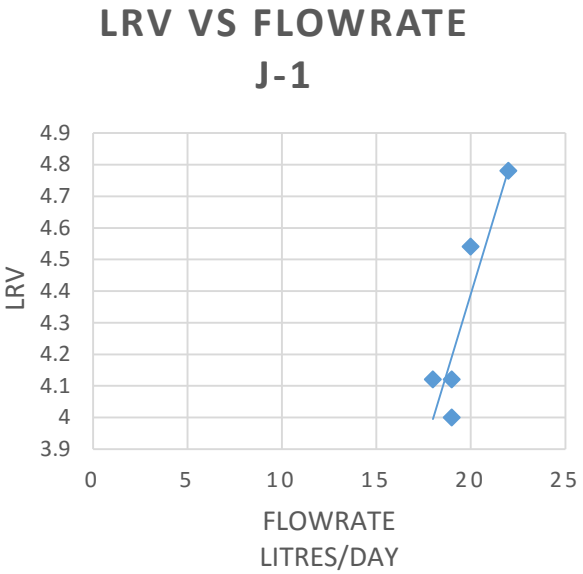


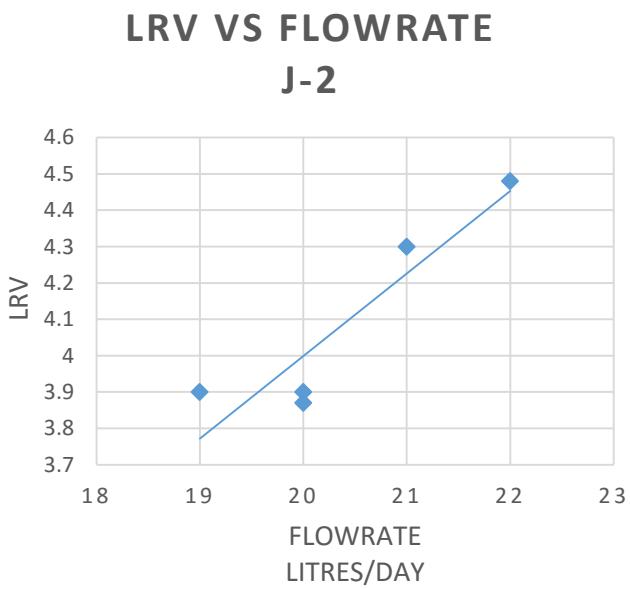


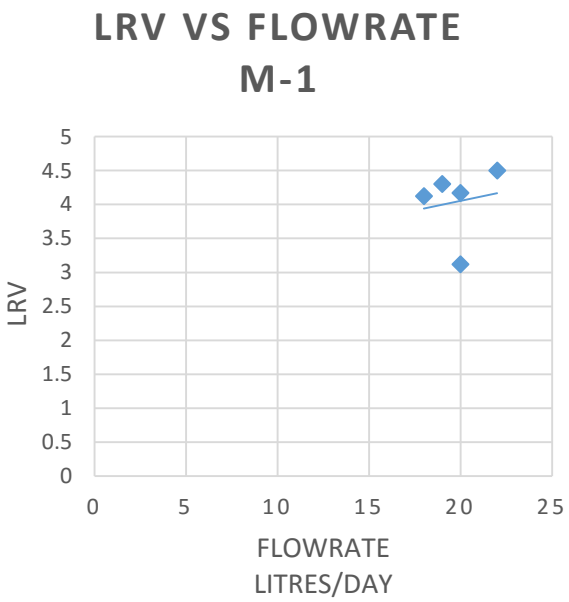


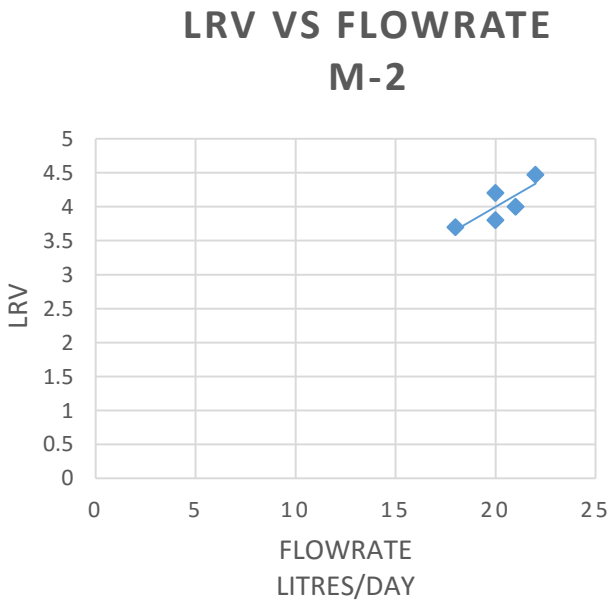


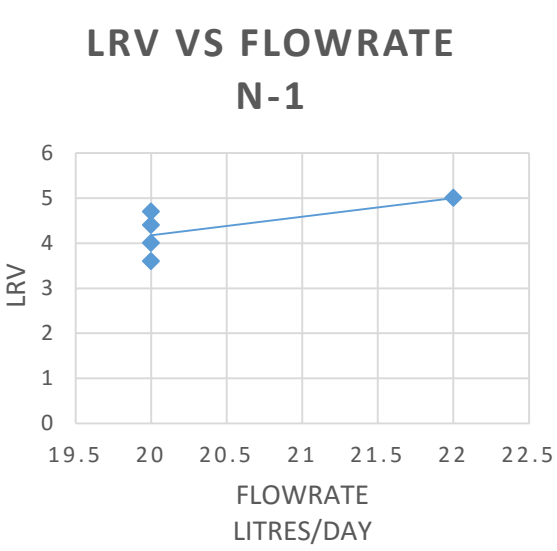
F1.8: LRV VS FLOWRATE

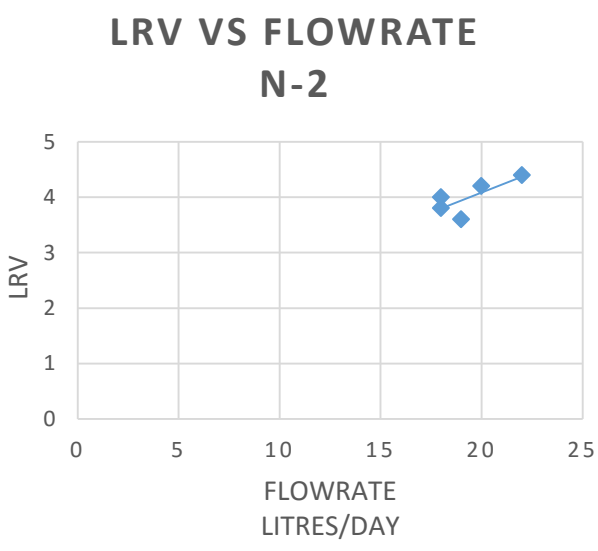






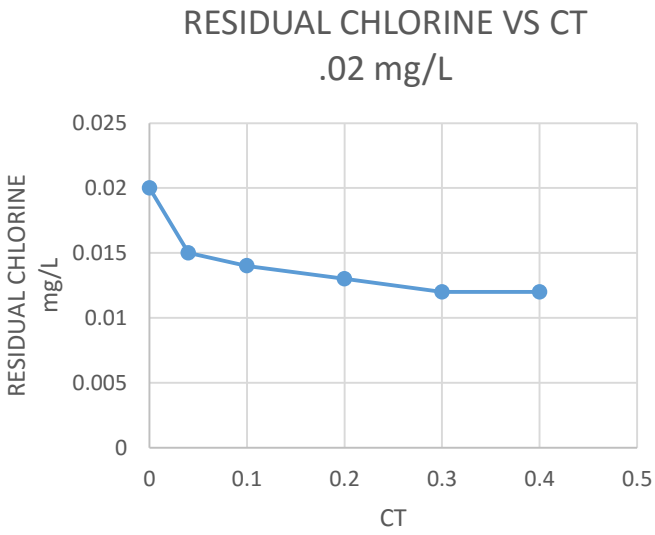


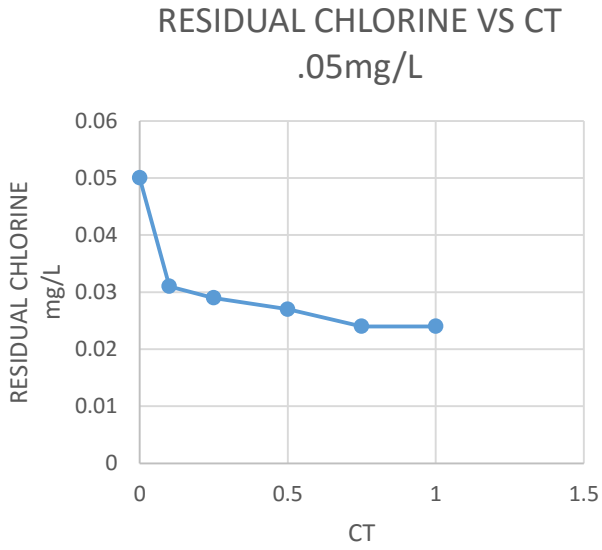


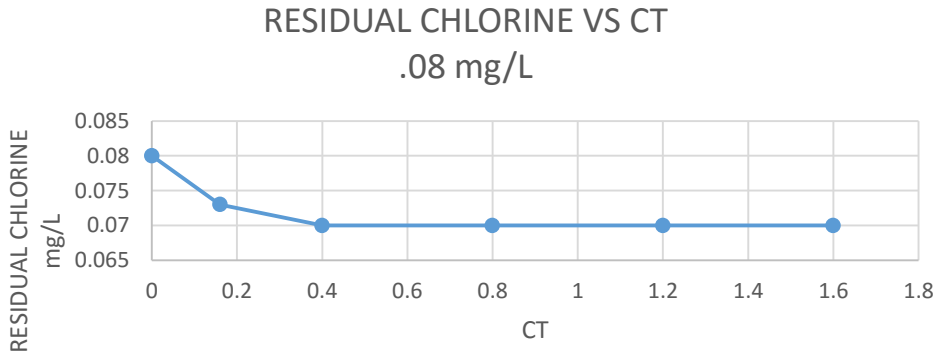


