CLOTH FILTER FOR DISASTER RELIEF WATER TREATMENT

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by
Shasta Le'ja Billings

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COMMITTEE MEMBERSHIP

- TITLE:** Cloth Filter for Disaster Relief Water Treatment
- AUTHOR:** Shasta Le'ja Billings
- DATE SUBMITTED:** March 2013
- COMMITTEE CHAIR:** Dr. Tryg Lundquist, Ph.D., Associate Professor
Civil and Environmental Engineering Department
Cal Poly, San Luis Obispo
- COMMITTEE MEMBER:** Dr. Yarrow Nelson, Ph.D., Professor
Civil and Environmental Engineering Department
Cal Poly, San Luis Obispo
- COMMITTEE MEMBER:** Dr. Shikha Rahman, Ph.D., Associate Professor
Civil and Environmental Engineering Department
Cal Poly, San Luis Obispo

ABSTRACT

Cloth Filter for Disaster Relief Water Treatment

Shasta Le'ja Billings

Relief organizations and governments strive to provide safe drinking water to natural disaster survivors as quickly as possible. However, drinking water is typically provided either as bottled water or via mobile water treatment equipment, both of which can be difficult or expensive to transport rapidly into disaster zones. An alternative is the waterbag point-of-use treatment device developed at Cal Poly that allows survivors to produce safe drinking water from contaminated local sources. The waterbag is a 10-L bladder designed for use with Procter & Gamble Purifier of Water (PÜR[®]) sachets, which contain coagulant and chlorine compounds. Following treatment with PÜR[®], treated water in the waterbag is flowed through an outlet port to a filter, primarily for parasitic cyst removal. Currently, the commercial version of the waterbag uses an effective but expensive hollow-fiber membrane microfilter (>\$10 each). This cost will likely decrease the use of the waterbag by relief organizations responding to large disasters. The goal of the present thesis research was to develop a novel, low cost (~\$5), effective, low-profile filter to be used with the waterbag in large-scale disaster relief. This new filter is referred to as an envelope filter due to its geometry and size.

Various prototype envelope filters were constructed using layers of nonwoven polypropylene filter cloth. Two types of cloth were used: a nominally-rated 1- μ m pore size cloth and an absolute-rated 1- μ m cloth. The filters tested were both internal and external to the waterbag and of various geometries. Filters were attached to the waterbag and used to filter defined test water after it had been treated with a PÜR[®] sachet. Test

water for design experiments consisted of tap water with addition of standard dust (to increase turbidity) and seasalts (to increase salinity). In addition to this basic test water, mock U.S. EPA Challenge Water #2 with added bacteria and cyst surrogates (fluorescent microspheres) was used to evaluate the filter prototype designs prior to testing according to U.S. EPA Guide Standard and Protocol for Testing Microbiological Water Purifiers in a commercial laboratory.

The filter design and mock challenge experiment results indicated that a 2-ply filter with one nominal and one absolute layer was the optimal filter design. In the mock U.S. EPA challenge tests, a flowrate of 20 mL/min allowed this filter met the turbidity, bacteria, and microsphere removal requirements determined by the WHO and The Sphere Project for emergency drinking water treatment as well as the U.S. EPA Guide Standard and Protocol for Testing Microbiological Water Purifiers.. This filter design was further tested using the U.S. EPA Challenge Water #2 with triplicate waterbags at the U.S. EPA-certified BioVir Laboratories in Benicia, Calif. All three waterbags with envelope filters met the recommendations for turbidity (<5 NTU) and for virus removal (>4 -log removal). Two of the three waterbags met the bacteria and microsphere removal requirements (>6 - and >3 -log removal, respectively). The failure of one of the prototypes to meet the requirements could have been due to improper setting of valve that throttled the flowrate through the filter or due to a slightly leaking hose pinch valve. Future work should include incorporating more reliable valves and improving the envelope filter design and materials to achieve higher allowable flowrates.

Keywords: cloth filter, disaster relief, water treatment

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CHAPTER 1: INTRODUCTION

Globally, 783 million people, or one in nine people around the globe, lack access to clean drinking water, and 2.5 million lives could be saved each year if everyone had access to clean drinking water and adequate sanitation. For example, about 2,000 children die every day from water-related diseases (WaterAid, 2012). Beyond these chronic problems, about 255 million people are affected by natural disasters each year (DayOne Response, 2012). Survivors are susceptible to illnesses and death from diseases due to inadequate sanitation and water supplies as well as poor hygiene (The Sphere Project, 2004). Governments and relief organizations, such as the Red Cross, UNICEF, and CARE respond after natural disasters by providing basic supplies including drinking water or drinking water treatment equipment. Relief organizations typically provide clean drinking water to survivors in two ways:

1. transporting pre-treated, clean drinking water to the disaster zone, or
2. distributing point-of-use (POU) drinking water treatment devices capable of treating contaminated water in the disaster zone (DayOne Response, 2012).

Option two, mentioned above, is more ideal as POU treatment devices are more compact, and survivors can treat contaminated water on their own, with minimal additional effort by the relief organization. Also, with a POU treatment device, survivors are more likely to be able to treat water until a permanent solution is available.

Standards for humanitarian assistance have been developed by both The Sphere Project and the World Health Organization (WHO) (The Sphere Project, 2004). These standards aimed to increase the quality of assistance survivors received after a natural disaster (The

Sphere Project, 2004). In addition to these standards, the United States Environmental Protection Agency (U.S. EPA) developed the Guide Standard and Protocol for Testing Microbiological Water Purifiers, which applies to domestic water purifiers in addition to POU purifiers. The U.S. EPA Guide Standard mandates minimum pathogen removal amounts for U.S. EPA-approved microbiological treatment devices.

Procter & Gamble manufactures a POU drinking water treatment method: PÜR® Purifier of Water chemical sachets (PÜR® sachet). The PÜR® sachet contains various coagulants, flocculants, and disinfection chemicals, and has met the U.S. EPA Guide Standard and Protocol for Testing Microbiological Water Purifiers required pathogen removals using the procedures printed on the sachets (Procter & Gamble, 2013). These instructions use a two-bucket treatment method. While the two-bucket method is effective for treatment, it also has some drawbacks. Namely, the method requires two 20-L buckets, a mixing tool, and a clean filter cloth. Disaster survivors or persons in the developing world may not be able to obtain these materials easily. Furthermore, the open buckets are not protected from the environment, which could allow the treated water to become re-contaminated.

Students at California Polytechnic State University, San Luis Obispo have been developing an alternative to the standard PÜR® two-bucket method since 2007 (Compas, 2009 and Herzog, 2011). This alternative uses a 10-liter plastic waterbag: the Polytech Waterbag referred to as the “waterbag” in this thesis and commercially as the DayOne Waterbag™. The waterbag system uses PÜR® for chemical treatment and also provides water collection, treatment, transport, and storage in a single unit.

The Mark I waterbag was in development from 2007-2009. Development consisted of testing various waterbag geometries and materials as well as usability, capacity, and mixing method (Compas, 2009). The Mark I waterbag used one PÜR[®] sachet and met the WHO emergency drinking water guidelines, but was unable to meet the U.S. EPA pathogen removal requirements. A patent was issued for the Mark I waterbag design and features (US PTO No. 7,514,006).

The Mark II waterbag was developed and optimized during 2009-2010. Optimization methods consisted of testing various waterbag geometries, mixing durations, mixing motions, as well as baffle designs (Herzog, 2011). The Mark II waterbag was able to pass the U.S. EPA purifier standard using two PÜR[®] sachets. A continuation-in-part pending application was submitted to include the findings from these optimization experiments. The Mark II waterbag was used during all experiments for this research.

An important component of the waterbag system is the filter used for the final discharge, which is required to meet the standards for disaster relief water treatment. Currently, available filters are effective, but they are also expensive and bulky. The purpose of the research presented in this thesis is to develop an improved filter to be used with the waterbag and to test the efficacy of the final design. Ten filter designs were tested over the course of 22 experiments. The specific objectives of this research included:

1. Design a filter prototype to meet water quality criteria for disaster relief that is much lower cost and geometrically flatter than commercially available POU filters. Water quality criteria adopted for this work were the WHO and The

Sphere Project emergency drinking water guidelines as well as the U.S. EPA Guide Standard and Protocol for Testing Microbiological Water Purifiers.

2. Conduct water quality experiments at a certified commercial laboratory to determine the efficacy of the filter in meeting the WHO, Sphere Project and U.S. EPA drinking water guidelines.

The following chapter provides background on filtration, water quality criteria, and other POU water treatment technologies.

CHAPTER 2: BACKGROUND

This chapter identifies standard drinking water contaminants, describes the U.S EPA Guide Standard and Protocol for Testing Microbiological Water Purifiers, and summarizes filtration mechanisms and technologies.

2.1 Drinking Water Contamination during Emergencies

Natural disasters (e.g., tsunamis, hurricanes, monsoons, mudslides, or floods) can contaminate drinking water sources and also damage drinking water treatment systems. The health of survivors is dependent in part on the supply of drinking water immediately following a natural disaster (The Sphere Project, 2004).

Drinking water contamination can be divided into two specific types: non-microbiological and microbiological. Non-microbiological contamination includes, among others, turbidity, pH, natural organic matter (NOM), and dissolved solids. Non-microbiological contamination has been extensively reviewed in previous waterbag theses and will not be further described here (Compas, 2009 and Herzog, 2011). Microbiological contamination includes bacteria, viruses, protozoa, and helminthes (MWH, 2005). The present thesis research focused on microbiological contamination, excluding helminthes which are more easily removed or inactivated than the other pathogens. Specifically, the research focused on how to remove protozoan cysts through filtration. The following brief review will discuss the microbiological contamination of drinking water due to bacteria, viruses, and protozoan cysts only.

In order to effectively treat and remove microbiological contamination, size and reaction to disinfection must be considered.

Bacteria –Bacteria typically range in size from 0.1 μm to 10 μm in diameter (MWH, 2005). As size decreases, removal efficiency by filtration decreases as well. Bacterial cells are killed when an adequate amount of disinfectant is added to the water and a proper contact time elapses (MWH, 2005).

Viruses – Viruses typically range in size from 0.02 μm to 0.1 μm in diameter (MWH, 2005). Due to their very small size, filtration is an ineffective removal technique. Most viruses are also killed when exposed to disinfectants, but some enteroviruses are resistant to disinfection (MWH, 2005).

Protozoa – Protozoan cysts typically range in size from 3 μm to 16 μm in diameter (MWH, 2005). Oocysts of *Cryptosporidium*, which are used as a benchmark organism in water treatment, range in size from 3 μm to 5 μm in diameter. Two common protozoan pathogens are *Giardia lamblia* and *Cryptosporidium parvum* (**Figure 2.1**). Both cause diarrhea in humans when ingested. Protozoa have a complicated lifecycle. One stage of reproduction allows the protozoa to be encased in a hard, protective shell, allowing the protozoa to survive in most environments and rendering it resistant to disinfection (MWH, 2005). Because it is resistant to disinfection, the oocyst must be physically removed from the water source via filtration.

Figure 2.1: *Cryptosporidium parvum* and *Giardia lamblia* cysts viewed with confocal microscopy (U.S. EPA, 2013).

2.2 U.S. EPA Guide Standard and Protocol for Testing Microbiological Water Purifiers

The U.S. EPA Guide Standard and Protocol for Testing Microbiological Water Purifiers applies to microbiological water purification units that “remove, kill or inactivate all types of disease-causing microorganisms from the water, including bacteria, viruses and protozoan cysts so as to render the processed water safe for drinking” (U.S. EPA, 1987).

The standard applies to three types of microbiological water purification units: ceramic filters, halogenated disinfectants, and ultraviolet disinfection (U.S. EPA, 1987).

Halogenated disinfectants are disinfectants that contain an element from the halogen group on the periodic table (i.e. chlorine, iodine, or bromine) (Metcalf & Eddy, 2003).

The U.S. EPA Guide Standard describes halogenated disinfectants as a process involving both chemical disinfection and filtration.

A microbiological water purifier must meet specific removal requirements as specified in the U.S. EPA Guide Standard (**Table 2.1**). The U.S. EPA Guide Standard also contains requirements or “recipes” for challenge waters to be used in experiments when measuring

performance of a microbiological water purifier. Specifically, Challenge Water #2 was used for experiments performed during this research (Table 2.2).

Table 2.1: Initial concentrations of organisms in Challenge Water #2 and required log removals for microbiological water purifiers, as specified by U.S. EPA and NSF.

Challenge Organism	Initial Challenge ¹	Minimum Required Reduction	
		Log	%
Bacteria:			
<i>Klebsiella terrigena</i> (EPA, NSF)			
<i>Escherichia coli</i> (NSF)	10 ⁷ / 100 mL	6	99.9999
<i>Bacillus atrophaeus</i> (spore form)			
Virus:			
Poliovirus 1 and Rotavirus (EPA)	10 ⁷ / L	4	99.99 ²
MS2 and fr coliphage (NSF)	10 ⁷ / L		
Protozoan Cyst:			
<i>Giardia muris</i> or <i>G. lamblia</i> (EPA)	10 ⁶ / L	3	99.9
Particles or microspheres 4-6 μm ³	10 ⁷ / L	3	99.9

¹ “Influent challenges may constitute greater concentrations than would be anticipated in source waters, but these are necessary to properly test, analyze, and quantitatively determine the indicated log reductions.” (U.S. EPA 1987).

² A combined 4-log reduction between both virus types listed is acceptable.

³ Microspheres used in place of protozoan cysts to ensure safety of researchers. Note, microspheres simulate protozoan cysts and function similarly in test water.

Table 2.2: U.S. EPA Challenge Water #2 inorganic characteristics to be treated with microbiological water purifiers using halogen disinfection.

Constituent	Challenge Value	Recommended Materials for Adjustment of Test Water Characteristics
Chlorine residual	none	deionized water
pH	9.0 ± 0.2	HCl or NaOH
TOC	>10 mg/L	humic acids
Turbidity	>30 NTU	fine test dust ¹
Temperature	4°C ± 0.1°C	refrigeration/ice
TDS	1500 ± 150 mg/L	sea salts

¹Fine test dust recommended was A2 Fine Test Dust iso 12103-1.

2.3 Filtration Mechanism and Technologies

Filtration is defined as “a process that separates suspended particles (a dispersed solid phase) from a liquid phase by passage of the suspension through a porous medium (either membranes or granular media)” (MWH, 2005). The following characteristics should be considered when determining the correct filtration material: media type, hydraulic loading, pore-size, pore length, tortuosity, hydrophobicity, bed depth, cloth thickness, head loss, cake formation/ripening/ dirt breakthrough, flow velocity, and particle characteristics (size, surface charge, and shape). For the present thesis research, only the following characteristics were considered: hydraulic loading, cloth thickness, cake formation/ripening/dirt breakthrough, and particle characteristics (size, surface charge, and shape).

Typically, membranes are manufactured from a synthetic material and 1-mm thick or less. Granular media ranges from 0.3 mm to 1.2 mm in diameter and granular media filters range from 0.9 m to 1.8 m in depth (MWH, 2005). The goal of the present thesis

research is to produce a compact filter to be used in conjunction with the waterbag. Therefore, the present research tested filters made of nonwoven fabric.

2.3.1 Hydraulic Loading

The hydraulic loading rate is defined as the liquid flow applied over the entire filter area. A 2011 study found that “hydraulic loading rates have a significant effect on the performance of porous media filters” (Wilson et al, 2011). The natural hydraulic loading rate applied to the filter cloth used for the present thesis research was too large for the filter cloth to perform effectively. Therefore, the flowrate was reduced with stopcock valves until the required microbiological removal rates were seen in treated, filtered effluent.

2.3.2 Cloth Thickness

Cloth thickness directly affects the head loss across the filter material. Head loss and filter material thickness are proportional to each other in that the thinner the filter material is, the lower the head loss (MWH, 2005).

2.3.3 Cake Formation/Ripening/Dirt Breakthrough

In membrane filtration, the dominant removal mechanism is straining and the other two removal mechanisms are cake filtration (i.e., schmutzdecke) and adsorption. As solids build-up against the filter cloth, a filter cake forms. The filter cake acts as a filtration material and provides another method of particle rejection. Cake formation increases the filter’s resistance to flow and leads to an increase in transmembrane pressure. Due to the build-up of solids, membrane filters are typically backwashed in order for the filter to continue functioning properly (MWH, 2005).

After a filter is backwashed, there is a period of time that passes while the filter is maturing. This is referred to as the ripening period. Typically, the water collected during the ripening period does not meet drinking water standards and should be discarded. A filter has completed the ripening period when effluent turbidity has returned to typical values (Suthaker, Smith, and Stanley, 1998). In the ripening period, particles are being caught by the clean filter particles; as more particles accumulate, the filter becomes more efficient at collecting additional particles (MWH, 2005).