F2: CHLORINATION

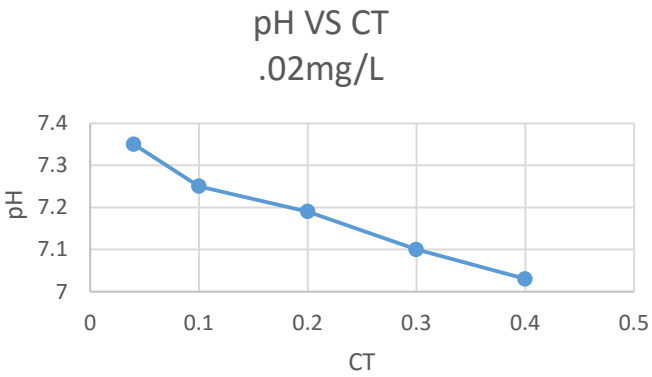
F2.1: RESIDUAL CHLORINE VS CT

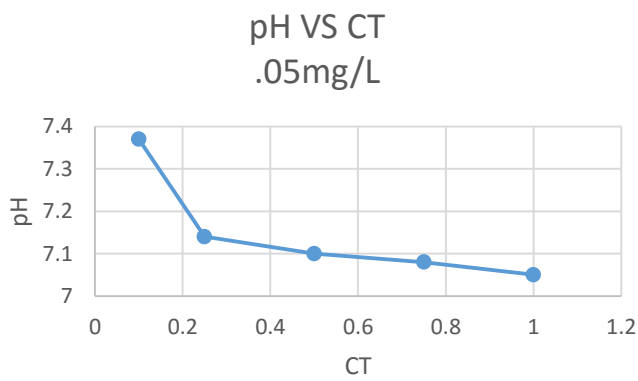


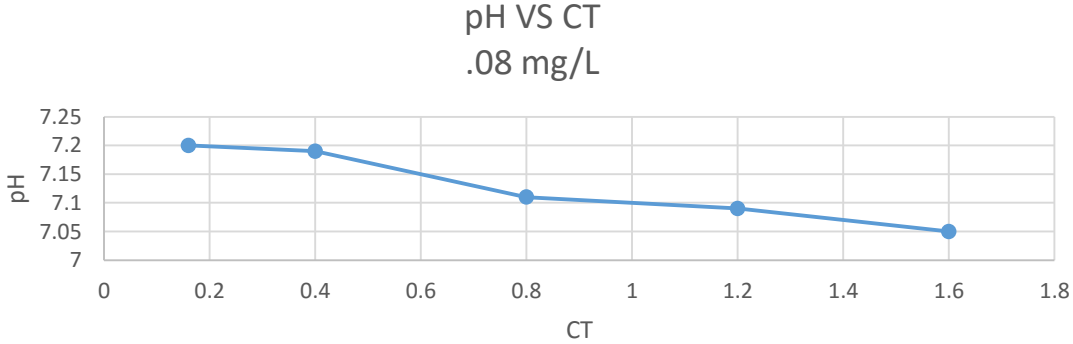




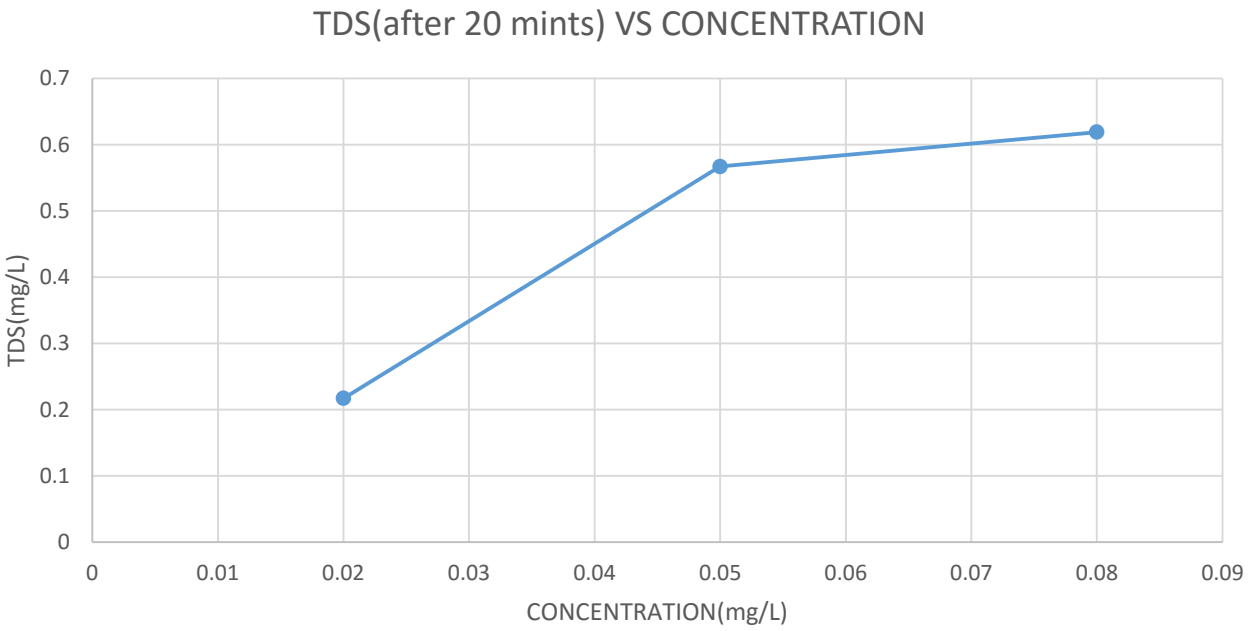
F2.2: pH VS CT



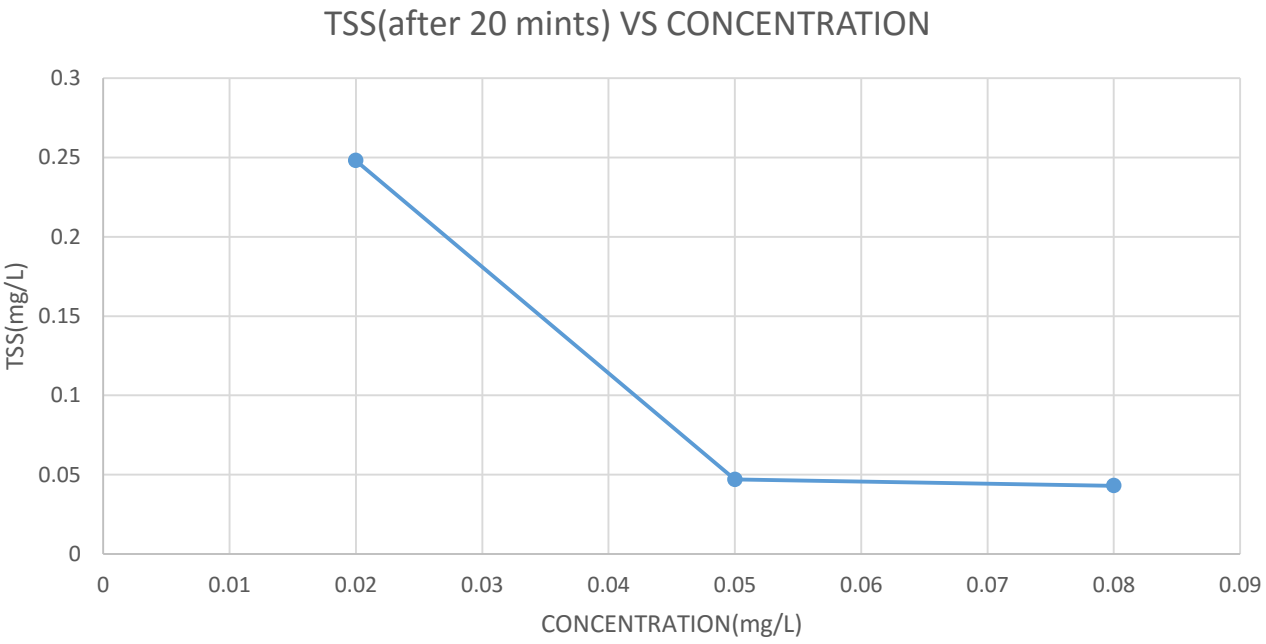




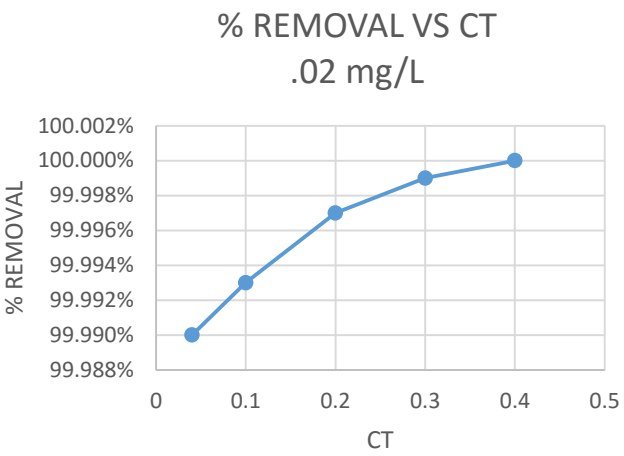
F2.3: TDS VS CONCENTRATION

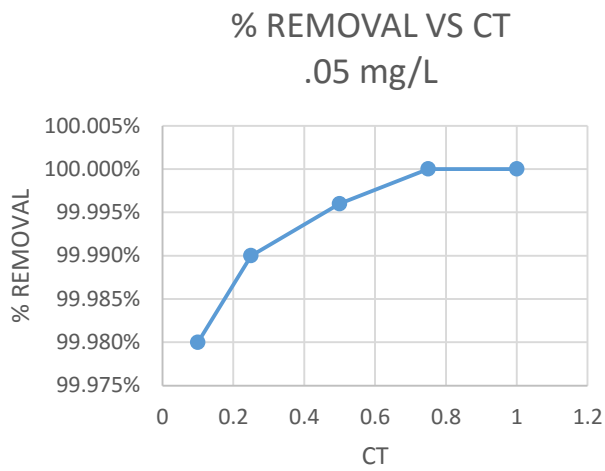