Breakthrough occurs when the filter can no longer contain any more particles. At this point, particles can pass through the filter, causing an increase in effluent turbidity. Once breakthrough occurs, the filter must be backwashed before it can be used again (MWH, 2005).

2.3.4 Particle Characteristics

Particle characteristics include size, surface charge, and shape. Particles typically range in size from 0.001 to 100 μm ; colloidal particles range from 0.001 to 1 μm and suspended particles are $>1 \mu\text{m}$ in diameter. Size is important as this dictates the pore size required in the chosen filter material. Natural waters typically are heterodispersed, or contain particles of a range of sizes (MWH, 2005).

Particle surface charge contributes to the stability of particles in a solution, which leads to particles staying in suspension in a solution. When particles stay in solution, this increases turbidity of the water sample. Surface charge can be caused by four different happenings: crystal imperfections, structural imperfections, preferential adsorption of specific ions, and ionization of inorganic groups on particulate surfaces. Crystal

imperfections arise when a metal in a metal oxide is replaced by a metal atom with a lower valence, resulting in a negative surface charge on the particle. Structural imperfections occur during the formation of the crystal. Broken bonds along the crystal edge can lead to surface charges. Preferential adsorption of specific ions occurs when a particle adsorbs natural organic matter (NOM, i.e. fulvic acid). NOM is a large macromolecule that contains carboxylic acid groups, which has a negative charge. Ionization of inorganic groups on particulate surfaces occurs when the solution the particles are in is either above or below the particle's zero point of charge pH. When the pH of the solution is above the zero point of charge, the surface charge will be negative (anionic). When the pH of the solution is below the zero point of charge, the surface charge will be positive (cationic) (MWH, 2005).

Particles in water are a variety of shapes: spheres, semi-spheres, ellipses, rods, disks, strings, and coils. Particle shape varies depending of source water characteristics and affects the electrical properties of the particle, the particle-particle interactions, and particle-solvent interactions (MWH, 2005).

2.3.5 Nonwoven Filter Material

Nonwoven filter material is defined as a “porous fabric composed of a random array of fibers or filaments and whose specific function is to filter and/or separate phases and components of a fluid being transported through the medium or to support the medium that does the separation” (Hutten, 2007).

The cloth used for filter construction in the present thesis research was manufactured from polypropylene bag filters. Polypropylene is the most hydrophobic of all industrial-

grade membrane materials. Polypropylene is also durable, chemically and biologically resistant, tolerant of high temperatures, and tolerant of a wide pH range (1 to 13).

However, polypropylene is not tolerant of chlorine (MWH, 2005).

2.3.6 Point-of-Use Filtration Technologies

The following section provides a synopsis of current filtration technologies for POU microbiological treatment devices. The technologies to be discussed are cotton filters (i.e. sari cloth or t-shirt), ceramic filters, LifeStraw[®], LifeStraw[®] Family, hollow-fiber microfilters, sheet microfilters, and bag filters.

Cotton Filters: A filter made from cotton is quite simple but not entirely effective. Compas (2009) found that when turbidity of tap water was increased to at least 350 NTU with the addition of kaolin acid-washed powder, at least three layers of 100% cotton t-shirt material were required before filtered effluent turbidity decreased below 10 NTU and five layers were needed to decrease filtered effluent turbidity to <5 NTU. Another cotton material commonly used is sari cloth, but this material exhibits the same non-effective microbiological removal that t-shirts do. It was found that folding a sari cloth four times only removed 99% (2-log removal) of *Vibrio cholera* (Colwell, 2003).

Ceramic Filters: Filters made of ceramic are produced from a mixture of combustible material and clay (Jellison et al, 2009). Ceramic filters do not have a specified pore size as pores are formed in the firing process (Jellison et al, 2009). Filters are sometimes coated with colloidal silver, which kills pathogens. Specifically, “silver disables the enzyme that pathogenic bacteria and fungi use

for oxygen metabolism, thus suffocating them; destroys pathogens with an electric charge; renders pathogens unable to reproduce; and, kills parasites while in their egg stage” (CAWST, 2006). Ceramic filters have been shown to reduce total coliform levels to non-detectable limits 93% of the time in field studies (Clasen, 2007). The drawbacks of ceramic filters are that education is required for correct use (Clasen & Smith, 2005) and that no chlorine residual is present in stored water (Woodrow Wilson International Center for Scholars, 2006).

Bag Filters: Bag filters are available in both felt, nominally-rated cloth and high-efficiency microfiber cloth (Rosedale, 2011 and Rosedale, 2012). All bags are available in either polyester or polypropylene and are available in 1- μ m pore-size (Rosedale, 2011 and Rosedale, 2012). The high-efficiency microfiber material bag has a 4.4 ft² area and the capacity to hold 79 g of dirt (Rosedale, 2012).

Flat Sheet Microfilters: Flat sheet microfilters are produced as one solid sheet. Only a single layer is used and it must be placed in a special filtration cell. Flat sheet microfilters are most commonly used in laboratory separations and are challenging to implement on an industrial scale (MWH, 2005).

Spiral Wound Microfilters: Spiral-wound microfilters are produced from stacked layers of flat sheet membranes (described above) with permeate and retentate spacers inserted in-between the layers. The layers and spacers are then rolled/wrapped around a tube. The tube allows the permeate to travel into the central collection tube.

Hollow Fiber Microfilters: Hollow fiber microfilters are produced as individual hollow tubes, the outside diameter ranges from 0.5 mm to 2 mm, and the wall thickness ranges from 0.07 mm to 0.6 mm (MWH, 2005). Transmembrane pressures typically range from 0.2 to 1 bar. Hollow fiber microfilters are the most common membrane filtration system currently used in water treatment (MWH, 2005).

LifeStraw[®]: LifeStraw[®] has been proven to meet the U.S. EPA Guide Standard and Protocol for Testing Microbiological Purifiers with no chemical treatment (Vestergard-Frandsen, 2011). Water travels through a 1-mm pore-size pre-filter (removes large particles and debris), and finally through a 0.2- μ m hollow-fiber microfiltration membrane (Vestergard-Frandsen, 2011). **Figure 2.2** shows a child properly using a LifeStraw[®]. A LifeStraw[®] has a usable life of roughly 1,500 L and an average flowrate over filtration lifetime of 200 mL/min (Vestergard-Frandsen, 2011). Frequent backwashing is suggested (at maximum, after every 5 L is drank) in order to improve the usable life of the LifeStraw[®] (Vestergard-Frandsen, 2011).

Figure 2.2: A child demonstrating how to properly use a LifeStraw[®] (Vestergard-Frandsen, 2011).

LifeStraw[®] Family: LifeStraw[®] Family has also been proven to meet the U.S. EPA Guide Standard and Protocol for Testing Microbiological (Vestergard-Frandsen, 2011). However, LifeStraw[®] Family contains a halogen chamber that releases chlorine into the water to reduce membrane fouling (Vestergard-Frandsen, 2011). In the LifeStraw[®] Family device, water first passes through an 80- μ m pre-filter, then a halogen chamber, then a 20-nm hollow-fiber ultrafiltration membrane (Vestergard-Frandsen, 2011). The small pore-size of the ultrafiltration membrane requires a large amount of head (**Figure 2.3**). The LifeStraw[®] Family device has a usable life of up to 18,000 L of water (enough water for family of five for three years) at a flowrate of approximately 12-15 L/hr (Vestergard-Frandsen, 2011). Frequent backwashing is suggested in order to

increase the usable life of the LifeStraw[®] Family device (Vestergard-Frandsen, 2011).

Figure 2.3: A family using the LifeStraw[®] Family product. Note the height the reservoir must be hung at in order for the unit to perform effectively (Vestergard-Frandsen, 2011).

Cotton filters and ceramic filters were not pursued for the present thesis research as the filter material is not able to meet U.S. EPA removal requirements. Due to the high cost and fragile nature of flat sheet, spiral wound, and hollow fiber microfilters, none were pursued in the present thesis research. Bag filters were chosen for the present research because of the low cost and ability to meet U.S. EPA removal requirements. The materials and methods used are described in the following chapter.

CHAPTER 3: MATERIALS AND METHODS

This chapter describes the filter design iterations, the waterbag systems operation procedures, the experimental designs for testing the filters, and the testing at Cal Poly. The culminating U.S. EPA Challenge Water testing at BioVir Laboratories is also described.

3.1 Filter Construction

Numerous filters were constructed for the present thesis research. Initially, 1-ply filters were constructed of the nominal filter cloth (further described in **Section 3.1.1**) in circular, square, and rectangular shapes. Both internal and external filters of the above mentioned shapes were constructed. Next, 2-ply filters were constructed of the nominal filter cloth in rectangular shapes. Then, 1-ply filters were constructed of the absolute filter cloth (further described in **Section 3.1.1**) in rectangular shapes. The final filter type constructed was the 2-ply nominal-absolute filter (further described in **Section 3.1.2**). The construction of this filter is described in detail in **Section 3.1.2**.

3.1.1 Materials Used for Filter Construction

All various materials used to construct filters are described herein. These materials include filter cloth, nylon netting, bulkhead fittings, and washers.

The 1-ply and 2-ply nominal filter prototypes were constructed of 1- μm , nominal-50% polypropylene felt filter cloth (hereinafter referred to as nominal filter cloth), with standard finish (Rosedale, 2011) (**Figure 3.1**). Nominal-50% means that the filter cloth will remove 50% of all particles 1 μm in diameter and allow the remaining 50% of particles 1 μm in diameter to pass through the filter cloth. Standard finish means that the

nominal filter cloth had not been coated in a glaze, as glazed finish filter cloth is also available for purchase. The nominal filter cloth was made of polypropylene fibers of various weight, diameter, and thickness that functions as a depth-type filter media (Rosedale, 2011). The product sheet for the nominal material can be found in **Appendix A**.

Figure 3.1: Photo-micrograph of 1-μm nominal filter cloth (1000X total magnification) (Compas, 2009).

The 1-ply absolute filter prototypes were constructed of 1-μm high efficiency-95% polypropylene microfiber filter cloth (hereinafter referred to as absolute filter cloth) (Rosedale, 2012) (**Figure 3.2**). The absolute filter cloth was comprised of four separate material layers (**Figure 3.3**). High-efficiency-95% means that 95% of particles 1 μm in diameter will be removed and only 5% of particles 1 μm in diameter will pass through the filter cloth. The product sheet for the absolute material can be found in **Appendix B**.

Figure 3.2: Photo-micrograph of one layer of the absolute filter cloth (100X total magnification). This picture only represents one plane of focus of this material; there are multiple planes. A large gap in this plane of focus would likely be covered by fibers in the next plane of focus.

Figure 3.3: Schematic of four microfiber layers that comprise one ply of the absolute filter cloth (Rosedale, 2011). Water flows through the inner cover through the filter layers and then through the outer cover.

The 2-ply nominal-absolute filter prototypes were constructed of an inner layer of nominal filter cloth which was then encased in an outer layer of absolute filter cloth.

Figure 3.7 shows a cross-section of this filter as constructed.

The nylon, 500-micron netting that was used on the exterior of filters in experiments A-3 and B-2 was purchased from Aquatic Eco-Systems (Part #M500). The 500-micron

netting was attached to the exterior of filters to prevent flocs from being embedded in the filter cloth. This netting was resistant to bacteria, cleaners, as well as acids and had 49% open space.

Miniature PVC tank adapters (hereinafter referred to as large diameter bulkhead fittings) were purchased from Ryan Herco Flow Solutions (Catalog # 7000.002) (**Figure 3.4**) (Ryan Herco, 2012). The large diameter bulkhead fittings were used in all experiments except C-2.

Figure 3.4: Large diameter bulkhead fitting (Ryan Herco, 2012).

Nylon miniature through-wall fittings (hereinafter referred to as small diameter bulkhead fittings) were purchased from McMaster-Carr (Catalog # 8671T23) (McMaster-Carr, 2011) (**Figure 3.5**). Nylon flat washers (hereinafter referred to as flat washers) were purchased from Grainger (Item # 5XU62) (Grainger, 2011). The small diameter bulkhead fittings and flat washers were used for experiments C-2 and D-2. The inner diameter of the flat washers was not large enough to fit over the small diameter bulkheads, so the washers were bored-out with a drill press in Cal Poly's machine shop.

Figure 3.5: Small diameter bulkhead fittings are circled.

3.1.2 Construction of 2-ply Nominal-Absolute Filter (tested at BioVir Laboratories)

An element used consistently in all filters was an internal spacer made of 7 count plastic canvas (Darice, Manufacturer #33900-1) to provide an open path for the water to contact the cloth (**Figure 3.6**). To make a spacer, a 6-cm by 12-cm rectangular piece of the canvas was folded over five 5-cm square pieces of the mesh to increase the size of the water path. Three edges of the spacers were whip-stitched with white, 100% polyester thread.

Figure 3.6: Filter internal spacer made of plastic mesh. As constructed, the final dimensions were 6 cm square by a maximum of 1 cm thick. Three edges are stitched close with white thread.

Once the internal spacer was finished, the filter cloth was cut out to fit around the spacer.

A 1-cm diameter hole was then punched through the filter cloth and a large diameter bulkhead fitting was installed through the hole. The filter cloth was then sealed on the three loose sides using heat-activated Super Weight Stitch-Witchery Fusible Bonding (Drtiz, Manufacturer #D223). The Stitch Witchery was placed in-between two layers of filter cloth, the filter cloth was covered with a damp cloth, a steam iron, set to “wool,” was pressed on each side of the filter for 10 sec. **Figure 3.7** shows a cross section of the filter as constructed.

Next, a layer of absolute filter cloth was prepared the same way and added over the nominal filter cloth. The bulkhead fitting (secured inside the nominal filter cloth) was fit through the hole in the external layer of absolute filter cloth. The external layer of absolute filter cloth was then also sewn on three sides using a sewing machine. Liquid Fusion clear urethane glue (Duncan Enterprises, 2012), was placed over all sewn seams

and in-between filter cloth plies around the edge of the filter. Liquid Fusion was chosen as it is non-toxic, odorless, and waterproof. Originally, hot glue was placed on all sewn seams and in-between filter cloth plies around the edge of the filter, but it was determined that hot glue was not water proof and therefore not effective.

All constructed filters were encased in a pouch constructed of one sheet of 6-mil low density polyethylene (LDPE) plastic. The 6-mil LDPE plastic sheeting was purchased from Plastic Sheeting Supply (IPS Packaging) in 1.83 m by 30.48 m rolls (Compas, 2009). A hole was punched through the plastic and stretched over the bulkhead fitting protruding from the filter. An additional hole was punched through the plastic outside the edge of the filter to allow for another bulkhead fitting. The additional hole was placed outside the edge of the filter to prevent flow-focusing of effluent. As can be seen in **Figure 3.15**, when the bulkhead fitting was not placed outside the edge of the filter, the flow is focused in that area and floc can be drawn through the filter material. The 6 mil LDPE pouch was sealed on the two loose sides with a Tabletop Poly Bag Sealer (Impulse, Model H-1029, ULINE[®] Shipping Supply Specialists). Once partially sealed, a bulkhead fitting was fit through the second hole in the filter pouch, and the last seal was then sealed. Plastic stopcock valves were threaded into both the pouch inlet and outlet bulkhead fittings to allow for flow control. A diagram of the cross-section of the filter is in **Figure 3.7**. A side view of the filter is in **Figure 3.8**.

Figure 3.7: A cross section of the 2-ply nominal-absolute filter used in experiments H-3 and I-1, as constructed. Water flows in the bulkhead fitting on the left, through the filter cloth layers, and out the bulkhead fitting on the right. Note, the base of the bulkhead fitting on the left is inside of the nominal filter cloth. Also note, in order to make the tightest seal possible, the rubber gasket for the bulkhead fitting was placed between the absolute filter cloth and the plastic filter pouch, and the nut for the bulkhead fitting was screwed onto the bulkhead fitting outside the plastic filter pouch.

Figure 3.8: Plan view of 2-ply nominal-absolute filter used in experiments H-3 and I-1. Water flowed in the bulkhead fitting on the left, through the filter cloth layers, and out the bulkhead fitting on the right.

3.2 Filter Designs

All experiments conducted for this research were performed using Mark II waterbags (Herzog 2011). Various filters were attached to the waterbag as denoted in the experiment name (described in **Section 3.3**). The rationale followed when developing filters is further described in **Chapter 4**. All filters were designed without backwashing. Initially 1-ply nominal internal filters of various shapes were tested (**Figure 3.9 and Figure 3.10**). Then 1-ply nominal external filters of various shapes were tested (**Figure 3.11, Figure 3.12, and Figure 3.13**).

Figure 3.9: Circular internal filter made of nominal filter cloth tested in experiment A-1. Scale: the large diameter bulkhead fitting measures 3.65 cm in diameter.

Figure 3.10: Square internal filter made of nominal filter cloth tested in experiments A-2 and A-3. The filter tested in A-2 was made of nominal material and the filter tested in A-3 was made of nominal material with 500 μm netting on the outside of the filter to prevent flocs from clogging the pores of the nominal filter cloth. Scale: the large diameter bulkhead fitting measures 3.65 cm in diameter.