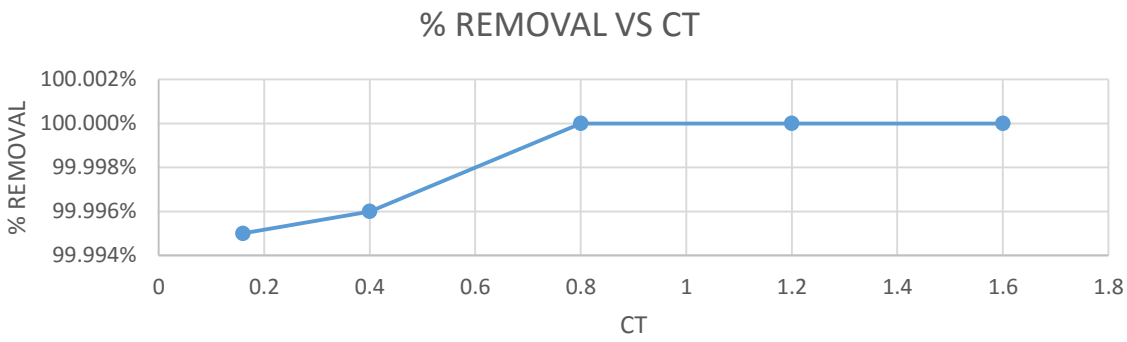
F2.4: TSS VS CONCENTRATION



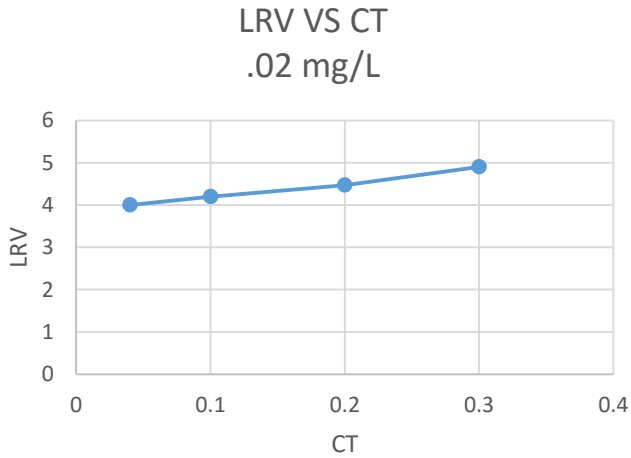
F2.5: % REMOVAL VS CT

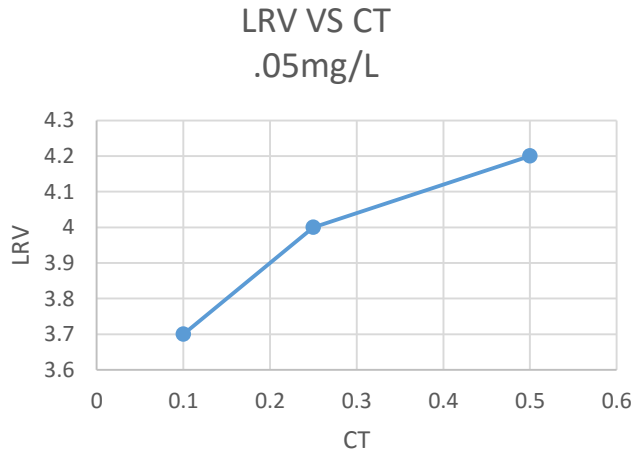


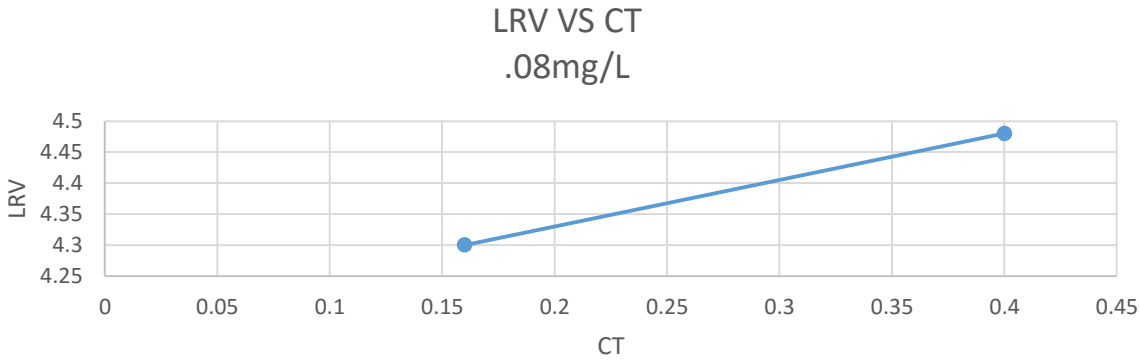




F2.6: LRV VS CT

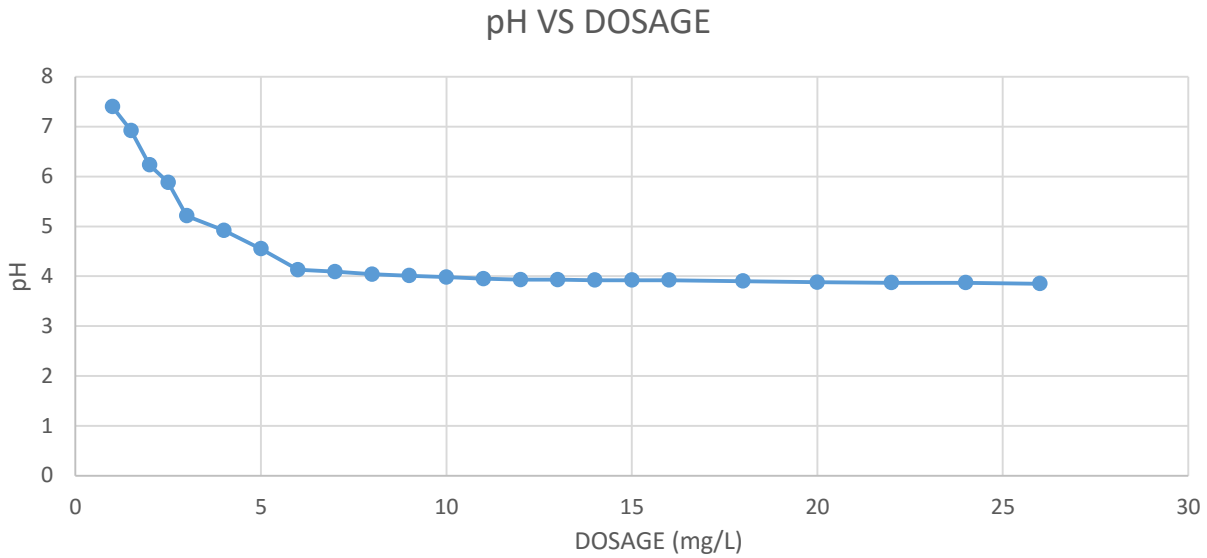




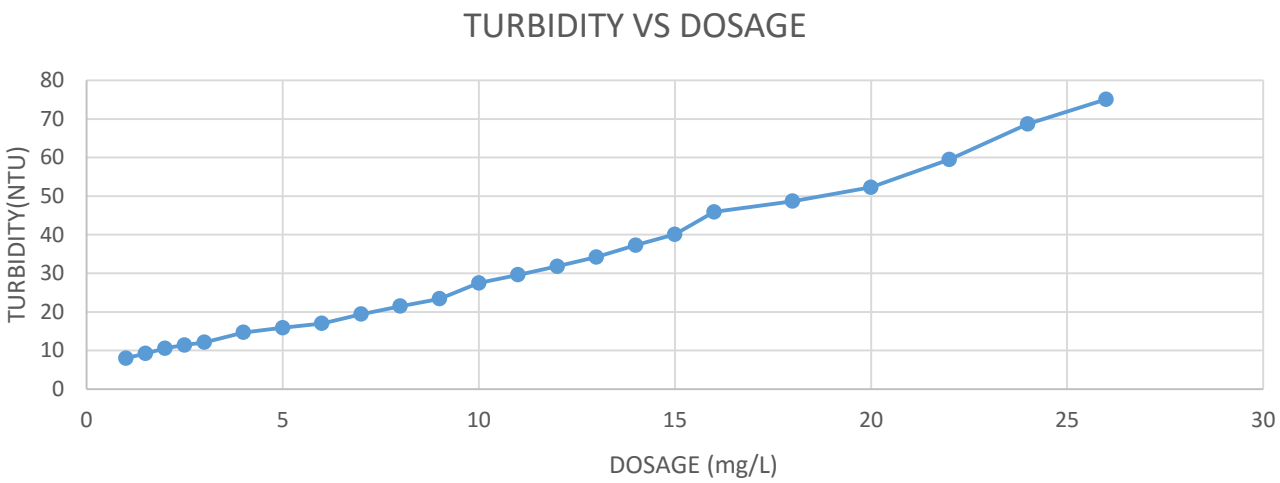


F3: COAGULATION AND SEDIMENTATION

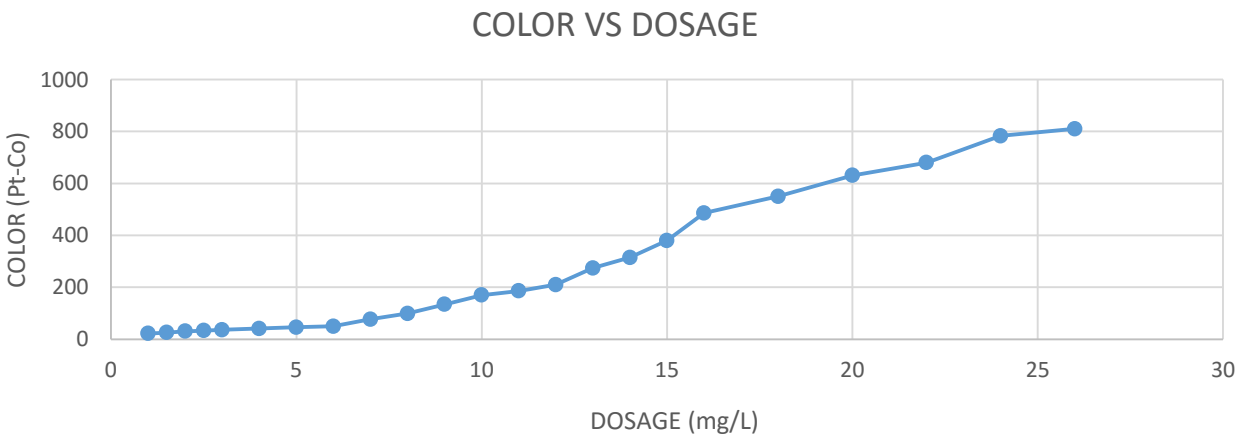
F3.1: pH VS DOSAGE



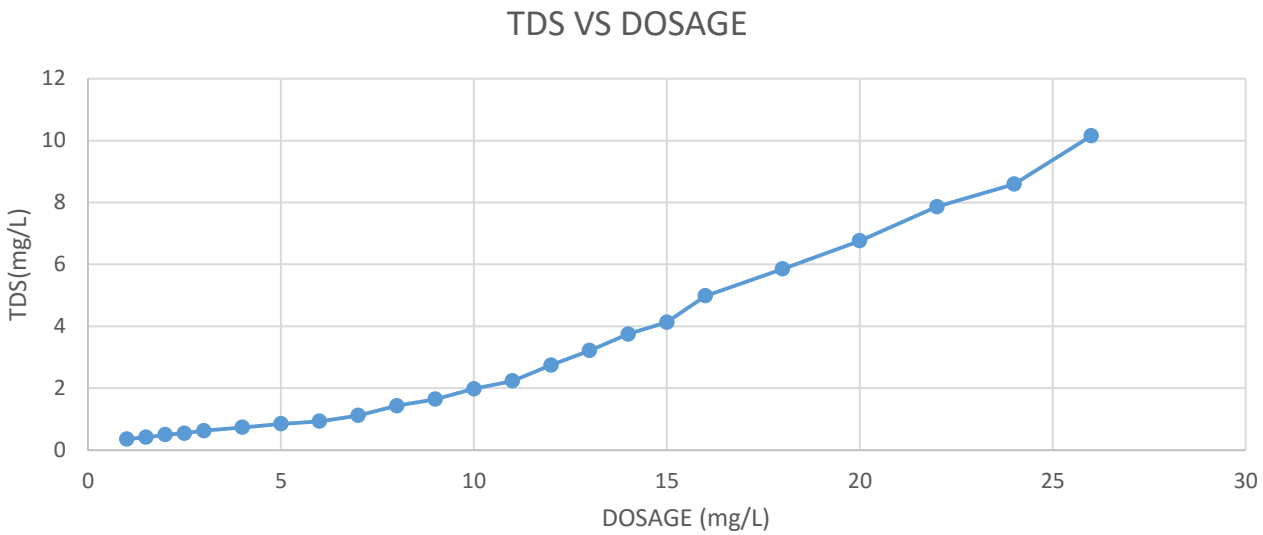
F3.2: TURBIDITY VS DOSAGE



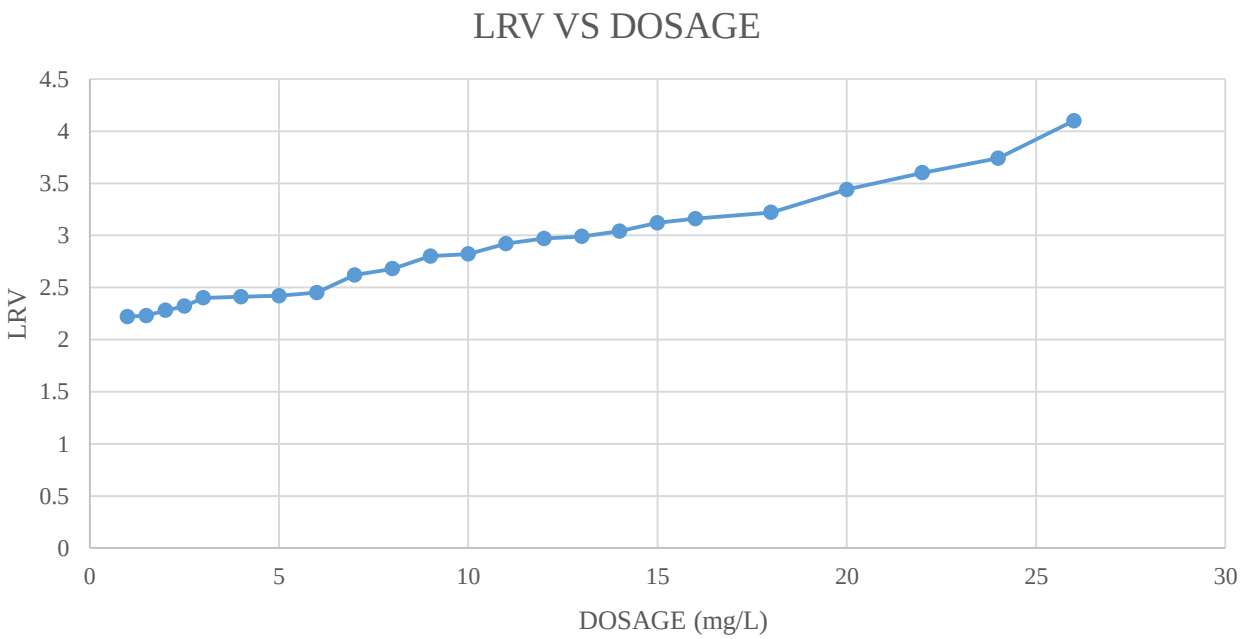
F3.3: COLOR VS DOSAGE



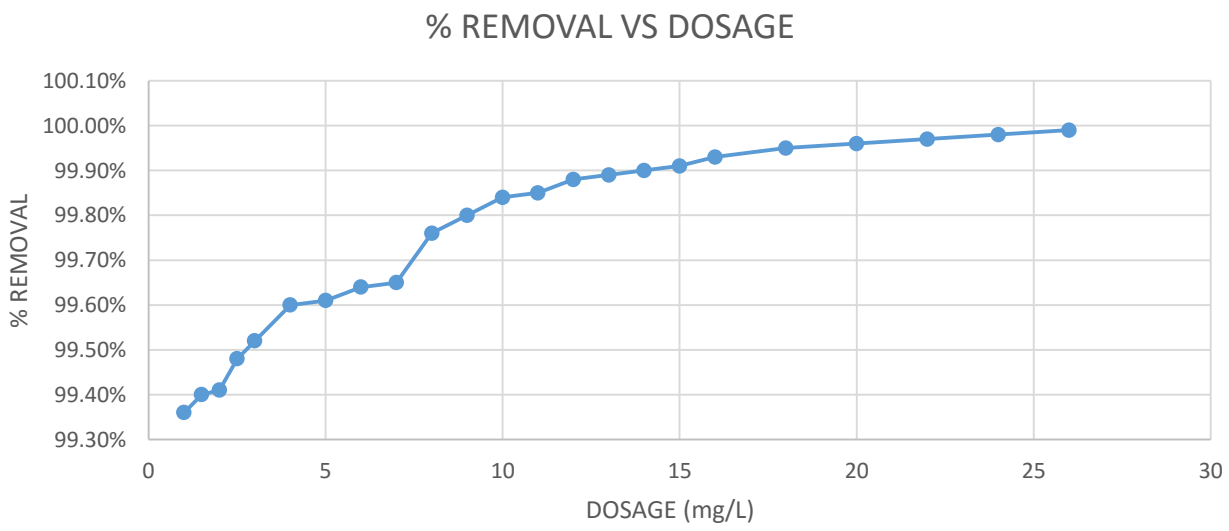
F3.4: TDS VS DOSAGE



F3.5: LRV VS DOSAGE

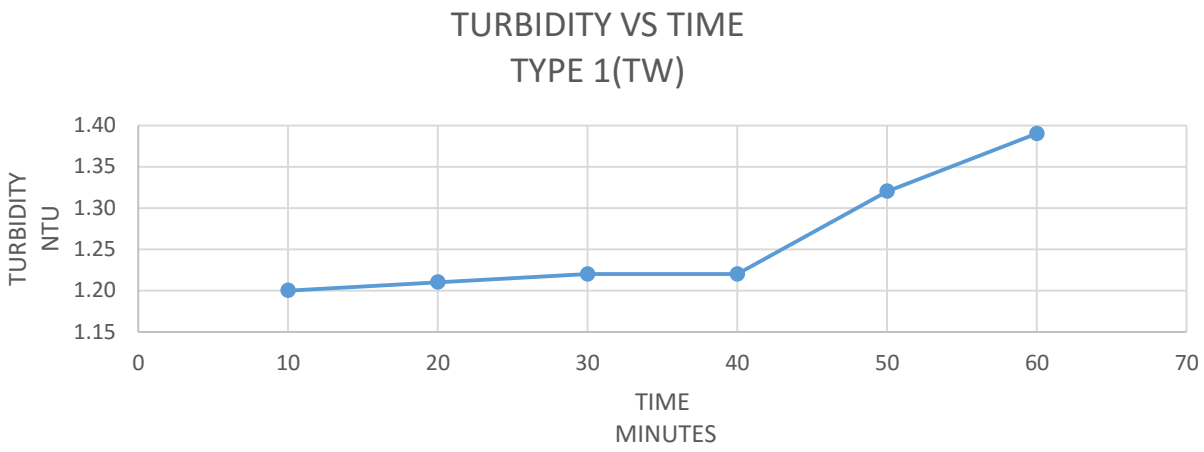


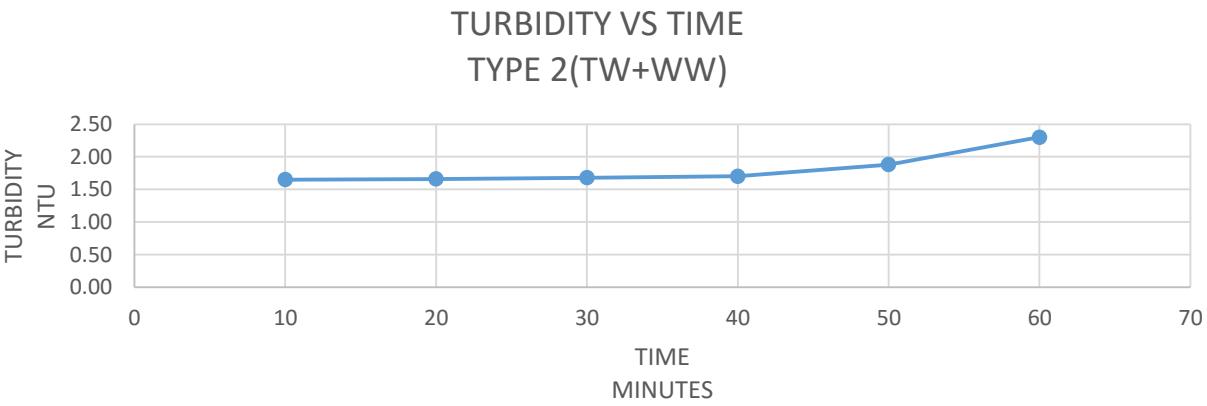
F3.5: % REMOVAL VS DOSAGE



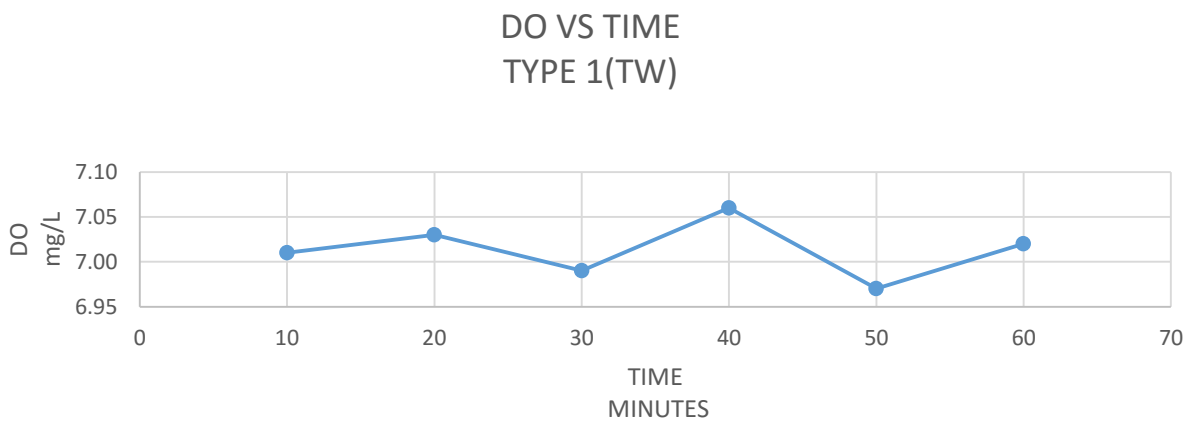