Figure 3.11: Circular external filter made of nominal filter cloth tested in experiment B-1. Scale: the large diameter bulkhead fitting measures 3.65 cm in diameter.

Figure 3.12: Filter pouch of the square external filter made of nominal filter cloth with 500 μm netting on the outside tested in experiment B-2. Water flowed from the waterbag, into the filter pouch (outside the filter), through the filter, and into the internal chamber of the filter before flowing out as filtered effluent. Scale: the large diameter bulkhead fitting measures 3.65 cm in diameter.

Figure 3.13: Filter pouch of the square external filter made of nominal filter cloth tested in experiment B-3. Water flowed from the waterbag, into the internal chamber of the filter, through the filter, and was collected in the filter pouch (outside the filter) before flowing out as filtered effluent. Scale: the large diameter bulkhead fitting measures 3.65 cm in diameter.

Both 1-ply and 2-ply nominal filters were tested for microsphere removal capabilities (Figure 3.14 and Figure 3.15).

Figure 3.14: 1-ply nominal filter tested in experiment E-1. Scale: the large diameter bulkhead fitting measures 3.65 cm in diameter.

Figure 3.15: 2-ply nominal filter tested in experiment E-2. The plastic pouch was removed before this picture was taken. Scale: this filter measures 11.4 cm by 11.4 cm. This photo was taken after use. Note the brown circle in the bottom, left hand corner of the filter. The brown circle is a stain caused by flocs and illustrates apparent focusing of flow in that area due to improper placement of the bulkhead fitting over the filter. Flow focusing is presumed to be detrimental to cyst removal.

Then, the 1-ply absolute filter, a bench-scale model of the 2-ply nominal-absolute filter and the 2-ply nominal-absolute (sealed with hot glue) filter were tested for microsphere

removal capabilities, as described in **Section 3.4** (**Figure 3.16**, **Figure 3.17**, and **Figure 3.18**).

Figure 3.16: 1-ply Absolute filter with hot glue applied around sewn seams, tested in experiment F-1. The plastic pouch was removed before this picture was taken. Scale: this filter measures 10.2 cm by 6.4 cm.

Figure 3.17: Bench-scale 2-ply nominal-absolute filter tested in experiment F-2. A 7.6 cm square of the absolute material was placed on the bottom of the vacuum filter housing (left picture), a laser-cut circle of the nominal material was placed on top of that (middle picture), and the top of the vacuum funnel housing was clamped in place over the two filter cloths (right picture).

Figure 3.18: 2-ply nominal-absolute filter with hot glue applied around sewn seams, tested in experiment F-3. The plastic pouch was removed before this picture was taken. Scale: this filter measures 11.4 cm by 11.4 cm.

The 1-ply nominal filter, 2-ply nominal filter, and 2-ply nominal-absolute (sealed with Liquid Fusion) filter were tested for treatment capabilities against mock challenge water at Cal Poly (**Figure 3.19, Figure 3.20, and Figure 3.21**).

Figure 3.19: 1-ply nominal filter tested in experiment H-1. The plastic pouch was removed before this picture was taken. Scale: the large diameter bulkhead fitting protrudes 2.2 cm out of the filter.

Figure 3.20: 2-ply nominal filter tested in experiment H-2. The plastic pouch was removed before this picture was taken. Scale: the large diameter bulkhead fitting protrudes 2 cm out of the filter.

Figure 3.21: 2-ply nominal-absolute filter, sealed with Liquid Fusion, tested in experiment H-3. Scale: the large diameter bulkhead fitting measures 3.65 cm in diameter.

The 2-ply nominal-absolute filter was then tested in triplicate with U.S. EPA Challenge Water #2 at BioVir Laboratories, Inc. in Benicia, California (**Figure 3.22**). A T-fitting was placed in the tubing between the pinch clamp and the filter. A tube with pinch valve descended from the T to a cubitainer. This was used to collect the sample of bag

effluent-filter influent. All BioVir samples were composites collected continuously during the filter operation.

Figure 3.22: Testing in triplicate at BioVir Laboratories with composite effluent collected in cubitainers. Scale: the tubing measures 0.75 cm in diameter. The sandwich bags hanging below the waterbags were taped in place to catch any leaks from the seals of the filter pouches.

3.3 Experimental Design

The research performed can be divided into two primary kinds of experiments: (1) design experiments – to determine the most effective and durable filter design as well as the most apt placement of the filter on the waterbag, and (2) U.S. EPA Challenge Water experiments – to test the performance of the filters against the Test Water #2 and to observe the filters’ performance regarding bacteria and cyst removal. Experimental objectives, test water preparation, and experimental procedures can be found in the following sections. The experimental plan is detailed in **Figure 3.23**.

Figure 3.23: Experiments performed. Filters for experiments A-1 through D-2 were made of nominal felt material. For the other experiments, the cloth type is specified in the diagram.

3.3.1 Experimental Plan

The twenty-two experiments are described herein (**Figure 3.23**), each with their purpose. Configuration experiments with both internal and external filters (A-1 through A-3 and B-1 through B-3) were conducted to determine a preferred filter geometry and placement of the filter on the waterbag. Configuration experiments regarding hardware (C-1 and C-2) were performed to determine the preferred bulkhead fittings to be used in filter construction. Configuration experiments regarding flow patterns using a dye tracer (D-1 and D-2) were used to determine how water actually flowed through the material. Microsphere removal experiments (E-1, E-2, and F-1 through F-3) helped determine the removal capabilities of various filter designs and over a range of flow rates. Mixing time experiments (G-1 through G-3) were used to optimize treatment prior to filtration. Mock challenge water experiments (H-1 through H-3) were conducted to determine which filter and flow rate was capable of meeting the bacteria and cyst removal requirements of the U.S. EPA Guide Standard and Protocol for Testing Microbiological Water Purifiers. Experiment I-1 was the U.S. EPA Challenge Water #2 trial at BioVir Laboratories using bacterial, viral, and cyst challenges. The experiments and rationale are explained in further detail in the following sections. General water preparation and experimental procedures for the experiments in **Figure 3.23** are detailed in the following section.

3.3.2 Water Preparation

Tap water served as the source water for all experiments. For all design experiments (A-1 through G-3), non-aerated tap water was used as chlorine residual was not measured in these experiments. For all U.S. EPA challenge water experiments (H-1 through I-1), aerated tap water was used since chlorine residual was a monitored chemical constituent

in these experiments. Tap water was aerated overnight in order to promote dechlorination and remove all chlorine that could interfere with experimental results. The chlorine residual was checked before water was used for experiments.

Test water used for all experiments contained A2 Fine Test Dust (ISO 12103-1; purchased from Powder Technology, Inc., Burnsville, MN) to increase turbidity and sea salts (Instant Ocean, Cincinnati, OH) to adjust total dissolved solids (TDS). The water prepared for U.S. EPA challenge water experiments was also chilled down to 6°C, and contained humic acid (Alfa Aesar, Ward Hill, Mass., Stock #41747, Lot #D25S004) to increase total organic carbon (TOC) as well as K-12 *E. coli* (initially prepared by Alice Hamrick in the Cal Poly Biology department, further grown in the Environmental Engineering lab) to increase biological cell concentration. The test water for experiments E-1 through H-3 also contained 3.1 µm diameter fluorescent green microspheres (Microgenics Corporation, purchased from Thermo Scientific, Catalog # G0300) with an excitation wavelength of 468 nm and an emission wavelength of 508 nm. The microspheres were in a suspension with a concentration of 6.08×10^8 spheres/mL.

In design experiments A-1 through E-2 (except D-1 and D-2), the turbidity of the test water ranged between 400 NTU and 500 NTU. The test water used in design experiments F-1 through G-3 as well as U.S. EPA challenge water experiments H-1 through I-1 had initial turbidities between 40 NTU and 60 NTU, which met the >30 NTU turbidity requirement of the U.S. EPA Challenge Test Water #2 recipe.

For experiments A-1 through G-3, source water was added to a 75-L RubberMaid® refuse container (hereinafter referred to as a large drum) with a ball-valve outlet (**Figure 3.24**)

in order to make the test water mixture. One liter of source water was removed from the large drum and placed in a glass blender. Pre-weighed amounts of specific ingredients were added to the one liter of source water and mixed using an Osterizer[®] glass blender (on pulse setting) for one minute. The blender was used to ensure adequate mixing of the powdered ingredients. The blended 1-L of source water and various ingredients was then poured back into the large drum. A Flotec[®] submersible sump pump (model FP0S2450A-08, 1/3 HP) was used to completely mix the test water for 30 minutes (**Figure 3.25**). Once mixing was complete, the sump pump was turned off and a waterbag was filled for the experiment. If greater than five minutes elapsed between turning the sump pump off and needing to fill another waterbag, the sump pump was turned on and the test water was mixed for an additional five minutes.

Figure 3.24: Large drum used to mix test water (Herzog, 2011).

Figure 3.25: Test water being mixed with a submersible sump pump.

For experiments H-1, H-2, and H-3, 15 L of chilled, de-chlorinated tap water was used as the source water. Source water was dechlorinated, chilled, and mixed into test water in 5 gallon buckets. One L of source water was removed from the 5 gallon bucket and placed in a glass blender. Pre-weighed amounts of specific ingredients were added to the 1-L of source water and mixed using an Osterizer[®] glass blender (on pulse setting) for one minute. The blended one liter of source water and various ingredients was then poured back into the 5 gallon bucket. The bucket was placed on a stir plate and mixed for 30 min with a magnetic stir-bar. Completely mixed test water was then poured into a waterbag for the experiment.

3.3.3 Experimental Testing Procedures

After the waterbags were filled with test water from either the large drum or 5 gallon bucket, a PÜR[®] sachet was added to the untreated water, the bag was closed, and each bag was mixed using a standardized mixing method. For experiments A-1 to E-2, bags were hung from a wooden dowel roughly four feet off the ground and twisted 180° from side-to-side for the specified mixing time (**Figure 3.26**). More head was needed for

experiments F-1 to H-3, so bags were hung from a wooden dowel roughly six feet off the ground and twisted 180° from side-to-side for the specified mixing time. During experiments F-1 and F-3, filters were placed on the floor in order to produce flow. All flow versus head data is available in **Appendix C**.

Figure 3.26: Set-up for experiments A-1 to E-2 (Herzog, 2011).

Treated, filtered effluent was collected in 1-L beakers. Samples were taken from the beakers to perform water quality testing. Residual water in the waterbag after testing as well as floc formed during treatment was poured down the drain. The red-tab valves (**Figure 3.21**) were used to control flow both into the filter and out of the filter pouch. The waterbag was filled with tap water initially to allow for the red tab valves to be set in the required location for proper flowrate required for the experiment. The pinch valve, used to prevent untreated water from entering the filter, was located between the waterbag outlet and filter pouch inlet. The pinch valve was closed while the waterbag was filled and the water was treated with a PÜR[®] sachet. After treatment, the pinch valve was opened and water flowed into the filter pouch.

A metronome was used to achieve consistent mixing at 100 beats per minute (bpm) through all experiments. Regarding bag rotation during mixing, one beat represented a complete 180° twist of the waterbag. Each bag was mixed constantly for five minutes.

The required chlorine contact time for PÜR® is 30 min. Therefore, all bags were allowed to settle, undisturbed, for 30 min before samples were taken. Note that Procter & Gamble's instructions for PÜR® require 25 min of settling, not 30 min as was used during all experiments except experiment I-1, because the 5 min mix is included in the total chlorine contact time of 30 min.

3.4 Water Quality Measurements

Both non-microbiological and microbiological variables were monitored in the experiments. The following section describes the water quality methods used.

3.4.1 Non-Microbiological Variables

Non-microbiological water quality constituents were turbidity, temperature, pH, and chlorine residual.

3.4.1.1 Turbidity

A HACH 2100P Portable Turbidimeter (Catalog #46500-00, Lot#L7002) was used to measure turbidity of all samples. The turbidimeter was calibrated before every experiment with StablCal® Stabilized Formazin Turbidity Standards (sealed vials of <0.1 NTU, 20 NTU, 100 NTU, and 800 NTU). During experiments, a sample was collected in a turbidimeter vial, the vial was capped, the vial exterior was dried with a soft cloth, and the exterior was polished with a drop of silicon oil. After analysis, the vials were rinsed with deionized water and placed upside down on a paper towel to dry before being used

to collect another sample. This turbidity measurement method is in accordance with the U.S. EPA Method 180.1 criteria for reporting drinking water analysis (HACH Company 2010).

3.4.1.2 Temperature

Temperature of the pre-treatment wastewater was measured with a classic mercury thermometer. Temperature measurements were taken immediately before the waterbags were filled, directly from the bucket the raw water was mixed in.

3.4.1.3 pH

The pH of treated, filtered effluent was measured with a Mettler Toledo Seven Easy pH meter (with a pH range from 0 to 14 and a resolution of 0.01). The pH meter was calibrated before every experiment using Fisher Scientific pH 4, 7, and 10 buffer solutions. pH samples from both pre-treatment and post-treatment water were collected in 250-mL beakers. pH measurements were allowed to equilibrate before readings were recorded.

3.4.1.4 Chlorine Residual

A HACH DR/890 Colorimeter (Catalog #4847000) and HACH DPD Free Chlorine Reagent powder pillows for 10 mL samples (Catalog #2105569) were used to measure free chlorine residual of samples. Ten-mL samples were collected in glass sample vials, a single reagent pillow packet was added to the samples, the vials were capped for mixing, and the exterior of the vials was polished with a soft cloth. Vials were mixed by continuous swirling and inversions for approximately 20 seconds and analyzed immediately after mixing. For analysis of samples, the HACH Colorimeter Program 9

was used. This program was selected because it has a method detection limit of 0.02 mg/L and a readable chlorine residual range of 0 to 2.00 mg/L. The U.S. EPA has accepted this method for reporting drinking water analysis (HACH Company, 2010). This method is also equivalent to Standard Method 4500-Cl G (HACH Company, 2000). As the same Colorimeter and Program was used, the calibration curve developed by Margaret Herzog for her thesis was used to determine chlorine content of samples instead of developing a new one (Herzog, 2011).

3.4.2 Microbiological Variables

Microbiological water quality constituents included *E. coli*, total coliform bacteria, and 3.1- μ m diameter microspheres, which are a surrogate for parasite cysts.

3.4.2.1 E. coli and Total Coliform Bacteria

IDEXX Colilert[®] 24-hour coliform/*E. coli* reagent and Quanti-Tray[®]/2000 methods were used to measure both total coliform bacteria and *E. coli*. Samples of source water; treated, pre-filtration; and treated, post-filtration were collected in sterile glass beakers and diluted with sterile DI water, if needed, in order for samples to be in the detectable concentration range of the Colilert method. Samples were then poured into 100-mL sterile polypropylene plastic bottles, each containing one 10-mg sodium thiosulfate tablet. After the sodium thiosulfate tablet was dissolved, one Colilert[®] snap pack (exclusively for 100-mL water samples) was added to the sample, and the bottle was closed and shaken to dissolve the reagent. Each sample plus Colilert[®] reagent was poured into an IDEXX Quanti-Tray[®]/2000, sealed with a Quanti-Tray[®] sealer, and incubated at 37°C for 24 hours. After 24 hours, the number of positive tray cells was determined. Yellow cells indicated positive results for total coliform bacteria; both yellow and fluorescent cells

indicated positive results for *E. coli*. Fluorescence of each sample was determined using a portable, long-wave UV light lamp (Blak-Ray Lamp, Model UVL-21, Serial #3418). Lastly, based on the number of positive cells observed, the most probable number (MPN) of bacteria was determined using a Colilert[®] MPN table (IDEXX, 2012).

3.4.2.2 Microspheres

A standard averaging technique was followed when determining the log removal of microspheres in an experiment. This method was followed by ATS Labs when Procter & Gamble performed a U.S. EPA Challenge Water test in January 2008. This method was further confirmed as common practice with Dr. Danielson, Laboratory Director, BioVir Laboratories (R. Danielson, personal communication, December 16, 2011).

An Olympus BX-41 epifluorescence microscope was used to enumerate the removal of microspheres in the samples. The microscope was equipped with a mercury-vapor lamp, filter set for fluorescent observation, and phase-contrast objective lenses.

A 10-mL sample was collected and vacuum-filtered through a 25-mm diameter, 0.22- μ m pore size Millipore[®] filter. The 25-mm diameter filter was placed on a microscope slide, a cover slip was placed over the filter, and clear finger nail polish was placed on all four corners of the cover slip to fix the filter and cover slip in place.

In preparation of viewing the slide with the microscope, the computer, microscope, burner, Optiscan unit, and camera were turned on to warm up for a few minutes. Filter wheel (FW) 1 was set to position 6 and FW 2 was set to position 5. The turret on the microscope was set to position 1 (bright field) for initial focusing. Once focused, the

turret was set to position 2(FITC filter), the shutter was turned on with the keypad, and the shutter was opened on the microscope.