F4: UV DISINFECTION

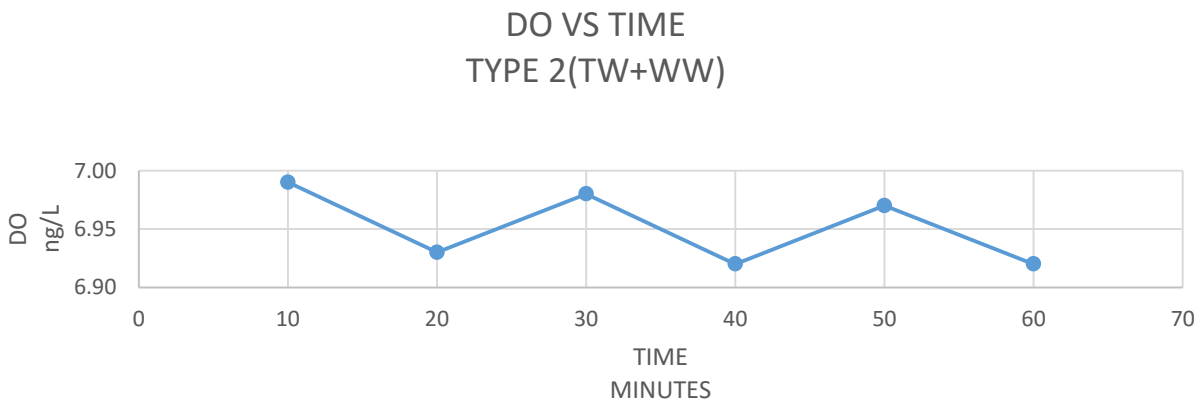
F4.1: TURBIDITY VS TIME



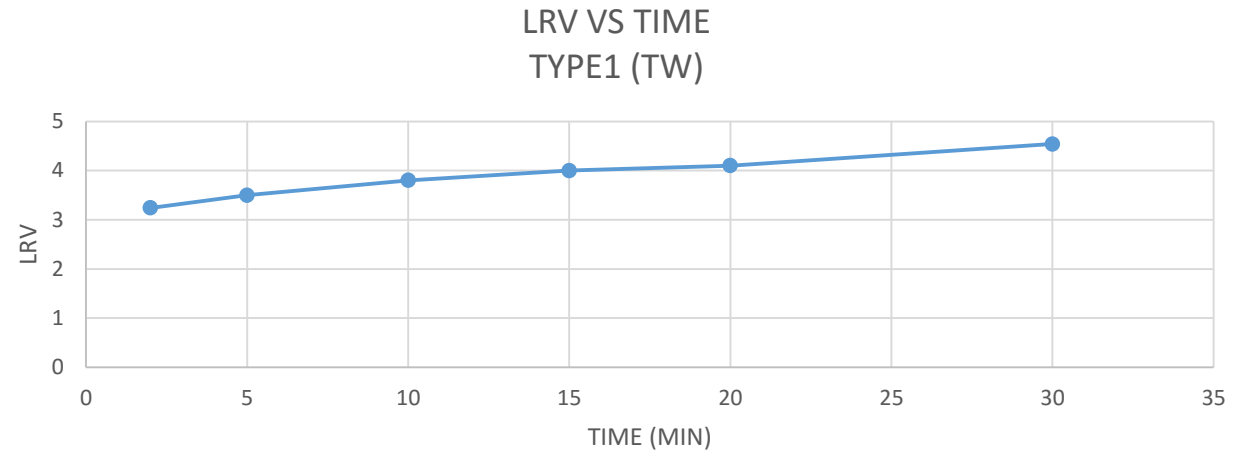


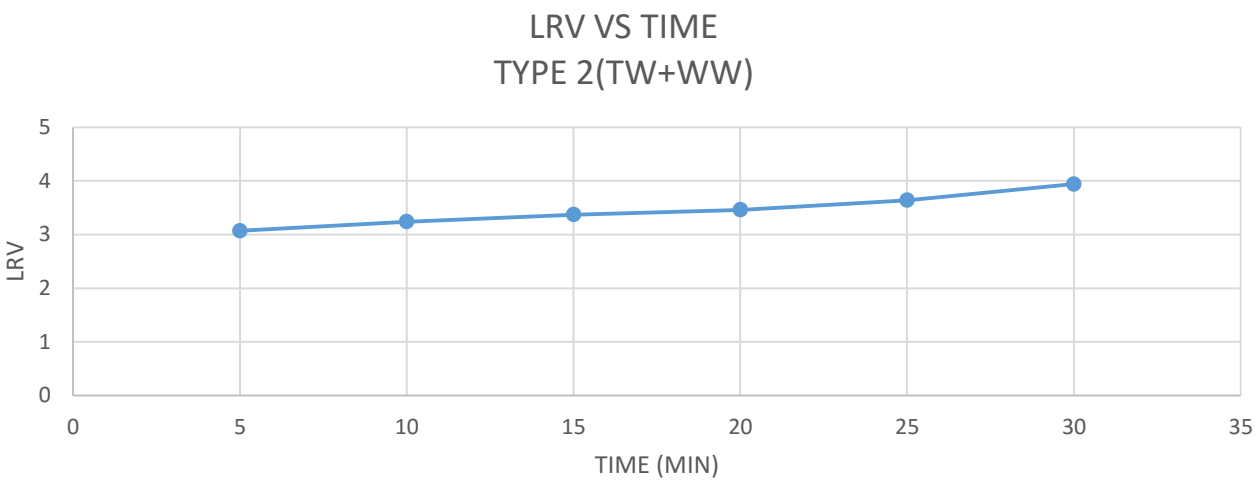
F4.2: DO VS TIME



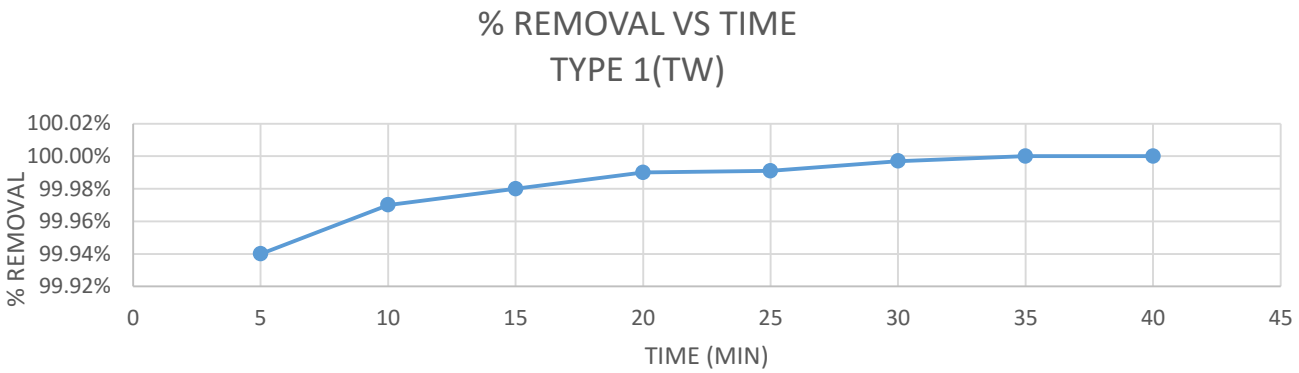


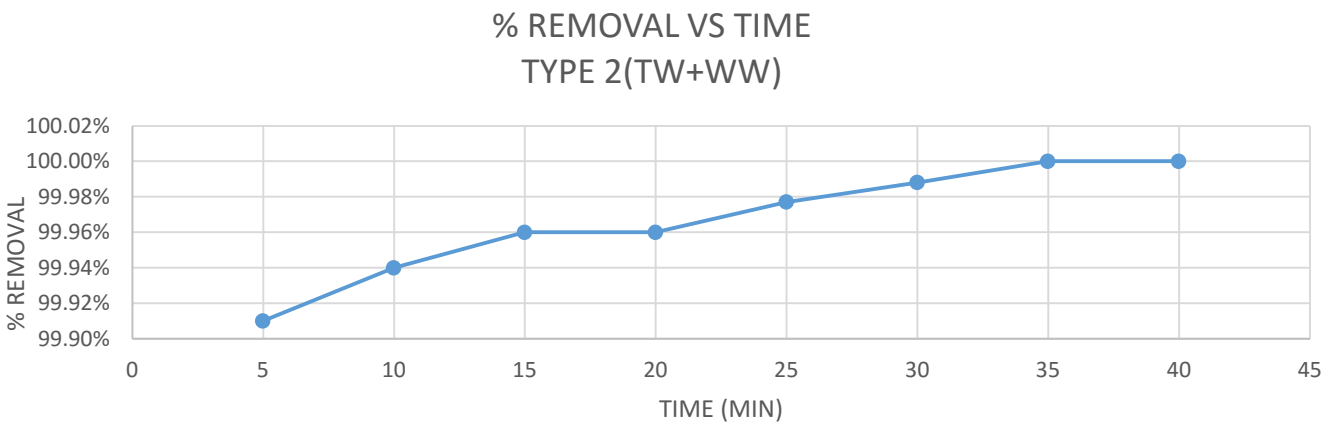
F4.3: LRV VS TIME





F4.3: % REMOVAL VS TIME





Appendix: Control Experiment TABLES

T1: Filtration Method by Ceramic Filter

T1.1: Microbiological result of E. coli

T1.1.1: Microbiological result of E. coli in 1st sampling

	M1-1	M1-2	M2-1	M2-2	J1-1	J1-2	J2-1	J2-2	N1-1	N1-2	N2-1	N2-2	Ne1-1	Ne1-2	Ne2-1	Ne2-2
EC (CFU/100mL)	7x10^5	20	9x10^5	30	6x10^5	10	3x10^5	10	42x10^5	40	9x10^5	40	0	0	0	0
Log Removal Value	4.5		4.48		4.78		4.48		5.02		4.35		N.C		N.C	
% reduction	99.998%		99.997%		99.998%		99.997%		99.9999%		99.995%		N.C		N.C	

T1.1.2: Microbiological result of E. coli in 2nd sampling

	M1-1	M1-2	M2-1	M2-2	J1-1	J1-2	J2-1	J2-2	N1-1	N1-2	N2-1	N2-2	Ne1-1	Ne1-2	Ne2-1	Ne2-2
EC (CFU/100mL)	4x10^5	30	6x10^5	110	8x10^5	60	4x10^5	50	9x10^5	90	7x10^5	100	0	0	0	0
Log Removal Value	4.12		3.74		4.12		3.9		4		3.84		N.C		N.C	
% removal	99.993%		99.980%		99.993%		99.987%		99.990%		99.986%		N.C		N.C	

T1.1.3: Microbiological result of E. coli in 3rd sampling

	M1-1	M1-2	M2-1	M2-2	J1-1	J1-2	J2-1	J2-2	N1-1	N1-2	N2-1	N2-2	Ne1-1	Ne1-2	Ne2-1	Ne2-2
EC (CFU/100mL)	10x10^5	50	12x10^5	80	7x10^5	20	6x10^5	30	9x10^5	20	16x10^5	100	0	0	0	0
Log Removal Value	4.3		4.18		4.54		4.3		4.65		4.2		N.C		N.C	
% removal	99.995%		99.993%		99.997%		99.995%		99.998%		99.994%		N.C		N.C	

T1.1.4: Microbiological result of E. coli in 4th sampling

	M1-1	M1-2	M2-1	M2-2	J1-1	J1-2	J2-1	J2-2	N1-1	N1-2	N2-1	N2-2	Ne1-1	Ne1-2	Ne2-1	Ne2-2
EC (CFU/100mL)	6x10^5	450	5x10^5	80	9x10^5	90	11x10^5	150	7x10^5	160	13x10^5	300	0	0	0	0
Log Removal Value	3.12		3.8		4		3.87		3.64		3.64		N.C		N.C	
% removal	99.925%		99.984%		99.990%		99.986%		99.977%		99.976%		N.C		N.C	

T1.1.5: Microbiological result of E. coli in 5th sampling

	M1-1	M1-2	M2-1	M2-2	J1-1	J1-2	J2-1	J2-2	N1-1	N1-2	N2-1	N2-2	Ne1-1	Ne1-2	Ne2-1	Ne2-2
EC (CFU/100mL)	15x10^5	100	8x10^5	80	12x10^5	90	4x10^5	50	11x10^5	40	6x10^5	60	0	0	0	0
Log Removal Value	4.17		4		4.12		3.9		4.44		4		N.C		N.C	
% removal	99.993%		99.990%		99.992%		99.987%		99.996%		99.990%		N.C		N.C	

T1.2: Physic-Chemical results

T1.2.1: Physic-Chemical results of 1st sampling

	M1-1	M1-2	M2-1	M2-2	J1-1	J1-2	J2-1	J2-2	N1-1	N1-2	N2-1	N2-2	Ne1-1	Ne1-2	Ne2-1	Ne2-2
Turbidity (NTU)	1.8	0.61	55.2	0.65	2.32	0.29	60.3	0.98	6.21	0.82	55.6	0.32	4.96	0.3	36.9	0.41
pH	7.41	8.49	7.43	8.4	7.34	8.5	7.4	8.5	7.32	8.41	7.25	8.57	7.4	8.34	7.38	8.49
EC (µS/cm)	745	887	749	866	615	710	723	641	745	850	764	845	593	573	792	559
Flow Rate(L/day)	22		22		22		22		22		22		22		22	
Color (pt-Co)	40	29	383	24	33	31	240	31	109	16	488	5	33	0	77	29

T1.2.2: Physic-Chemical results of 2nd sampling

	M1-1	M1-2	M2-1	M2-2	J1-1	J1-2	J2-1	J2-2	N1-1	N1-2	N2-1	N2-2	Ne1-1	Ne1-2	Ne2-1	Ne2-2
Turbidity (NTU)	2.1	0.7	60.1	0.86	1.95	0.4	55.2	1.2	4.3	0.95	50.3	0.43	3.5	0.4	32.4	0.53
pH	7.63	8.07	7.59	8.22	7.77	8.03	7.66	8.26	7.96	8.08	7.89	8.05	7.6	8.18	7.97	8.16
EC (µS/cm)	735	850	766	820	680	750	710	680	780	810	728	850	610	550	680	650
Flow Rate(L/day)	20		19		21		22		21		20		19		20	
Color (pt-Co)	45	32	350	40	65	39	252	45	125	25	420	15	35	6	74	50

T1.2.3: Physic-Chemical results of 3rd sampling

	M1-1	M1-2	M2-1	M2-2	J1-1	J1-2	J2-1	J2-2	N1-1	N1-2	N2-1	N2-2	Ne1-1	Ne1-2	Ne2-1	Ne2-2
Turbidity (NTU)	3.5	1.2	65.3	1.9	1.4	0.9	50.3	2.2	5.3	1.6	45.3	1.2	2.3	0.9	36.2	0.98
pH	7.02	8.03	7.7	8.1	7.77	8.06	7.53	8.25	7.63	8.36	8.2	8.3	8.11	8.2	7.06	8.01
EC (µS/cm)	770	850	730	880	635	755	760	677	745	890	740	885	580	530	720	615
Flow Rate(L/day)	18		18		19		19		20		18		18		19	
Color (pt-Co)	50	36	420	75	73	45	302	90	140	40	450	35	48	12	98	55

T1.2.4: Physic-Chemical results of 4th sampling

	M1-1	M1-2	M2-1	M2-2	J1-1	J1-2	J2-1	J2-2	N1-1	N1-2	N2-1	N2-2	Ne1-1	Ne1-2	Ne2-1	Ne2-2
Turbidity (NTU)	2.5	0.63	40.6	0.68	1.35	0.33	45.2	1.1	5.3	0.89	35.1	0.35	5.1	0.34	40.3	0.48
pH	7.58	8.52	7.56	8	7.54	8.21	7.57	8.57	7.6	8.06	7.72	8.21	7.62	8.25	7.7	8.25
EC (µS/cm)	790	850	725	850	680	765	715	785	715	910	810	950	615	590	820	610
Flow Rate(L/day)	21		20		23		22		20		20		21		20	
Color (pt-Co)	35	31	450	29	46	38	290	35	150	20	450	7	32	2	80	36

T1.2.5: Physic-Chemical results of 5th sampling

	M1-1	M1-2	M2-1	M2-2	J1-1	J1-2	J2-1	J2-2	N1-1	N1-2	N2-1	N2-2	Ne1-1	Ne1-2	Ne2-1	Ne2-2
Turbidity (NTU)	2.5	0.63	40.6	0.68	1.35	0.33	45.2	1.1	5.3	0.89	35.1	0.35	5.1	0.34	40.3	0.48
pH	7.58	8.52	7.56	8	7.54	8.21	7.57	8.57	7.6	8.06	7.72	8.21	7.62	8.25	7.7	8.25
EC (µS/cm)	790	850	725	850	680	765	715	785	715	910	810	950	615	590	820	610
Flow Rate(L/day)	21		20		23		22		20		20		21		20	
Color (pt-Co)	35	31	450	29	46	38	290	35	150	20	450	7	32	2	80	36

T1.2.6: Physic-Chemical results of 6th sampling

	M1-1	M1-2	M2-1	M2-2	J1-1	J1-2	J2-1	J2-2	N1-1	N1-2	N2-1	N2-2	Ne1-1	Ne1-2	Ne2-1	Ne2-2
Turbidity (NTU)	1.3	0.9	45	1.2	2.5	0.85	50.2	2.1	3.2	2.5	32.3	1.5	5.3	1.9	45.2	1.8
pH	7.36	7.88	7.33	7.63	7.74	7.86	7.39	7.88	7.28	8.22	7.34	7.8	7.2	7.37	7.19	7.52
EC (µS/cm)	690	785	780	910	680	750	780	680	715	965	755	910	575	530	685	530
Flow Rate(L/day)	18		19		19		18		19		17		19		16	
Color (pt-Co)	54	41	410	42	70	56	370	80	190	54	420	42	35	14	110	70