To enumerate the microspheres in a sample, the area of the field of view (FOV) was first determined with a hemacytometer (**Figure 3.27**). The effective diameter of the 25-mm diameter filter was determined using calipers. The effective diameter was the area that water passed through. No water passed through the periphery of the filter where the vacuum filtration funnel covered the outside edge of the filter. The effective diameter was then used to calculate the usable area of the 25-mm diameter filter. Both the area of the FOV and the usable filter area were recorded for later use.

Figure 3.27: Hemacytometer used to determine the area of the FOV, observed at 100X total magnification.

Ten random FOVs were captured and the number of microspheres in each FOV was counted and recorded (**Figure 3.28**).

**Figure 3.28: An FOV at 100X total magnification.
The green dots are the fluorescent microspheres.**

The concentration in each sample was determined using the following equation:

$$\frac{\text{total \# spheres in 10 FOV}}{\text{filtered sample volume (L)}} * \frac{\text{usable area of Millipore filter (mm}^2\text{)}}{\text{FOV area (mm}^2\text{)} * 10 \text{ FOV counted}} = \frac{\text{\# spheres}}{L}$$

Sphere concentration was determined for raw/untreated, pre-filter, and post-filter samples. This allowed the removal capabilities of the filter to be determined. The log of each concentration was then taken to determine the log removal capability of the filter.

3.5 Design Experiments

Design experiments included eighteen individual experiments which tested three general areas: (1) configuration, (2) microsphere removal, and (3) mixing time. The primary objective of these experiments was to identify the optimum filter cloth, filter shape, filter placement on the waterbag, hardware used in filter manufacturing, and flowrate through the filter that produced final treated effluent with adequate log removal of bacteria, viruses, and protozoan cysts and well as turbidity of <5 NTU.

3.5.1 Water Preparation for Design Experiments

The design experiments followed the general water preparation procedures detailed in Section 3.2 with the exception of experiment F-2. For the bench-scale 2-ply nominal-absolute filter tested in experiment F-2, 1-L of tap water was dosed with 1.65 μL of spheres and mixed for 30 min using a magnetic stir bar and stir plate. Twenty mL of the test water was filtered through the bench-scale 2-ply nominal-absolute filter with the vacuum pump assembly. The filtrate was collected in a flat-bottomed test tube inside the vacuum flask. The filtrate was then analyzed for microspheres. Several test variables and information regarding design experiments can be found in **Table 3.1**.

Table 3.1: Design experiment information (includes test water variables, ingredient amounts, and mixing time)

Experiment	Primary Variable(s)	Source Water	A2 Fine Test Dust Amount Added per 10 L (g)	Instant Ocean Amount Added per 10 L (g)	Humic Acid Amount Added per 10 L (g)	Mixing Speed (beats per minute)	Mixing Time (min)
A-1 to 3, B-1 to 3, and C-1 to 3	Turbidity and filter life	Tap water	5	10	None	100	5
D-1 & D-2	Use of filter area	Tap water with Rhodamine dye	--	--	--	--	--
E-1 & 2	Microsphere removal	Tap water	5 & 0.5, respectively	10	0.4	100	5
F-1 to 3	Microsphere removal	Tap Water	0.5	10	0.4	100	5
G-1 to 3	Waterbag mixing time	Tap water	0.5	10	0.4	100	5

3.5.2 Experimental Procedures for Design Experiments

The water quality constituents measured during each experiment are listed in **Table 3.2**.

Turbidity was measured in all experiments except for D-1 and D-2 as these were dye study experiments. No design experiments included the measurement of microbiological constituents. However, experiments E-1 through F-2 included the measurement of removal of microspheres by the filters.

Table 3.2: Variables measured during the design experiments

Experiment	Variables Measured			
	Turbidity	Flow through filter cloth	Microsphere removal	Temperature
A-1	X			
A-2	X			
A-3	X			
B-1	X			
B-2	X			
B-3	X			
C-1	X			
C-2	X			
D-1		X		
D-2		X		
E-1	X		X	
E-2	X		X	
F-1	X		X	X
F-2	X		X	X
F-3	X		X	X
G-1	X		X	X
G-2	X		X	X
G-3	X		X	X

In the mixing time experiments, an initial 5 min mix was performed followed by a 5 min resting period. This cycle continued until the desired mixing time was achieved. All bags were allowed to settle for 30 min after their respective mixing times were complete.

For the dye studies performed in experiments D-1 and D-2, the rhodamine dye-water mixture used was a 100X dilution of rhodamine dye with a density of approximately 1 g/mL. Three mL of the diluted rhodamine dye was injected into the tubing leading from the waterbag to the filter during each trial of experiments D-1 and D-2.

3.6 U.S. EPA Challenge Water Experiments

After determining the optimum filter cloth and design, the next step was to test various filters against U.S. EPA Challenge Water (Test Water #2) to determine which filter was most effective. Three experiments tested the performance of various filters against the U.S. EPA Challenge Water (Test Water #2) recipe. The first experiment performed, experiment H-1, tested the 1-ply nominal filter to ensure that proper treatment was not possible with this design, as described in Chapter 4. The second experiment performed, experiment H-2, tested the 2-ply nominal filter to ensure that proper treatment was not possible with this design even at a very low flowrate. The next experiment performed, experiment H-3, tested the 2-ply nominal-absolute (liquid fusion) filter to determine the greatest flowrate that could pass through the filter while still performing proper removal and treatment. Experiments H-1, H-2, and H-3 were used to determine which filter was to be tested during the last U.S. EPA Challenge Water experiment (I-1). The objective of experiment I-1 was to test the final filter design in triplicate against U.S. EPA Challenge Water (Test Water #2) at BioVir Laboratories in Benicia, CA and confirm that the filter would perform adequate pathogen removals.

3.6.1 Water Preparation for Mock Challenge Water Experiments

The test water for the U.S. EPA Challenge Water experiments was prepared in the same manner of the optimization experiments except that a few additional ingredients were added as well. The U.S. EPA Challenge Water (Test Water #2) test water required additional modifications in that humic acid was required, the temperature was adjusted to near 4°C, and K-12 *E. coli* was added to the test water. The temperature of the test water was lowered by storing the test water overnight in a 5.5°C refrigerator. Ice cubes were not added to the source water to further lower the temperature as they would add chlorine to the test water. Experiments H-1, H-2, and H-3 did include *E. coli* and microspheres to mimic the Challenge Test Water #2 recipe. When preparing to work with microorganisms, all glassware and dilution water was sterilized by autoclaving prior to use. Alice Hamrick of the Biological Sciences Department at Cal Poly grew and provided a stock K12 *E. coli* culture for use in the lab (A. Hamrick, personal communication, July 23, 2012). The original culture was grown in LB liquid growth medium and stored in a 30°C incubator between experiments. The *E. coli* concentration of the stock solution was estimated by measuring the optical density at 600-nm of the solution using a UV/V spectrophotometer (an OD₆₀₀ of 1.0 equates to a cell concentration of 8×10^8 cells/mL, website calculator used located at <http://www.genomics.agilent.com/CalculatorPopupWindow.aspx?CalID=7>). Once the absorbance was measured, a concentration could be estimated, and the required volume of the solution to meet the $10^7/100$ mL bacterial initial concentration in the test water was pipetted into the test water. The experiment variables and information for the U.S. EPA Challenge Water tests can be found in **Table 3.3**.

Table 3.3: U.S. EPA Challenge Water experiment information including test water variables, source water types, ingredient amounts, mixing speeds, and mixing lengths.

Experiment	Number of Prototypes Tested	Output Variable	Source Water	A2 Fine Test Dust Mass (g) Added to 15 L	Instant Ocean Mass (g) Added to 15 L	Humic Acid Mass (g) Added to 15 L	Mixing Speed (beats per minute)	Mixing Time (min)
H-1	1	Sphere removal	Aerated tap water	0.5	15	0.6	100	5
H-2	1	Sphere removal	Aerated tap water	0.5	15	0.6	100	5
H-3	1	Water flowrate through filter	Aerated tap water	0.5	15	0.6	100	5
I-1	3	None	Source water and ingredients prepared by BioVir Laboratories, Inc.					

3.6.2 Experimental Procedure for Mock Challenge Water Experiments

The goal of experiments H-1 and H-2 was to determine if the 1-ply nominal and 2-ply nominal filters could meet the pathogen removal requirements set forth in the U.S. EPA Guide Standard and Protocol for Testing Microbiological Water Purifiers (**Table 2.1**).

The goal of experiment H-3 was to determine the proper flowrate through the 2-ply nominal-absolute filter capable of meeting the removal requirements set forth in the U.S. EPA Guide Standard and Protocol for Testing Microbiological Water Purifiers (**Table 2.1**). After the U.S. EPA Challenge Water (Test Water #2) (**Table 2.2**) was prepared in a large bucket, a waterbag was filled with 10 L of test water, a PÜR[®] sachet was added, and the bag was mixed following the standard mixing procedure.

Additional variables were measured in experiments H-1, H-2, and H-3 in addition to variables measured in the optimization experiments (**Table 3.4**). Turbidity, temperature, *E. coli*, total coliforms, chlorine residual, and microsphere removal were measured during these experiments.

Table 3.4: Variables measured during U.S. EPA Challenge Water experiments

Experiment	Non-Microbiological Variables				Microbiological Variables		
	Turbidity	pH	Temp.	Flowrate	Total Coliform	<i>E. coli</i>	Microsphere Removal
H-1	X		X	X	X	X	X
H-2	X		X	X	X	X	X
H-3	X		X	X	X	X	X
I-1	X	X	X	X	X	X	X

3.6.3 Water Preparation at BioVir for Official Challenge Water Experiment

BioVir staff prepared a 40 L batch of U.S. EPA Challenge Test Water #2 with characteristics listed in **Table 3.5**.

Table 3.5: Characteristics of U.S. EPA Challenge Water #2, prepared by BioVir staff (BioVir, 2012)

Variable	Value
Volume	40 L
pH	9.1
Chlorine	Non-Detect
TDS	1450 mg/L
Turbidity	33 NTU*
TOC	12.6 mg/L
Temperature	4°C

* Before Humic acid added

The Challenge Test Water was inoculated with challenge microorganisms and fluorescent microspheres before filling the prototypes. The microorganisms were the bacterium *Escherichia coli* (ATCC11229), MS2 coliphage (ATCC15597-B1), and fr coliphage (ATCC15767-B1) (BioVir, 2012). The microspheres were 3.1 µm diameter fluorescent microspheres as a surrogate for *Cryptosporidium* oocysts (Duke Scientific Corp., Palo Alto, CA) (BioVir, 2012). The test water was stirred continuously with a magnetic stir bar atop a large stir plate after ingredient addition. The U.S. EPA Challenge Water was stirred continuously through experiment I-1 to ensure homogenization of the Test Water #2 before filling each prototype.

3.6.4 Experimental Procedure at BioVir for Official Challenge Water Experiment

Prototypes were tested in triplicate in experiment I-1. The mixing and sampling procedures as well as the mixing, settling, disinfection, and filtration methods were the same for all three prototypes. All three prototypes were initially filled with tap water,

each bag was closed via the dry-bag closure, and each bag was hung from a hook on the top of a large insulated tank (**Figure 3.22**) in order to calibrate the flowrate of water through the 2-ply nominal-absolute filter to 20 mL/min. Vinyl tubing was attached to the flow-control valve leaving the filter pouch. The tubing was inserted into autoclaved 1-L graduated cylinders placed directly beneath each prototype. The flow-control valves at both the entrance and the exit of the filter pouch were opened. A stopwatch was used to monitor elapsed time as water filled the graduated cylinder. The flow-control valves were adjusted until the proper 20 mL/min flowrate was obtained. The remaining tap water was poured out of the prototypes, the black pinch valve was closed, and the vinyl tubing was removed to prepare for filling the prototypes with test water.

After test water preparation, the waterbags were filled and mixed on a staggered timetable in order to allow for an uninterrupted five minute mixing period for each bag. After being filled with test water, one PUR[®] sachet was added to the prototype, the bag was closed via the dry-bag closure, and the bag was hung from a hook on the top of a large insulated tank (**Figure 3.22**). Each prototype was mixed for five minutes at 100 bpm (**Table 3.3**), and then allowed to settle and disinfect for 25 minutes before filtration through the 2-ply nominal-absolute filter used in this experiment (Note that this 25-minute settling period comports with the PUR instructions. Thirty minutes was used in the previous experiments of this thesis.).

During the settling period, six cubitainers were placed. Two cubitainers were placed underneath each prototype to collect both the pre-filter and post-filter water samples over time. The vinyl tubing was rinsed with isopropyl alcohol before it was re-attached to the prototypes and placed into the cubitainers. The alcohol was allowed to evaporate prior to

being used. After the 25-min settling and disinfection period had elapsed, the black pinch valve was opened, allowing treated water to enter the filter pouch. Both pre-filter and post-filter water samples were collected. The pre-filter sample flowrate was approximately 20-mL/min. After the experiment was over, the collected water samples were poured from the cubitainers into labeled sterile plastic screw-top sample bottles and handed over to BioVir staff for further analysis (BioVir 2012). Each sample bottle contained the proper amount of sterile sodium thiosulfate to neutralize any residual disinfectant in the collected water (BioVir, 2012). The BioVir test report (**Appendix D**) described the sample handling and processing.

3.7 Quality Control

To determine the precision of results, quality control (QC) procedures were included in experiments. QC procedures included testing of a single prototype throughout the entirety of an experiment, taking multiple (split) constituent readings, taking duplicate samples, calibrating using a standard, and using a developed calibration curve.

For water quality, QC procedures were included in turbidity and chlorine residual measurements. When measuring turbidity, a sample was read multiple times by the turbidimeter and the measured values were averaged for use in data analysis. When measuring chlorine residual, a calibration curve developed by Margaret Herzog during her 2010-2011 research was used when measuring samples with the colorimeter (Herzog, 2011).

CHAPTER 4: RESULTS AND DISCUSSION

This chapter includes the results and discussion of both the design and U.S. EPA Challenge Water experiments.

4.1 Design Experiments

During all design experiments, filters were tested for turbidity removal as well as clogging rate. The goal of these experiments was to produce a filter that met turbidity requirements while also having a usable lifetime of at least 12 full waterbag uses. The primary objective of the design experiments was to determine the best size, shape, material, and use of a filter that would meet both the WHO and Sphere Project emergency guidelines for water treatment. In order to meet the guidelines, water turbidity must be <5 NTU and free chlorine residual should be within 0.2-0.5 mg/L (The Sphere Project, 2004; WHO, 2006). Three types of design experiments were performed: (1) configuration experiments regarding internal filters, external filters, hardware, and dye studies; (2) microsphere removal experiments to determine the capabilities of both the nominal and absolute material; and (3) mixing time experiments to determine the effect of various mixing times on flocculation and turbidity.

4.1.1 Configuration Experiments A-1 to A-3: Internal Filters

Several internal filters were tested to determine turbidity removal capabilities, usable lifetime, and visual appearance to the user. Circular, square, and square with 500- μ m netting filters were tested in experiments A-1, A-2, and A-3, respectively.

The circular filter design tested in experiment A-1 filtered 120 L of treated water (12 waterbag uses) without clogging and turbidity of effluent was consistently <1.5 NTU,

meeting the <5 NTU requirement. However, the plastic jacket, included in the design to prevent settling flocs from gathering on the filter, caused a large amount of flocs to be caught in the jacket during the waterbag cleanout process, and thus this design was not further pursued. The caught floc also caused the filter to get dirty during the 12 uses as some of the floc that is traditionally rinsed out after use was trapped in the jacket and not removed (**Figure 4.1**). The plastic jacket around the internal filter also prevented all floc from being removed from the waterbag during the waterbag cleanout process, causing the waterbag and filter to appear dirty in subsequent uses (**Figure 4.2**).

Figure 4.1: Circular filter after 12 uses, note the thick layer of floc on the filter cloth. Scale: the hole in the center is 2.22 cm in diameter.

Figure 4.2: Floc caught in cone of waterbag after it had been cleaned.

The square filter design tested in experiment A-2 filtered 100 L of treated water (10 waterbag uses) before clogging and turbidity of the effluent was consistently <5 NTU. This is likely because the square filter had less surface area available for filtration than the circular filter. For experiment A-3, multiple layers of 500- μm netting were glued to the outside of a square filter. The netting was added to reduce the amount of flocs removed from the effluent by the filter cloth, thereby reducing the amount of flocs that clogged the pores of the filter cloth. The square filter with 500- μm netting tested in experiment A-3 did not clog after 12 uses and effluent turbidity met the <5 NTU requirement. Thus, the addition of the netting increased the usable life of the square filter by keeping the filter cloth cleaner.