T1.2.7: Physic-Chemical results of 7th sampling

	M1-1	M1-2	M2-1	M2-2	J1-1	J1-2	J2-1	J2-2	N1-1	N1-2	N2-1	N2-2	Ne1-1	Ne1-2	Ne2-1	Ne2-2
Turbidity (NTU)	1.25	0.62	35.3	0.71	2.2	0.35	51.3	1.5	4.3	0.95	30.1	0.38	6.2	0.36	41.2	0.47
pH	7.52	7.93	7.63	7.84	7.93	8	7.1	7.85	7.67	7.84	7.54	7.53	7.85	8	7.63	8.1
EC (µS/cm)	695	810	715	825	710	850	790	685	740	950	745	812	520	560	755	595
Flow Rate(L/day)	20		20		22		21		20		19		20		19	
Color (pt-Co)	42	35	455	36	49	41	360	40	115	28	465	9	31	6	95	46

T1.2.8: Physic-Chemical results of 8th sampling

	M1-1	M1-2	M2-1	M2-2	J1-1	J1-2	J2-1	J2-2	N1-1	N1-2	N2-1	N2-2	Ne1-1	Ne1-2	Ne2-1	Ne2-2
Turbidity (NTU)	3.5	0.75	32.5	1.2	2.3	0.85	42.3	1.9	2.5	1.2	39.2	0.65	6.1	0.75	39.8	0.56
pH	7.24	7.7	7.75	8.25	7.87	8.65	7.67	7.95	7.5	8	7.45	8	7.88	8.1	8.3	8.45
EC (µS/cm)	755	715	724	736	688	711	760	690	748	845	785	865	584	560	725	545
Flow Rate(L/day)	20		19		22		20		19		17		19		17	
Color (pt-Co)	38	36	395	38	58	43	250	56	120	35	395	18	45	8	150	63

T1.2.9: Physic-Chemical results of 9th sampling

	M1-1	M1-2	M2-1	M2-2	J1-1	J1-2	J2-1	J2-2	N1-1	N1-2	N2-1	N2-2	Ne1-1	Ne1-2	Ne2-1	Ne2-2
Turbidity (NTU)	3.4	0.63	45.2	0.75	1.2	0.39	42.3	1.8	5.2	1.1	46.2	0.56	7.2	0.7	32.3	0.56
pH	7.15	7.3	7.95	8.1	7.5	7.75	7.15	7.35	7.85	8.25	7.1	8.3	7.21	7.6	7.65	7.98
EC (µS/cm)	795	824	766	865	725	762	698	624	742	814	735	842	575	532	745	514
Flow Rate(L/day)	20		21		21		21		20		18		19		18	
Color (pt-Co)	39	36	350	38	49	43	280	55	95	35	340	15	40	11	150	63

T2: CHLORINATION

T2.1: Microbiological result of E. coli

T2.1.1: Microbiological result of E. coli (.02 mg/L)

Dose	0.02 mg/L					
Time (min)	0	2	5	10	15	20
Bacteria (cfu/100 mL)	12x10^5	120	80	40	16	0
Residual Chlorine (mg/L)	0.02	0.015	0.014	0.013	0.012	0.012
% removal	0%	99.99%	99.993%	99.997%	99.999%	100%
LRV		4	4.2	4.47	4.9	

T2.1.2: Microbiological result of E. coli (.05 mg/L)

Dose	0.05 mg/L					
Time (min)	0	2	5	10	15	20
Bacteria (cfu/100 mL)	9x10^5	100	50	30	0	0
Residual Chlorine (mg/L)	0.05	0.031	0.029	0.027	0.024	0.024
% removal	0%	99.98%	99.990%	99.996%	100%	100%
LRV		3.7	4	4.22		

T2.1.3: Microbiological result of E. coli (.08 mg/L)

Dose	0.08 mg/L					
Time (min)	0	2	5	10	15	20
Bacteria (cfu/100 mL)	12x10^5	60	40	0	0	0
Residual Chlorine (mg/L)	0.08	0.073	0.07	0.07	0.07	0.07
% removal		99.995%	99.996%	100.000%	100.000%	100.000%
LRV		4.3	4.48			

T2.2: Physic-chemical result of Chlorination

T2.2.1: Physic-chemical result of Chlorination (.02 mg/L)

TIME(min)	PH	TEMPERATURE	TDS(20 mints)	TSS(20 mints)
2	7.35	26.5	0.217 mg/L	0.248 mg/L
5	7.25	26.5		
10	7.19	26.1		
15	7.1	26.6		
20	7.03	26.7		

T2.2.2: Physic-chemical result of Chlorination (.05 mg/L)

TIME	PH	TEMPERATURE	TDS(20 mints)	TSS(20 mints)
2	7.37	26.5	0.567 mg/L	0.047 mg/L
5	7.14	26		
10	7.1	26.1		
15	7.08	26.3		
20	7.05	26.7		

T2.2.3: Physic-chemical result of Chlorination (.08 mg/L)

TIME	PH	TEMPERATURE	TDS	TSS
2	7.2	26.5	0.619 mg/L	0.043 mg/L
5	7.19	26.3		
10	7.11	26.2		
15	7.09	26.3		
20	7.05	26.8		

T3: COAGULATION AND SEDIMENTATION

T3.1: Microbiological result of E. coli

Sample	Alum Dosage (mg/L)	Bacteria (CFU/100mL)	%removal	LRV
1	0	5X10^5		
2	0.5	3200	99.36%	2.19
3	1	3000	99.40%	2.22
4	1.5	2960	99.41%	2.23
5	2	2600	99.48%	2.28
6	2.5	2400	99.52%	2.32
7	3	2000	99.60%	2.40
8	4	1960	99.61%	2.41
9	5	1800	99.64%	2.42
10	6	1760	99.65%	2.45
11	7	1200	99.76%	2.62
12	8	1000	99.80%	2.68
13	9	800	99.84%	2.80
14	10	750	99.85%	2.82
15	11	600	99.88%	2.92
16	12	540	99.89%	2.97
17	13	500	99.90%	3.00
18	14	450	99.91%	3.04
19	15	380	99.92%	3.12
20	16	340	99.93%	3.16
21	18	270	99.95%	3.12
22	20	180	99.96%	3.44
23	22	130	99.97%	3.60
24	24	90	99.98%	3.74
25	26	40	99.99%	4.10

T3.2: Physic-chemical results of Coagulation and Sedimentation

DOSAGE (mg/L)	PH	TURBIDITY(NTU)	TOTAL DISSOLVED SOLIDS(mg/L)	COLOR(Pt-Co)
1	7.4	8	0.354	22
1.5	6.92	9.2	0.412	26
2	6.23	10.6	0.498	31
2.5	5.88	11.4	0.543	33
3	5.21	12.1	0.627	36
4	4.92	14.7	0.731	41
5	4.55	15.9	0.845	46
6	4.13	17	0.930	50
7	4.09	19.4	1.114	77
8	4.04	21.5	1.432	99
9	4.01	23.4	1.641	134
10	3.98	27.5	1.978	170
11	3.95	29.6	2.235	186
12	3.93	31.8	2.744	210
13	3.93	34.2	3.213	274
14	3.92	37.3	3.749	315
15	3.92	40.1	4.130	380
16	3.92	45.9	4.985	486
18	3.9	48.7	5.850	550
20	3.88	52.3	6.761	631
22	3.87	59.5	7.860	680
24	3.87	68.7	8.592	783
26	3.85	75.1	10.154	810

T4: UV DISINFECTION

T4.1: Microbiological result of E. coli

T4.1.1: TYPE 1(TAPE WATER)

Time (min)	0	5	10	15	20	25	30	35	40
Bacteria (cfu/100 mL)	7x10^5	400	220	100	70	60	20	0	0
% removal	0%	99.94%	99.97%	99.98%	99.99%	99.991%	99.997%	100.000%	100.00%
LRV		3.24	3.5	3.8	4	4.1	4.54	N.C	N.C

T4.1: Microbiological result of E. coli

T4.1.2: TYPE 2(TAPE WATER+WASTE WATER)

Time (min)	0	5	10	15	20	25	30	35	40
Bacteria (cfu/100 mL)	7x10^5	600	400	300	240	160	80	0	0
% removal	0%	99.91%	99.94%	99.96%	99.97%	99.977%	99.988%	100.000%	100.00%
LRV		3.07	3.24	3.37	3.46	3.64	3.94	N.C	N.C

T4.2: Physic-chemical results of UV DISINFECTION
T4.2.1: TYPE 1(TAPE WATER)

TIME(MIN)	DO(mg/L)	TURBIDITY(NTU)
10	7.01	1.20
20	7.03	1.21
30	6.99	1.22
40	7.06	1.22
50	6.97	1.32
60	7.02	1.39

T4.2: Physic-chemical results of UV DISINFECTION
T4.2.2: TYPE 1(TAPE WATER+WASTE WATER)

TIME(MIN)	DO(mg/L)	TURBIDITY(NTU)
10	6.99	1.65
20	6.93	1.66
30	6.98	1.68
40	6.92	1.70
50	6.97	1.88
60	6.92	2.30