Since both circular and square filters accumulated floc on the exterior of the filter, it was determined that an internal filter would not be pursued as all filters tested were not visually appealing and could deter the user from continued use of the waterbag. An internal filter would also not allow for a simple exchange of an old filter for a new filter by the user.

4.1.2 Configuration Experiments B-1 to B-3: External Filters

Several external filters were tested to determine turbidity removal capabilities, usable lifetime, and visual appearance to the user. Circular, square with 500- μ m netting, and square filters were tested in experiments B-1, B-2, and B-3, respectively.

The circular filter tested in experiment B-1 was only tested for 5 waterbag uses as the filter pouch could not be properly attached to the waterbag to prevent raw, untreated water from entering the filter pouch. Also, the weight of the filter pouch filled with water put too much strain on the bulkhead fitting attaching the filter pouch to the waterbag during the mixing step, causing the bulk head fitting to rip out of the waterbag.

The square filter with 500- μ m netting tested in experiment B-2 was used for 12 waterbag uses without clogging and effluent turbidity was consistently <1.5 NTU, meeting the <5 NTU requirement. As described in **Section 3.2**, water flowed from the waterbag into the filter pouch, through the 500- μ m netting and filter cloth, and into the internal chamber of the filter, where it flowed out as effluent. Due to the floc being filtered out on the external side of the filter, this filter also became quite soiled after 12 uses (**Figure 4.3**). It was assumed that the dirty filter could deter the user from continued use of the waterbag, so the flow of water was reversed in experiment B-3.

Figure 4.3: Square filter with 500-μm netting after 12 uses. Scale: the large diameter bulkhead fitting is 2.22 cm in diameter.

The square filter tested in experiment B-3 was used for 12 waterbag uses and effluent turbidity was consistently <1.5 NTU, meeting the <5 NTU requirement. As noted in **Section 3.2**, water flowed from the waterbag into the internal chamber of the filter, through the filter cloth, and collected in the filter pouch where it flowed out as effluent. This design was much more aesthetically pleasing to the user as the floc was captured inside the filter and not visible to the user (**Figure 4.4**). Even after 12 uses, the filter still appears fairly clean externally (**Figure 4.5**).

Figure 4.4: Floc caught in the internal chamber of the square filter tested in experiment B-3 after 12 uses. Scale: the hole in the lower half of the picture is 2.22 cm in diameter.

Figure 4.5: External appearance of square filter tested in experiment B-3 after 12 uses. Scale: the large diameter bulkhead fitting is 2.22 cm in diameter.

In experiment B-3, the water entered the internal chamber of the filter and flowed perpendicular to the filter cloth. The high velocity of the water in the perpendicular flow was believed to possibly force microspheres through the filter cloth. It was also

hypothesized that a rectangular filter would be more beneficial as the water could flow tangentially to the material, allowing the water to diffuse through the filter cloth as opposed to being forced through it. Therefore, a rectangular filter was used in all subsequent experiments. From these experiments, it was determined that an external filter with an internal chamber to catch floc would be the best design to further pursue.

4.1.3 Configuration Experiments C-1 and C-2: Hardware

The filters constructed for experiments A-1 to B-3 were all constructed with large diameter bulkhead fittings. The flow of water from the waterbag, through the filter was too fast and the large diameter bulkhead fittings had a larger than ideal diameter for the development of a low-profile filter, so it was hypothesized that using a lower-profile bulkhead fitting would reduce the hydraulic loading onto the filter cloth as well as allow the filter to have a thinner profile. Therefore, small diameter bulkhead fittings and flat washers were obtained (**Section 3.1**). The large diameter bulkhead fittings were used in the filter constructed for experiment C-1. The small diameter bulkhead fittings and low profile washers were used in the filters constructed for experiment C-2.

No difference was observed in hydraulic loading onto the filter cloth between the two bulkhead fittings because flowrates through each bulkhead fitting were similar when the flow control valves were fully open. Therefore, it was determined that no change in bulkhead fittings was required, and large diameter bulkheads were used in all subsequent experiments.

4.1.4 Configuration Experiments D-1 and D-2: Dye Studies

Dye studies were conducted with both the square filters used in experiment B-3 and the rectangular filters used in experiments C-1 and C-2. Dye studies were performed on both clean and dirty, square and rectangular filters to determine how water flowed through the filter cloth during the usable lifetime of the filter.

First, a dye study of a clean, square filter was performed to determine how the water initially flowed through the clean material (**Figure 4.6**). Next, a dye study of a dirty, square filter was performed to determine how the flow of water through the material changed once the filter had been used (**Figure 4.7**).

Figure 4.6: Side view of rhodamine dye and water mixture flowing through a clean, square filter in experiment D-1. Note, the dye was concentrated during this trial for experiment D-1 and could have affected the results. Scale: the square filter measures 7.6 cm by 7.6 cm.

Figure 4.7: Side view of rhodamine dye and water mixture flowing through a dirty, square filter in experiment D-1. Note, the dye was concentrated during this trial of experiment D-1 and could have affected the results. Scale: the square filter measures 7.6 cm by 7.6 cm.

By comparison of **Figure 4.6** and **Figure 4.7**, it was determined that in a clean filter, water being filtered only flowed through the filter cloth that was below the point of entry into the internal chamber of the filter. **Figure 4.7** also showed that after use, the pores began to clog, and the water being filtered flowed through slightly more of the filter area, as can be seen by the rhodamine dye and water mixture forming a straight line halfway across the filter face, as compared to the curved line around the bulkhead fitting in **Figure 4.6**. These observations reinforced the hypothesis that the filter should be rectangular in shape to allow for a larger usable filter area as the rectangular filter was the same height as the square filter, but had a longer length. The observations also led to a

hypothesis that the inlet into the internal chamber of the filter needed to be as high as possible to allow for use of the largest amount of filter area.

The dye study of the square filter also showed the jetting-action of water being forced through the filter cloth upon entry into the internal chamber (**Figure 4.8**).

Figure 4.8: Plan view of plume of rhodamine dye and water mixture jetting out of the internal chamber of a square filter in experiment D-1. Scale: the large diameter bulkhead on the left side of the filter measures 3.65 cm in diameter.

The jetting of water through the material of the square filters could potentially force microspheres through the filter cloth as well. This was not ideal as the filter would not be performing microsphere removal as microspheres could be forced through the filter cloth.

Figure 4.8 reinforced the hypothesis that parallel flow to filter cloth rather than perpendicular flow is preferred as the water would be able to diffuse slowly through the filter cloth rather than being forced through as a jet.

The small diameter bulkhead fitting used on the clean filter shown in **Figure 4.9** was placed as close the top of the filter as physically possible during filter construction.

Figure 4.9: Side view of a clean, rectangular filter with a high bulkhead fitting used in experiment D-2. Scale: the rectangular filter measures 10.2 cm by 15.2 cm.

Figure 4.10: Side view of a dirty, rectangular filter with a middle bulkhead fitting used in experiment D-2. Scale: the large diameter bulkhead fitting on the left side of the filter measures 3.65 cm in diameter.

Comparison of **Figure 4.9** and **Figure 4.10** indicates that increasing the height of the inlet bulkhead fitting on the filter increases the filter area used by the water. Experiment D-2 also suggested that parallel flow along the filter allowed the water to diffuse through

the material (**Figure 4.11**) as opposed to the jetting observed in perpendicular flow (**Figure 4.8**). Therefore, it was determined that a rectangular filter with a high-mounted bulkhead fitting would be used in all subsequent experiments.

Figure 4.11: Side view of thin plume of rhodamine dye and water mixture observed along clean, rectangular filter tested in experiment D-2. Scale: the clear tubing in the upper half of the picture measures 0.75 cm in diameter.

4.1.5 Microsphere Removal Experiments E-1 and E-2: Nominal Material Filters

Initially a 1-ply nominal filter was tested in experiment E-1 for microsphere removal capabilities. After analysis under the fluorescent microscope, 440 microspheres were observed (4.4×10^4 spheres/L). It was hypothesized that decreasing the flowrate by half and adding a second layer of the nominal material would decrease the number of microspheres observed under the fluorescent microscope by four.

A 2-ply nominal filter was tested in experiment E-2. Note, a stopcock valve was used to throttle the flowrate of treated water entering the inner chamber of the filter from the waterbag to roughly 500 mL/min. Analysis of the post-filter effluent showed 123

microspheres in the effluent (1.2×10^4 spheres/L), thereby indicating the hypothesis was correct. At the conclusion of experiments E-1 and E-2, it was determined that a 2-ply filter would be used in all subsequent experiments and the flowrate would be continually reduced until removal requirements were achieved.

4.1.6 Microsphere Removal Experiments F-1 to F-3: Absolute Material Filters

A 1-ply absolute filter was assembled and tested for usability and microsphere removal capabilities in experiment F-1. This filter required the waterbag to be raised 65 in off the ground and the filter to be placed on the ground (instead of attached to the waterbag) in order to produce flow. The flowrate decreased drastically after four liters of water were filtered and became clogged. Enumeration of samples determined that 162 spheres were present in the 10 mL filtered effluent sample (1.6×10^4 spheres/L). From these results, it was determined that the absolute material would yield more positive results when used as a polishing filter after the water had passed through the nominal filter, which would act as a roughing filter.

A bench-scale 2-ply nominal-absolute filter was tested in experiment F-2. Analysis of the filtrate showed numerous spheres in the sample. It was hypothesized that source water leaked around the edges of the vacuum filter funnel assembly, as the edges were not sealed; this could have led to the observed microspheres in the sample. It was determined that a full-scale 2-ply nominal-absolute filter would be built in order to determine removal capabilities.

A full-scale 2-ply nominal-absolute filter was tested in experiment F-3. Flow was produced from this filter when the filter was attached to the waterbag and the waterbag

was raised 65 in off the ground. This filter performed quite well and only 54 spheres were observed in the effluent sample (5.4×10^3 spheres/L). Therefore, the 2-ply nominal-absolute filter will be used in subsequent mock challenge water experiments.

4.1.7 Mixing Time Experiments G-1 to G-3: Mixing Time with 2-ply Nominal Filters

Experiments G-1 to G-3 were performed to determine if a longer mixing time would positively influence turbidity and microsphere removal. It was hypothesized that a longer mixing time would allow more flocs to form, thus removing more turbidity and microspheres from the treated effluent. Therefore, 5 min, 10 min, and 15 min mixing times were tested.

Unfiltered samples were collected for these experiments as turbidity and presence of flos were the main variables in question. Samples were taken at 0 L, when no water had previously been draw out of the waterbag, and after 4 L had been drawn out of the waterbag. Samples were collected in 100 mL beakers. After visual inspection, samples taken from the 5 min mix waterbag tested in experiment G-1 had the least amount of floc present (**Figure 4.12** and **Figure 4.13**).

Figure 4.12: Experiment G-1 (5 min mix waterbag). The photo shows about 80 mL of unfiltered sample collected in a 100 mL beaker before any water had been drained from the bag.

Figure 4.13: Experiment G-1 (5 min mix waterbag). The photo shows about 80 mL of unfiltered sample in a 100 mL beaker after 4 L had been drained from the bag.

After visual inspection, samples taken from the 10-min mix waterbag tested in experiment G-2 had the greatest amount of floc present as well as the highest turbidity

(**Figure 4.14** and **Figure 4.15**). The effluent also had a discernible yellow hue, as can be seen in **Figure 4.14** and **Figure 4.15**.

Figure 4.14: Experiment G-2 (10 min mix waterbag). The photo shows about 80 mL of unfiltered sample collected in a 100 mL beaker before any water had been drained from the bag.

Figure 4.15: Experiment G-2 (10 min mix waterbag). The photo shows about 80 mL of unfiltered sample in a 100 mL beaker after 4 L had been drained from the bag.

After visual inspection, samples taken from the 15 min mix waterbag tested in experiment G-3 had less floc present than the 10 min mix, but more floc than the 5 min mix (**Figure 4.16** and **Figure 4.17**). The turbidity of samples taken from the 15 min mix waterbag was greater than that measured from the 5 min mix waterbag and less than that measured from the 10 min mix waterbag.

Figure 4.16: Experiment G-3 (15 min mix waterbag). The photo shows about 80 mL of unfiltered sample collected in a 100 mL beaker before any water had been drained from the bag.

Figure 4.17: Experiment G-3 (15 min mix waterbag). The photo shows about 80 mL of unfiltered sample collected in a 100 mL beaker after 4 L had been drained from the bag.

From these experiments, based on the increased amount of floc present in the unfiltered 0-L samples of both the 10 min and 15 min mix times, it was determined that the extended mixing time resulted in too much shear force introduced into the waterbag. This increased shear broke the original large flocs formed during the 5 min mix into smaller pieces that took much longer to settle by gravity. By comparison of the 0-L samples with the 4-L samples, it was also determined that while the flocs from the 10 min and 15-min mix periods are smaller than those from the 5-min mix period, they are still large enough to be affected by gravity. The smaller floc size was indicated by the decreased amount of floc present in the 4-L samples from both the 10- and 15-min mix periods. As time elapsed during the experiments, smaller flocs were able to settle out. From the results of these experiments, it was determined that a 5-min mix, as previously used, would continue to be used for all subsequent experiments.

4.2 U.S. EPA Challenge Water Experiments

The final experiments tested various filters' ability to meet the U.S. EPA Guide Standard and Protocol for Testing Microbiological Water Purifiers. The three filters tested against U.S. EPA Challenge Water #2 were 1-ply nominal, 2-ply nominal, and 2-ply nominal-absolute. The three final filters were tested to determine treatment capability and appropriate flowrate for the filter to be used during the final experiment at BioVir Laboratories. Upon completion of these experiments, the 2-ply nominal-absolute filter was used for the official U.S. EPA Challenge Test was conducted at BioVir Laboratories.

4.2.1 Experiments H-1 to H-3: Mock Challenge Water

Three filter designs were tested in the Cal Poly lab against mock U.S. EPA Challenge Water#2: 1-ply nominal filter (experiment H-1), 2-ply nominal filter (experiment H-2), and 2-ply nominal-absolute (liquid fusion) filter (experiment H-3). Turbidity, flowrate, head, chlorine residual, temperature, bacteria removal, as well as microsphere removal data were collected.

4.2.1.1 Experiment H-1: 1-ply Nominal Filter

In experiment H-1, the 1-ply nominal filter was tested at a 500 mL/min flowrate. Microsphere samples were collected and analyzed from the untreated test water and after 4-L of treated effluent had been filtered. **Table 4.1** details the initial; treated, unfiltered; and treated, filtered effluent microsphere concentrations as well as log removals during each step in the treatment process. The overall microsphere removal for the 1-ply nominal filter was 0.60 logs. Due to the low sphere removal results, it was determined that the 1-ply nominal filter could not meet the U.S. EPA Challenge Water #2 removal

requirements and would not be used for the official U.S. EPA Challenge test at BioVir Laboratories.

Table 4.1: Microsphere concentration and log removal at each step in the treatment process with 1-ply nominal filter during the Mock Challenge Water #2 treatment attempt in experiment H-1.

Step in the Treatment Process	Concentration (spheres/L)	Log Removal of Each Step
Source water	1.42×10^6	--
Treated, unfiltered effluent	5.81×10^5	0.39
Treated, filtered effluent	3.59×10^5	0.21
Overall removal	--	0.60

4.2.1.2 Experiment H-2: 2-ply Nominal Filter

In experiment H-2, the 2-ply nominal filter was tested at a flowrate of 65 mL/min. Grab samples were collected of untreated test water and after 4 L of treated effluent had been filtered. The source water temperature was 14°C and the initial turbidity was 47.0 NTU. On average, treated, unfiltered turbidity was 3.65 NTU and treated, filtered turbidity was 3.35 NTU. Both of these measured turbidity values meet the <5 NTU requirement, as required by The Sphere Project (The Sphere Project, 2004). A chlorine residual of 0.05 mg/L was measured in the treated, filtered effluent sample. The measured microsphere removal at each step in the treatment process can be seen **Table 4.2**. The microsphere removal increased with the addition of a second layer of nominal filter cloth and decreasing the flowrate by approximately 7.5 times, but was still below the U.S. EPA Challenge Water removal requirement of 3-log removal. **Table 4.3** outlines the total coliform and *E. coli* removals at each step in the treatment process. The bacteria removal of 5.01 and 5.03 log (coliform and *E. coli* removals, respectively) was not sufficient to meet the U.S. EPA Challenge Water requirement of 6-log removal.

Table 4.2: Microsphere concentration and log removal at each step in the treatment process with 2-ply nominal filter during the Mock Challenge Water #2 treatment attempt in experiment H-2.

Step in the Treatment Process	Concentration (spheres/L)	Log Removal of Each Step
Source water	9.18x10 ⁵	--
Treated, unfiltered effluent	3.63x10 ⁴	1.40
Treated, filtered effluent	1.81x10 ⁴	0.30
Overall removal	--	1.70

Table 4.3: Coliform and *E. coli* concentration and log removal at each step in the treatment process with 2-ply nominal filter during the Mock Challenge Water #2 treatment attempt in experiment H-2.

Step in the Treatment Process	Concentration (MPN/100-mL)	Log Removal of Each Step
Source water, coliform ¹	2.71x10 ⁶	--
Treated, unfiltered effluent, coliform	--	--
Treated, filtered effluent, coliform	26.5	--
Overall coliform removal	--	5.01
Source water, <i>E. coli</i> ¹	1.72x10 ⁶	--
Treated, unfiltered effluent, <i>E. coli</i>	--	--
Treated, filtered effluent, <i>E. coli</i>	16.1	--
Overall <i>E. coli</i> removal	--	5.03

¹ A source water sample was not collected for experiment H-2. Therefore, the average of all concentrations of source water for experiment H-3 was taken to allow for enumeration.

Due to the poor microsphere and bacteria removal results, it was determined that the 2-ply nominal filter could not meet the U.S. EPA Challenge Water #2 removal requirements and would not be used for the official U.S. EPA Challenge test at BioVir Laboratories.

4.2.1.3 Experiment H-3: 2-ply Nominal-Absolute Filter

The 2-ply nominal-absolute filter was tested in experiment H-3 at two flowrates: 50 mL/min and 20 mL/min. Grab samples were collected of untreated test water and after 4

L of treated effluent had been filtered. For the 50 mL/min tests, the source water temperature was 14°C and 11°C in Bag 1 and 2, respectively. Turbidity of source water, pre-filter samples, and post-filter samples are all shown in **Figure 4.18**. Both pre-filter and post-filter samples meet the <5 NTU requirement, as required by The Sphere Project (The Sphere Project, 2004).

Figure 4.18: Turbidity of samples collected at various points from waterbags with a 50 mL/min flowrate throughout experiment H-3.

Chlorine residuals of 0.04 and 0.03 mg/L were measured in the treated, filtered effluent samples from Bag 1 and 2, respectively. The measured chlorine residuals did not meet the required 0.2-0.5 mg/L chlorine residual mandated by The Sphere Project and the WHO. Microsphere removal increased with the use of the absolute material (**Table 4.4**) up to an overall removal of 2.18 logs, but was still below the U.S. EPA Challenge Water removal requirements of 3-log removal. **Table 4.5** outlines the total coliform and *E. coli*

removals at each step in the treatment process. The bacteria log removal was not sufficient to meet the U.S. EPA Challenge Water requirement of 6-log removal. The results of the total coliform and *E. coli* test were not exact because not enough dilutions were performed to find the exact concentration and log removals.

Table 4.4: Microsphere concentration and log removal at each step in the treatment process with 2-ply nominal-absolute filter during the Mock Challenge Water #2 treatment attempt in experiment H-3 at 50 mL/min flowrate.

Step in the Treatment Process	Concentration (spheres/L)	Log Removal of Each Step
Source water ¹	1.10x10 ⁷	--
Treated, unfiltered effluent ¹	9.62x10 ⁴	1.75
Treated, filtered effluent ¹	2.90x10 ⁴	0.43
Overall removal ¹	--	2.18

¹ Two filters were tested at this flowrate, so average values are reported.

Table 4.5: Coliform and *E. coli* concentration and log removal at each step in the treatment process with 2-ply nominal-absolute filter during the Mock Challenge Water #2 treatment attempt in experiment H-3 at 50 mL/min flowrate.

Step in the Treatment Process	Concentration (MPN/100 mL)	Log Removal of Each Step
Source water, coliform ¹	1.61x10 ⁶	--
Treated, unfiltered effluent, coliform ¹	>2419.6	<2.86
Treated, filtered effluent, coliform ¹	>2419.6	--
Overall coliform removal ¹	--	<2.86
Source water, <i>E. coli</i> ¹	1.10x10 ⁶	--
Treated, unfiltered effluent, <i>E. coli</i> ¹	>2419.6	<2.66
Treated, filtered effluent, <i>E. coli</i> ¹	1011.2	>0.38
Overall <i>E. coli</i> removal ¹	--	>3.04

¹ Two filters were tested at this flowrate, so average values are reported.

Due to the low microsphere and bacteria log removal results, it was determined that the 2-ply nominal-absolute filter could not meet the U.S. EPA Challenge Water #2 removal requirements even when the flowrate was only 50 mL/min. Therefore, this flowrate would not be used for the official U.S. EPA Challenge test at BioVir Laboratories.

As a 50 mL/min flowrate did not provide adequate removal, the flowrate was reduced to 20 mL/min. For the 20 mL/min tests, the source water temperature was 9°C and 9.5°C in Bag 1 and 2, respectively. A port screen was also taped over the exit port on the waterbag leading to the filter pouch. The port screen (plastic material with approximately 0.5 mm pore size) prevented unsettled flocs from entering the filter. Turbidity of source water, pre-filter samples, and post-filter samples are all shown in **Figure 4.19**. Both pre-filter and post-filter samples meet the <5 NTU requirement, as required by The Sphere Project (The Sphere Project, 2004).

Figure 4.19: Turbidity of samples collected at various points from waterbags with a 20 mL/min flowrate and a port screen throughout experiment H-3.

Chlorine residuals of 0.04 and 0.06 mg/L were measured in the treated, filtered effluent samples from Bag 1 and 2, respectively. The measured microsphere removal at each step in the treatment process can be seen in **Table 4.6**. The microsphere removal increased

when the flowrate was decreased by approximately 2.5 times to 3.92 log and now exceeded the U.S. EPA Challenge Water removal requirement of 3-log removal. **Table 4.7** outlines the total coliform and *E. coli* removals at each step in the treatment process. The bacteria removal was 6.74 and 6.50 log (coliform and *E. coli* removals, respectively), which exceeded the U.S. EPA Challenge Water requirement of 6-log removal.

Table 4.6: Microsphere concentration and log removal at each step in the treatment process with 2-ply nominal-absolute filter and a port screen during the Mock Challenge Water #2 treatment attempt in experiment H-3 at 20 mL/min flowrate.

Step in the Treatment Process	Concentration (spheres/L)	Log Removal of Each Step
Source water ¹	7.33x10 ⁶	--
Treated, unfiltered effluent ¹	1.75x10 ⁴	2.70
Treated, filtered effluent ¹	9.00x10 ²	1.22
Overall removal ¹	--	3.92

¹ Two filters were tested at this flowrate, so average values are reported.

Table 4.7: Coliform and *E. coli* concentration and log removal at each step in the treatment process with 2-ply nominal-absolute filter and a port screen during the Mock Challenge Water #2 treatment attempt in experiment H-3 at 20 mL/min flowrate.

Step in the Treatment Process	Concentration (MPN/100 mL)	Log Removal of Each Step
Source water, coliform ¹	3.26x10 ⁶	--
Treated, unfiltered effluent, coliform ¹	2	6.44
Treated, filtered effluent, coliform ¹	<1	0.30
Overall coliform removal ¹	--	6.74
Source water, <i>E. coli</i> ¹	2.03x10 ⁶	--
Treated, unfiltered effluent, <i>E. coli</i> ¹	2	6.20
Treated, filtered effluent, <i>E. coli</i> ¹	<1	0.30
Overall <i>E. coli</i> removal ¹	--	6.50

¹ Two filters were tested at this flowrate, so average values are reported.

Due to the sufficient microsphere and bacteria log removal results, it was determined that the 2-ply nominal-absolute filter could meet the U.S. EPA Challenge Water #2 removal

requirements when a port screen was in place and the flowrate was reduced to 20 mL/min. Therefore, this would be the filter used for the official U.S. EPA Challenge test at BioVir Laboratories.

4.2.2 Experiment I-1: Official EPA Challenge Water #2 Attempt

The 2-ply nominal-absolute (liquid fusion) filter was tested in triplicate against the U.S. EPA Microbiological Water Purifier Guide Standard and Testing Protocol at BioVir Laboratories on August 17, 2012. The purpose of this test was to determine if the 2-ply nominal-absolute (liquid fusion) filter could meet the pathogen removal requirements of Test Water #2. The waterbags were filled with tap water first to ensure that all valves were set in the appropriate place to throttle the flowrate to 20 mL/min. Once the waterbags were calibrated to the correct flowrate, they were filled with Challenge Test Water #2, dosed with one PÜR[®] sachet, mixed for five minutes at 100 bpm, allowed to settle and disinfect for 25 min, and effluent was filtered and collected in cubitainers for further analysis. Two different effluent samples were collected, an unfiltered sample and a filtered sample, in order to determine removal capabilities of the 2-ply nominal-absolute (liquid fusion) filter.

Dr. Robert Cooper and his staff prepared the challenge test water and performed the analysis of the raw, treated-unfiltered, and treated-filtered samples. The initial microbiological concentrations in the raw water were 7.3×10^6 colony forming units (CFU)/100 mL *E. coli*, 1.3×10^5 plaque forming units (PFU)/mL coliphage, and 5.6×10^5 beads/L fluorescent microspheres. The *E. coli*, coliphage, and fluorescent microspheres represented the bacteria, virus, and protozoan oocyst elements of the Challenge Test (Cooper, 2012). Final removals of all three prototypes are listed in **Table 4.8**, **Table 4.9**,

and **Table 4.10**. The bacteria, virus, and microsphere removal requirements were met in two of the three bag and filter combinations tested. The complete BioVir Laboratories Test Report for experiment I-1 can be found in **Appendix D**. Note, the flowrate for Bag 3 was the most variable during experiment I-1. This variability could have led to the poor removals observed.

Table 4.8: *E. coli* (CFU/100 mL) removal results (BioVir, 2012)

Influent	Bag 1		Bag 2		Bag 3	
	Bag Effluent	Post Filter Effluent	Bag Effluent	Post Filter Effluent	Bag Effluent	Post Filter Effluent
7.3×10^6	<1	<1	<1	<1	1.5×10^4	2.2×10^2
Log Reduction		>6.7		>6.7	2.6	4.5

Table 4.9: Coliphage (PFU/mL) removal results (BioVir, 2012)

Influent	Bag 1		Bag 2		Bag 3	
	Bag Effluent	Post Filter Effluent	Bag Effluent	Post Filter Effluent	Bag Effluent	Post Filter Effluent
1.3×10^5	<1	<1	<1	<1	9	4
Log Reduction		>5.1		>5.1		≥ 4.3

Table 4.10: Microsphere (Beads/L) removal results (BioVir, 2012)

Influent	Bag 1		Bag 2		Bag 3	
	Bag Effluent	Post Filter Effluent	Bag Effluent	Post Filter Effluent	Bag Effluent	Post Filter Effluent
5.6×10^5	7.7×10^3	<50/L	7.0×10^3	1.2×10^2	4.4×10^3	<10
Log Reduction	1.9	>4.1	1.9	3.7	2.1	2.7

When considering the variability in the microsphere results, it was noted that there was a small volume of water between the exit port and the clamp valve that might not get

treated to the same extent as the majority of the water in the waterbag. The inconsistency of this volume among the triplicate bags could possibly be the cause of the variable results observed. Dr. Robert Cooper also reported that the lower bacteria log removal observed in Bag 3 could have been due to only 9 μL of untreated source water contamination in the effluent cubitainer (Dr. Robert Cooper, personal communication, October, 2012).

Turbidity, pH, and free chlorine residual were also measured on-site by Cal Poly researchers. The average initial turbidity value was 39.7 NTU, which satisfies the U.S. EPA Guide Standard and Testing Protocol. Unfiltered post-treatment turbidities varied slightly between Bag 1 and 2 and greatly between Bag 2 and 3 (**Figure 4.20**). The pH was 5.7 in Bag 1; pH of samples from Bag 2 and 3 was not measured. The free chlorine residual was 0.03 in Bags 1, 2, and 3. A low free chlorine residual is expected when test waters contain such high organic carbon content as that of U.S. EPA Challenge Water #2.

Figure 4.20: Turbidity of samples collected by Cal Poly researchers during the 2012 U.S. EPA Challenge Water test from waterbags tested in triplicate.

The results of the U.S. EPA Challenge Water experiment showed that after treating a contaminated water source with one PŪR[®] sachet in the waterbag, the 2-ply nominal-absolute (liquid fusion) filter can successfully meet turbidity and pathogen (virus) reductions for emergency relief required by the U.S. EPA when used with a 20 mL/min flowrate. These results are in contrast to both the initial BioVir testing in 2009 (Compas, 2009) and the most recent BioVir testing in 2010 (Herzog, 2011). The 2009 BioVir test found that effective treatment was not obtainable with one PŪR[®] sachet and a filter constructed of one layer of the nominal material (Compas, 2009). The 2010 BioVir test found that effective treatment was obtainable with two PŪR[®] sachets and a filter made of one layer of the nominal material (Herzog, 2011).

CHAPTER 5: CONCLUSIONS

The present thesis research aimed to design and develop a low-profile, low-cost, and effective cloth filter for use with the Cal Poly waterbag disaster relief system. Many design iterations were tested and an optimal filter design was developed over the course of 22 experiments. The performance of this optimal design was then characterized using challenge waters. While the new filter is promising, additional testing and characterization is needed as both high removal performance and a simultaneously high flowrate was not possible.

5.1 Optimization and U.S. EPA Challenge Water

Both the design experiments as well as the U.S. EPA Challenge Water experiments led to conclusions regarding filter design and construction for the waterbag. A properly functioning filter helps to remove disinfection-resistant organisms from the waterbag effluent. The experiments showed that an external 2-ply nominal-absolute filter (sealed with Liquid Fusion) gave the best performance when treating U.S. EPA Challenge Water #2. The 2-ply nominal-absolute filter consisted of an internal plastic spacer, an inner layer of 1- μ m nominal filter cloth, and an outer layer of 1- μ m absolute filter cloth. However, the flowrate had to be throttled to 20 mL/min, and performance was inconsistent, perhaps due to non-optimal valves.

When tested in triplicate at BioVir, two out of three bag/filter combinations met and exceeded bacteria, viruses, and protozoa removal requirements (6-log removal, 4-log removal, and 3-log removal, respectively) while one bag only removed 4.5 log of bacteria, ≥ 4.3 log of viruses, and 2.7 log of protozoa. These results contradict removals observed during mock Challenge Water #2 experiments performed at Cal Poly. During

experiment H-3, the 2-ply nominal-absolute filter (sealed with Liquid Fusion) consistently met both bacteria and microsphere removal requirements when flowrate was throttled to 20 mL/min. The low bacteria and microsphere removals could have been due to leaks in the filter pouch, which could have allowed untreated water to drip into the cubitainers. Another possibility is that the initial volume of water caught in the tubing leading from the waterbag to the filter pouch is not adequately treated by the PÜR[®] sachet, resulting in untreated test water mixing with treated, filtered effluent.

Emergency relief guidelines specify a chlorine residual of 0.2-0.5 mg/L for POU treatment devices (Sphere Project, 2004 and WHO, 2006). The present thesis research also showed that when using one PÜR[®] sachet to treat water in the waterbag, a minimum chlorine residual of 0.2 mg/L was not obtained when using Challenge Water #2 which has a high humic acid content to simulate very low quality source water.

5.2 Future Research

Future research on filters for the waterbag is suggested to better characterize the performance of the envelope filter when constructed of non-woven cloth. The influence on performance of the water volume held in the bag effluent tube should be examined. If this volume is not being sufficiently coagulated and disinfected, this volume should be decreased or eliminated. A bag effluent port with integrated valve is one possible way to do this. Another area that may deserve study is the effect of jostling the waterbag and filter during treatment. Jostling may dislodge cysts or flocs from the filter. In the present study, composite samples were used in the commercial lab testing. However, water quality is likely to change over the course of a run. Thus, grab samples taken at intervals over the course of a run might reveal that some aliquots are off-specification. Finally, if a

filter backwashing procedure can be developed that is practical and effective, extended life and/or better water quality performance may be achievable.

Filter media that meets cyst removal goals at minimum low rates of about 200 mL/min, instead of the 20 mL/min needed in the present study, should be sought. Currently available membrane filters, such as the Gravityworks filter, are ideal except for their high cost and bulkiness relative to the envelope filter.

Another way to evaluate filters is on a lifecycle cost basis. Although the upfront cost is high, existing membrane filters, such as the Gravityworks filter, if they have a long lifetime might be considered affordable. As suggested above for the envelope filter, backwashing procedures could be developed and performance and lifetime assessed. In this way, the lifecycle cost and performance of the envelope filter can be compared with commercial filters, which is a needed step prior to commercialization of an envelope filter.

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APPENDIX A: NOMINAL FILTER CLOTH PRODUCT SHEET

Product Sheet from Rosedale Products of California, Inc. for Standard Filter Bag.

R FILTER BAG Design Details

Standard Filter Bag Types

MOLDED ROSEDALE TOP BAGS are stocked with polypropylene tops in sizes 1, 2, 3, 4, 8 & 9.

RING TOP BAGS are stocked in sizes 1, 2, 3, 4, 8, 9 & 12 with galvanized steel, rings.

HANDLES are standard on all bags.

ALL STANDARD STOCK BAGS have sewn construction.

FILTER BAG FINISH

Felt filter bags are supplied with a glazed finish to reduce fiber migration. Mesh filter bags are supplied with a plain finish as woven.

Microfiber filter bags have spunbonded covers to prevent fiber migration.

CONSTRUCTION

Standard filter bags are typically manufactured with a metal ring, either galvanized carbon steel or stainless steel, sewn in the top of the filter bag. Woven fabric handles are also sewn.

Another design incorporates a molded plastic top. These tops typically are polypropylene or polyester with molded lifting handles. Various types of tops are available to fit specific manufacturers' housings.

All Welded Construction

All seams and the collar are sonically welded, enhancing filtration quality, eliminating leaks and bypass that may have occurred with sewn seams.

Bag With Metal Ring Top

Bag With Molded Rosedale Top

Nominal Micron Rating- 50%	High Efficiency Micron Rating- 95%
1	35
5	48
10	55
25	65
50	70
100	110
200	200

Felt Filter Bag Micron Rating

For years filter bag manufacturers have used nominal ratings, i.e., about 50% efficiency for polyester and polypropylene felt filter bags. The table gives the micron ratings at about 95% efficiency.

Filter Bag Pressure Drop

The graphs give the clean pressure drop through a number 2 size bag for water, 1 CPS @ 68°F

To determine the pressure drop caused by the filter bag, follow these steps:

Step 1 Select the type of bag, micron rating and flow rate, determine the pressure drop for water, 1 cps @ 68°F, for a size #2 bag.

Step 2 Correct for bag size from the Bag Size Correction table at the right if the bag size is different than a #2 size.

Step 3 If the viscosity of the liquid is greater than 1 cps (water@ 68°F), multiply the result from step 2 by the proper correction factor from the Viscosity Correction table at the right.

The value obtained in Step 3 is the clean pressure drop caused by the filter bag.

SUMMARY

For new applications, the clean pressure drop of the system, housing and bag should be 2.0 PSI or less. The lower the value is, the more contaminant a bag will hold. For applications with low dirt loading, this value can go to 3.0 PSI or more. Consult the factory for recommendations when the clean pressure drop of the system exceeds 3.0 PSI.

Bag Size Correction

Bag Size	Dia. x Length	Multiply By
1	7.2 x 16	2.25
2	7.2 x 32	1.0
3	4.3 x 8	9.0
4	4.3 x 14	4.5
8	5.7 x 21	2.25
9	5.7 x 37	1.50

Viscosity Correction

Viscosity CPS	Correction Factor
50	4.5
100	8.3
200	16.6
400	27.7
800	50.0
1000	56.2
1500	77.2
2000	113.6
4000	161.0
6000	250.0
8000	325.0
10,000	430.0

S T A N D A R D F I L T E R B A G D E S I G N D E T A I L S

Construction	Fiber	Available Micron Ratings																			
		1	2.5	5	10	20	25	30	40	50	75	100	150	200	250	300	400	600	800	1000	1500
Felts	Polyester																				
	Polypropylene																				
Multifilament Meshes	Polyester																				
Monofilament Meshes	Nylon																				
High-Efficiency Microfiber	Polypropylene																				
Oil Removal	Polypropylene																				

Size	Diameter (Inches)	Length (Inches)	Area Ft ²	Metal Ring Type	Available In Sizes	Molded Rosedale Type	Available In Sizes
1	7.2	16	2.0	Fits Housings Brands: Rosedale Krystil Strainrite Micron Technologies Filtration Systems Parker "G" Style Eaton Filtration Others		Fits Housings Brands: Rosedale Strainrite Micron Technologies
2	7.2	32	4.5				
3	4.3	8	0.5				
4	4.3	14	1.0				
5	6.1	20	2.8				
7	5.7	15	1.5				
8	5.7	32	2.0				
9	5.7	32	3.0				
12	8.4	34	5.5				
X01	5	20	2.0				

MOLDED ROSEDALE TOPS - RPO STYLE

Filter bags with molded Rosedale tops require no filter bag hold down devices. As the differential pressure in the application increases, the integrity of the seal improves. Polypropylene tops are standard with polyester optional for temperatures over 200°F, or for chemical capability.

THE MOLDED ROSEDALE TOP OFFERS THE BEST BAG-TO-HOUSING SEAL IN TODAY'S MARKETPLACE, IN ADDITION TO BEING THE EASIEST TO INSTALL AND REMOVE.

FILTER BAG WITH MOLDED ROSEDALE TOP JUST PRIOR TO INSTALLATION IN BASKET HOLDER

FILTER BAG WITH MOLDED ROSEDALE TOP INSTALLED IN HOUSING

	<p>FELT filter bag materials are made from synthetic fibers in polypropylene or polyester. The proper combination of fiber diameters, weights and thickness results in an economical depth type filter media. Polypropylene and polyester bags are supplied with a glazed finish to reduce fiber migration. These bags have a nominal micron rating. Filter efficiency is about 50%.</p>	
	<p>MULTIFILAMENT MESH materials are offered in polyester and are woven from threads made of small fibers twisted together. Bags made of this material are low cost and considered disposable. They have lower efficiencies than the monofilament mesh. Filter efficiencies are about 80%.</p>	
	<p>MONOFILAMENT MESH is offered in nylon and is a woven material. Each thread is a single filament. The openings are square. They have excellent strength and are considered to be cleanable. Filter efficiency is 90% or more.</p>	<ul style="list-style-type: none"> Operates on the principle of surface filtration Wide range of micron ratings Reusable or disposable Non-fiber releasing Good efficiencies High contaminant quantities under correct conditions
	<p>MICROFIBER filter bags provide high efficiency and high contaminant holding capacity at low ratings. Bags are available in polypropylene. Filter efficiency is 95% or more.</p> <p>MICROFIBER polypropylene filter bags also can remove oil from water and other liquids. Optimized designs are called "OIL REMOVAL BAGS".</p>	

OTHER BAG TYPES AND DESIGNS

500 SERIES 3M TYPE multiple layer filter bags with microfiber filter layers and felt prefilter layers. Up to 5 layers of felt

DOUBLE & TRIPLE LAYER felt bags where the micron rating of the layers are designed to optimize service life.

SPECIAL SIZE & DESIGN bags are available in all materials and most micron ratings.

OIL REMOVAL BAGS require a special design to obtain to result in the largest surface area of fibers in a bag for maximum oil removal capacity. These are standard in micron ratings of 10 and 25.

FILTER BAG HOLD-DOWNS

Adjustable filter bag hold-downs for Size #1 and #2 bags are available for side entry housings manufactured by:

Filter Specialists, Inc. / Micron Technologies / Krystil Klear / Strainrite / Other Side Entry Brands

Available in polypropylene, they provide additional positive filter bag hold-down capabilities for critical applications where necessary. It is suitable for ring top bags and bags with molded plastic tops. It is necessary for many bags with molded tops and ring bags if the bag manufacturer improperly designs and manufactures them.

A FILTER BAG HOLD-DOWN IS NOT REQUIRED WHEN USING FILTER BAGS WITH MOLDED ROSEDALE TOPS.

How To Order Build an ordering code as shown in the example

Example: PE - 25 - G - 2 - RPO - WE

MATERIALS & MICRON RATING

Beta (Polyester) = **BB**
 Microns = **1, 10, 12**

Polyester Felt = **PE**
 Microns = **1/2, 1, 5, 10, 25, 50, 100, 200**

Polypropylene Felt = **PO**
 Microns = **1/2, 1, 5, 10, 25, 50, 100, 200**

Polyester Multifilament Mesh = **PEM**
 Microns = **75, 100, 150, 200, 250, 300, 400, 600, 800, 1000, 1500**

Nylon Monofilament Mesh = **NMO**
 Microns = **5, 10, 25, 50, 75, 100, 150, 200, 250, 300, 400, 600, 800, 1000**

Polypropylene Microfiber = **POMF**
 Microns = **1, 3, 8, 19, 25**

Polyester Microfiber = **PEMF**
 Microns = **1, 3, 8, 19, 25**

Oil Removal = **OR**
 Microns = **10, 25**

BAG CONSTRUCTION

WE = Welded Construction
 (Not available on POMF or PEMF)
No Symbol = Sewn (BB)

BAG STYLES

S = Galvanized Carbon Steel Ring
S-SS = 304 Stainless Steel Ring
RPO = Molded Polypropylene Rosedale Top
RPE = Molded Polyester Rosedale Top

BAG SIZES (Inches)

	Dia.	x	Length
1	7.2	x	16
2	7.2	x	32
3	4.3	x	8
4	4.3	x	12
7	5.7	x	15
8	5.7	x	21
9	5.7	x	32
12	8.4	x	34

BAG FINISH

G = Felt - Glazed or Singed
 (Standard with RPO and RPE top)
P = Polyester

APPENDIX B: ABSOLUTE FILTER CLOTH PRODUCT SHEET

Product Sheet for Rosedale Products of California, Inc. High Efficiency Liquid Bags.

R Rosedale High Efficiency Filter Bags

Our HI-E series of bag filters meets the most stringent needs for fine process, hydraulic fluid, and lubricant filtration. All are made of unique microfiber materials, designed to increase the efficiency and dirt-holding capacities of these bags.

Microfiber Material Construction

Polyester or polypropylene microfibers and standard fibers are variably calendered to produce a single layer of microfiber material. Our unique construction can provide filtration to a 1 micron rating. Polyester microfiber material should be used where oil adsorption is not desirable or where higher temperatures are required.

Filtration Level

These bags have been tested by an independent laboratory to determine the filtration efficiency and dirt holding capabilities for each. They have been manufactured so that the efficiencies for both polyester and polypropylene are identical. See Filtration Efficiency Chart below.

HI-E Series Filter Bags Using Microfiber Construction

PEMF/POMF BAGS: High Efficiency Filtration using a single layer of microfiber material. Excellent for general polishing applications with low dirt load.

GRADED DENSITY BAGS: High Efficiency Filtration with multiple layers of microfiber material and pre-filtration layers. Has 4 times the dirt holding capacity of the PEMF/POMF series bags.

BAG-SIZE PLEATED CARTRIDGES: High Efficiency Filtration with 12 times the dirt holding capacity and microfiber material supported by flow-enhancing mesh. The extra surface area greatly increases the dirt holding capacity.

Filtration Efficiency

Model Number	PEMF 1 POMF 1 523 PL PEMF 1 PL POMF 1	PEMF 3 POMF 3 525 PL PEMF 3 PL POMF 3	PEMF 8 POMF 8 527 PL PEMF 8 PL POMF 8	PEMF 19 POMF 19 529 PL PEMF 19 PL POMF 19
	MICRON RATING			
95%	1.0	3.0	8.0	19.0
99%	2.0	5.0	19.0	25.0

* This test was conducted using AC Fine Test dirt interfaced into water at 10 GPM, Single-Pass.

PEMF/POMF Series

The microfiber bag is encased in spun-bonded material inside and out to prevent bag material migration into the fluid stream. Heavy-duty handles for ease in removal are a standard feature. The fully shaped bottoms enhance the pressure capacities of these bags. **THE PEMF/POMF SERIES HAS 4.4 SQ. FT. OF SURFACE AREA.**

Bag-Sized Pleated Cartridges

With the PL Series pleated cartridges, we've combined the best features of bags and cartridges into one. It has the advantages of a bag; low in cost, easy to handle, and contaminant is trapped inside, but with the greater surface area and dirt-loading capabilities of pleated cartridges. The seams in these filter elements are ultrasonically welded, eliminating the problems associated with sewn seams. The microfiber material is sandwiched between two flow-enhancing polypropylene mesh screens, then pleated. The cartridge bottom and top sealing ring are made of solid molded polypropylene and are welded to the ends of the pleated cylinder without the use of adhesive. The sealing ring is a pliable gasket, increasing the efficiency and integrity of the seal. **THE PL SERIES HAS 25 SQ. FT. OF SURFACE AREA.**

500 Series, Graded Density Bags

The 500 Series FAT BAGS® have approximately four times the dirt-holding capacity of our PEMF/POMF series bags at equivalent filtration levels. You can now use bags, where performance levels previously required cartridges. These Graded Density Bags are made of multiple layers of microfibers and standard fibers variably calendered, providing filtration to 1 micron. Heavy-duty handles for ease in removal are a standard feature. The fully shaped bottoms enhance the pressure capacities of the bag. **THE 500 SERIES HAS 9 LAYERS OF MICROFIBER MATERIAL, EACH WITH 4.4 SQ. FT. OF SURFACE AREA.**

Chemical Compatibilities

	EXCELLENT	GOOD	FAIR	POOR
	Bag Material (Fiber)			
	Nylon	Polyester	Polypropylene	
Organic Solvents	Blue	Blue	Blue	
Animal /Vegetable and Petro Oils	Blue	Blue	Blue	
Microorganisms	Blue	Blue	Blue	
Alkalies	Green	Green	Blue	
Organic Acids	Blue	Green	Blue	
Oxidizing Agents	Red	Green	Green	
Mineral Acids	Red	Green	Green	

Temperature Limitations, 325°F for Nylon and Polyester, 225°F for Polypropylene.

Note: For more complete information on chemical compatibilities, refer to pages 222 through 231.

Dirt Holding Capacity

Pressure Drop

Total pressure drop is the sum of the filter housing pressure drop plus the pressure drop through the bag, and is a function of viscosity as well as flow rate.

Using water as the test media, the pressure drop for these high-efficiency bags is less than 0.5 psi.

Little or no pressure drop across the filter element at rated flow yields maximum dirt holding capacity (element life). Increases in the pressure drop are then due solely to the particulate accumulation.

How To Order

Build an ordering code as shown in these examples

PEMF/POMF SERIES FILTER BAGS

Example:

PEMF - 3 - 2

MICROFIBER MATERIAL

Polyester = **PEMF**
Polypropylene = **POMF**

MICRON RATING (95%)

1.0 micron = **1**
3.0 micron = **3**
8.0 micron = **8**
19.0 micron = **19**

BAG SIZE

(dimensions in inches)

Symbol	Dia.	x	Length
1 =	7-1/16	x	16
2 =	7-1/16	x	32
3 =	4-1/8	x	8
4 =	4-1/8	x	14
7 =	5-5/8	x	15
8 =	5-5/8	x	21
9 =	5-5/8	x	32

500 SERIES GRADED DENSITY BAGS

Example:

GD - PO - 523 - 1

Graded Density Bag

MICROFIBER MATERIAL

Polyester = **PE**
Polypropylene = **PO**

MICRON RATING (95%)

1.0 micron = **523**
3.0 micron = **525**
8.0 micron = **527**
19.0 micron = **529**

BAG SIZE

(dimensions in inches)

Symbol	Dia.	x	Length
1 =	7-1/16	x	16
2 =	7-1/16	x	32

PLEATED CARTRIDGES

Example:

PL- PEMF - R1 - 1 - P1

MICROFIBER MATERIAL

Polyester = **PL-PEMF**
Polypropylene = **PL-POMF**

TOP SEALING RING DESIGN

Flared Polypropylene (P1-P2) = **R1**
Solid Polypropylene (P3-P9) = **R2**

MICRON RATING (95%)

1.0 micron = **1**
3.0 micron = **3**
8.0 micron = **8**
19.0 micron = **19**

BAG SIZE

(dimensions in inches)

Symbol	Dia.	x	Length
P1 =	7-1/16	x	11-1/8
P2 =	7-1/16	x	26-1/8
P3 =	4-1/8	x	5-1/16
P4 =	4-1/8	x	11-1/16
P7 =	5-5/8	x	10-3/4
P8 =	5-5/8	x	16-1/8
P9 =	5-5/8	x	26-3/4

APPENDIX C: FLOW VS. HEAD DATA

EXPERIMENT A-1 DATA

INTERNAL FILTER (Bag 1) - Run 1										
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)
Raw Water	0		0	0	0	0	#DIV/0!	0		35.00
	1	1.46	0.1	100	2.1	0.035	0.04762	2857.14	35.00	34.25
	2	1.36	1	1000	21.7	0.362	0.04608	2764.98	34.25	33.00
	3	1.31	1	1000	22.3	0.372	0.04484	2690.58	33.00	31.75
	4	1.36	1	1000	23.5	0.392	0.04255	2553.19	31.75	30.50
	5	1.78	1	1000	27	0.450	0.03704	2222.22	30.50	29.00
	6	1.68	1	1000	27	0.450	0.03704	2222.22	29.00	27.50
	7.1	1.61	1.1	1100	32	0.533	0.03438	2062.50	27.50	25.50
	8	1.53	0.9	900	35	0.583	0.02571	1542.86	25.50	23.00
	9	1.52	1	1000	80.3	1.338	0.01245	747.20	23.00	20.00
Notes: 100 mL leaked from bulk head fitting due to improper rubber gasket placement										

INTERNAL FILTER (Bag 1) - Run 2										
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)
Raw Water	0		0	0	0	0	#DIV/0!	0		N/M
	1		1	1000	20	0.333	0.05000	3000.00	N/M	N/M
	2		1	1000	22	0.367	0.04545	2727.27	N/M	N/M
	3		1	1000	23	0.383	0.04352	2610.97	N/M	N/M
	4		1	1000	52	0.867	0.01923	1153.85	N/M	N/M
	5		1	1000	30	0.500	0.03333	2000.00	N/M	N/M
	6		1	1000	31	0.517	0.03226	1935.48	N/M	N/M
	7		1	1000	34	0.567	0.02941	1764.71	N/M	N/M
	8		1	1000	42	0.700	0.02381	1428.57	N/M	N/M
	9	1.46	1	1000	180	3.000	0.00556	333.33	N/M	N/M
Notes:										

INTERNAL FILTER (Bag #1) - Run 3										
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)
Raw Water	0		0	0	0	0	#DIV/0!	0		34.50
	2	0.74	2	2000	42	0.700	0.04762	2857.14	34.50	32.50
	4	0.66	2	2000	50	0.833	0.04000	2400.00	32.50	30.25
	6	0.56	2	2000	59	0.983	0.03390	2033.90	30.25	27.50
	8	0.60	2	2000	71	1.183	0.02817	1690.14	27.50	23.75
	9.65	0.64	1.65	1650	175	2.917	0.00943	565.71	23.75	18.00
Notes:										

INTERNAL FILTER (Bag #1) - Run 4										
Water	Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)
Raw Water	0		0	0	0	0	#DIV/0!	0		34.75
	2	0.48	2	2000	45	0.750	0.04444	2666.67	34.75	32.75
	4	0.39	2	2000	50	0.833	0.04000	2400.00	32.75	31.00
	6	0.38	2	2000	59	0.983	0.03390	2033.90	31.00	28.50
	8	0.43	2	2000	74	1.233	0.02703	1621.62	28.50	25.50
	10	0.52	2	2000	150	2.500	0.01333	800.00	25.50	18.50
Notes:										

INTERNAL FILTER (Bag #1) - Run 5										
Water	Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)
Raw Water	0		0	0	0	0	#DIV/0!	0		34.25
	2	0.54	2	2000	45	0.750	0.04444	2666.67	34.25	32.50
	4	0.45	2	2000	52	0.867	0.03846	2307.69	32.50	30.25
	6	0.53	2	2000	59	0.983	0.03390	2033.90	30.25	28.00
	8	0.47	2	2000	68	1.133	0.02941	1764.71	28.00	24.75
	10	0.70	2	2000	137	2.283	0.01460	875.91	24.75	18.25
Notes:										

For Runs 6-12, head was measured incorrectly. Head was measured from the outlet port on the waterbag instead of from the ground.

INTERNAL FILTER (Bag 1) - Run 6										
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)
Raw Water	0	416	0	0	0	0	#DIV/0!	0		15.75
	2	1.00	2	2000	50	0.833	0.04000	2400.00	15.75	13.50
	4	1.02	2	2000	58	0.967	0.03448	2068.97	13.50	11.00
	6	0.98	2	2000	68	1.133	0.02941	1764.71	11.00	8.75
	8	0.99	2	2000	97	1.617	0.02062	1237.11	8.75	4.75
	8.65	1.06	0.65	650	108	1.800	0.00602	361.11	4.75	1.00
Notes: About 100 mL leaked out from bulk head fitting										

INTERNAL FILTER (Bag 1) - Run 7										
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)
Raw Water	0	411	0	0	0	0	#DIV/0!	0		16.00
	2	0.85	2	2000	52	0.867	0.03846	2307.69	16.00	14.25
	4	0.79	2	2000	59	0.983	0.03390	2033.90	14.25	12.00
	6	0.89	2	2000	69	1.150	0.02899	1739.13	12.00	9.25
	8	1.07	2	2000	89	1.483	0.02247	1348.31	9.25	6.00
	9	0.75	1	1000	98	1.633	0.01020	612.24	6.00	1.50
Notes: About 100 mL leaked out from bulk head fitting										

1 um NOMINAL FILTER (Bag 1) - Run 8										
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)
Raw Water	0	503	0	0	0	0	#DIV/0!	0		16.50
	2	0.45	2	2000	55	0.917	0.03636	2181.82	16.50	14.75
	4	0.48	2	2000	63	1.050	0.03175	1904.76	14.75	12.00
	6	0.41	2	2000	80	1.333	0.02500	1500.00	12.00	9.00
	8	0.45	2	2000	121	2.017	0.01653	991.74	9.00	5.50
	8.775	0.43	0.775	775	120	2.000	0.00646	387.50	5.50	1.50
Notes:										

1 um NOMINAL FILTER (Bag 1) - Run 9										
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)
Raw Water	0	466	0	0	0	0	#DIV/0!	0		16.50
	2	9.09	2	2000	64	1.067	0.03125	1875.00	16.50	14.50
	4	1.29	2	2000	74	1.233	0.02703	1621.62	14.50	11.00
	6	0.65	2	2000	98	1.633	0.02041	1224.49	11.00	8.00
	8	0.85	2	2000	169	2.817	0.01183	710.06	8.00	4.25
	8.8	0.94	0.8	800	217	3.617	0.00369	221.20	4.25	0.50
Notes: Initial turbidity incredibly high. I hypothesize that there was a smudge or fingerprint on the glass vial causing the high turbidity.										

1 um NOMINAL FILTER (Bag 1) - Run 10										
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)
Raw Water	0	420	0	0	0	0	#DIV/0!	0		16.00
	2	0.96	2	2000	78	1.300	0.02564	1538.46	16.00	13.50
	4	0.39	2	2000	97	1.617	0.02062	1237.11	13.50	10.50
	6	0.40	2	2000	141	2.350	0.01418	851.06	10.50	8.25
	8	0.41	2	2000	246	4.100	0.00813	487.80	8.25	3.50
	8.6	0.67	0.6	600	142	2.367	0.00423	253.52	3.50	0.75
Notes:										

1 um NOMINAL FILTER (Bag 1) - Run 11										
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)
Raw Water	0	453	0	0	0	0	#DIV/0!	0		16.25
	2	2.62	2	2000	88	1.467	0.02273	1363.64	16.25	13.75
	4	0.87	2	2000	107	1.783	0.01869	1121.50	13.75	10.50
	6	0.65	2	2000	150	2.500	0.01333	800.00	10.50	8.00
	8	0.74	2	2000	234	3.900	0.00855	512.82	8.00	4.00
	8.85	0.64	0.85	850	240	4.000	0.00354	212.50	4.00	0.50
Notes:										

1 um NOMINAL FILTER (Bag 1) - Run 12										
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)
Raw Water	0	505	0	0	0	0	#DIV/0!	0		16.50
	2	6.23	2	2000	104	1.733	0.01923	1153.85	16.50	14.00
	4	2.19	2	2000	130	2.167	0.01538	923.08	14.00	11.25
	6	1.96	2	2000	187	3.117	0.01070	641.71	11.25	9.00
	8	1.10	2	2000	302	5.033	0.00662	397.35	9.00	4.75
	8.625	0.87	0.625	625	159	2.650	0.00393	235.85	4.75	3.00
Notes: See explanation during Run 9...										

EXPERIMENT A-2 DATA

1 um NOMINAL FILTER (Bag #5) - Run 1										
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)
Raw Water	0	N/M	0	0	0	0	#DIV/0!	0		33.00
	2	1.15	2	2000	59	0.983	0.03390	2033.90	33.00	30.50
	4	0.91	2	2000	68	1.133	0.02941	1764.71	30.50	28.25
	6	2.30	2	2000	67	1.117	0.02985	1791.04	28.25	25.50
	8	0.78	2	2000	74	1.233	0.02703	1621.62	25.50	21.50
	9	0.83	1	1000	45	0.750	0.02222	1333.33	21.50	19.50
Notes:										

For Runs 2-10, head was measured incorrectly. Head was measured from the outlet port on the waterbag instead of from the ground.

1 um NOMINAL FILTER (Bag 5) - Run 2										
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)
Raw Water	0	431	0	0	0	0	#DIV/0!	0		17.00
	2	0.58	2	2000	91	1.517	0.02198	1318.68	17.00	15.50
	4	0.60	2	2000	78	1.300	0.02564	1538.46	15.50	13.50
	6	0.53	2	2000	94	1.567	0.02128	1276.60	13.50	10.50
	8	0.48	2	2000	102	1.700	0.01961	1176.47	10.50	8.00
	10.0	0.53	2	2000	233	3.883	0.00858	515.02	8.00	3.00
Notes:										

1 um NOMINAL FILTER (Bag 5) - Run 3

Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)
Raw Water	0	460	0	0	0	0	#DIV/0!	0		17.00
	2	0.37	2	2000	67	1.117	0.02985	1791.04	17.00	15.50
	4	0.44	2	2000	87	1.450	0.02299	1379.31	15.50	12.75
	6	0.42	2	2000	97	1.617	0.02062	1237.11	12.75	10.00
	8	0.94	2	2000	120	2.000	0.01667	1000.00	10.00	6.75
	9.0	0.33	1	1000	95	1.583	0.01053	631.58	6.75	3.75

Notes:

1 um NOMINAL FILTER (Bag 5) - Run 4

Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)
Raw Water	0	329	0	0	0	0	#DIV/0!	0		17.75
	2	0.47	2	2000	75	1.250	0.02667	1600.00	17.75	16.00
	4	0.29	2	2000	91	1.517	0.02198	1318.68	16.00	13.50
	6	0.26	2	2000	102	1.700	0.01961	1176.47	13.50	11.25
	8	2.57	2	2000	124	2.067	0.01613	967.74	11.25	8.00
	10.0	0.33	2	2000	208	3.467	0.00962	576.92	8.00	2.75

Notes:

1 um NOMINAL FILTER (Bag 5) - Run 5

Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)
Raw Water	0	32.1	0	0	0	0	#DIV/0!	0		17.50
	2	1.29	2	2000	102	1.700	0.01961	1176.47	17.50	15.75
	4	1.26	2	2000	123	2.050	0.01626	975.61	15.75	13.00
	6	0.42	2	2000	163	2.717	0.01227	736.20	13.00	10.75
	8	0.39	2	2000	221	3.683	0.00905	542.99	10.75	8.00
	9.4	0.41	1.4	1400	194	3.233	0.00722	432.99	8.00	4.75

Notes:

1 um NOMINAL FILTER (Bag 5) - Run 6										
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)
Raw Water	0	27.9	0	0	0	0	#DIV/0!	0		16.00
	2	0.34	2	2000	149	2.483	0.01342	805.37	16.00	14.00
	4	0.38	2	2000	167	2.783	0.01198	718.56	14.00	11.25
	6	0.36	2	2000	185	3.083	0.01081	648.65	11.25	8.75
	8	0.31	2	2000	235	3.917	0.00851	510.64	8.75	5.25
	9.0	0.33	1	1000	207	3.450	0.00483	289.86	5.25	3.00
Notes:										

1 um NOMINAL FILTER (Bag 5) - Run 7										
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)
Raw Water	0	23.3	0	0	0	0	#DIV/0!	0		16.00
	2	1.32	2	2000	120	2.000	0.01667	1000.00	16.00	13.50
	4	0.44	2	2000	144	2.400	0.01389	833.33	13.50	10.50
	6	0.52	2	2000	163	2.717	0.01227	736.20	10.50	8.00
	8	0.44	2	2000	217	3.617	0.00922	553.00	8.00	4.00
	8.6	0.38	0.55	550	86	1.433	0.00640	383.72	4.00	2.50
Notes:										

1 um NOMINAL FILTER (Bag 5) - Run 8										
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)
Raw Water	0			0	0	0	#DIV/0!	0		15.75
	2	0.36	2	2000	66	1.100	0.03030	1818.18	15.75	13.75
	4	0.30	2	2000	80	1.333	0.02500	1500.00	13.75	11.50
	6	0.36	2	2000	99	1.650	0.02020	1212.12	11.50	9.25
	8	0.32	2	2000	132	2.200	0.01515	909.09	9.25	5.50
	9	0.25	1	1000	95	1.583	0.01053	631.58	5.50	3.25
Notes:										

1 um NOMINAL FILTER (Bag 5) - Run 9										
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)
Raw Water	0		0	0	0	0	#DIV/0!	0		17.00
	2	0.37	2	2000	126	2.100	0.01587	952.38	17.00	15.00
	4	0.32	2	2000	122	2.033	0.01639	983.61	15.00	12.00
	6	0.47	2	2000	195	3.250	0.01026	615.38	12.00	9.50
	8	0.26	2	2000	277	4.617	0.00722	433.21	9.50	6.50
	9	0.17	1	1000	184	3.067	0.00543	326.09	6.50	4.50
Notes:										

1 um NOMINAL FILTER (Bag 5) - Run 10										
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)
Raw Water	0		0	0	0	0	#DIV/0!	0		15.25
	2	0.17	2	2000	251	4.183	0.00797	478.09	15.25	13.25
	4	0.16	2	2000	313	5.217	0.00639	383.39	13.25	10.00
	6	0.14	2	2000	349	5.817	0.00573	343.84	10.00	7.50
	8	0.09	2	2000	521	8.683	0.00384	230.33	7.50	4.25
	9	0.14	1	1000	380	6.333	0.00263	157.89	4.25	2.00
Notes:										

EXPERIMENT A-3

500 um NETTING + 1 um NOMINAL FILTER (Bag #6) - Run 1										
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)
Raw Water	0	N/M	0	0	0	0	#DIV/0!	0		34.25
	2	0.97	2	2000	37	0.617	0.05405	3243.24	34.25	32.25
	4	1.21	2	2000	40	0.667	0.05000	3000.00	32.25	29.50
	6	0.88	2	2000	45	0.750	0.04444	2666.67	29.50	26.50
	8	0.91	2	2000	50	0.833	0.04000	2400.00	26.50	23.00
	9	0.79	1.3	1300	40	0.667	0.03250	1950.00	23.00	19.00
Notes:										

For Runs 2-10, head was measured incorrectly. Head was measured from the outlet port on the waterbag instead of from the ground.

500 um NETTING + 1 um NOMINAL FILTER (Bag 6) - Run 2										
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)
Raw Water	0	431	0	0	0	0	#DIV/0!	0		17.25
	2	0.58	2	2000	44	0.733	0.04545	2727.27	17.25	15.50
	4	1.56	2	2000	46	0.767	0.04348	2608.70	15.50	13.00
	6	0.59	2	2000	54	0.900	0.03704	2222.22	13.00	10.25
	8	0.79	2	2000	68	1.133	0.02941	1764.71	10.25	7.00
	9.0	0.71	1	1000	46	0.767	0.02174	1304.35	7.00	4.25
Notes:										

500 um NETTING + 1 um NOMINAL FILTER (Bag 6) - Run 3										
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)
Raw Water	0	337	0	0	0	0	#DIV/0!	0		16.50
	2	0.95	2	2000	45	0.750	0.04444	2666.67	16.50	14.00
	4	1.46	2	2000	53	0.883	0.03774	2264.15	14.00	11.00
	6	1.02	2	2000	59	0.983	0.03390	2033.90	11.00	8.50
	8	1.03	2	2000	74	1.233	0.02703	1621.62	8.50	5.50
	9.4	1.04	1.4	1400	97	1.617	0.01443	865.98	5.50	1.50
Notes:										

500 um NETTING + 1 um NOMINAL FILTER (Bag 6) - Run 4										
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)
Raw Water	0	412	0	0	0	0	#DIV/0!	0		16.00
	2	0.74	2	2000	45	0.750	0.04444	2666.67	16.00	13.50
	4	0.45	2	2000	52	0.867	0.03846	2307.69	13.50	10.50
	6	0.40	2	2000	62	1.033	0.03226	1935.48	10.50	8.00
	8	0.51	2	2000	80	1.333	0.02500	1500.00	8.00	4.75
	10.0	0.47	2	2000	80	1.333	0.02500	1500.00	4.75	1.50
Notes:										

500 um NETTING + 1 um NOMINAL FILTER (Bag 6) - Run 5										
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)
Raw Water	0	32.1	0	0	0	0	#DIV/0!	0		17.00
	2	0.43	2	2000	49	0.817	0.04082	2448.98	17.00	16.00
	4	0.51	2	2000	53	0.883	0.03774	2264.15	16.00	13.25
	6	0.42	2	2000	65	1.083	0.03077	1846.15	13.25	10.00
	8	0.42	2	2000	89	1.483	0.02247	1348.31	10.00	6.75
	9.4	0.45	1.4	1400	169	2.817	0.00828	497.04	6.75	3.50
Notes:										

500 um NETTING + 1 um NOMINAL FILTER (Bag 6) - Run 6										
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)
Raw Water	0	27.9	0	0	0	0	#DIV/0!	0		15.75
	2	0.32	2	2000	48	0.800	0.04167	2500.00	15.75	14.00
	4	0.35	2	2000	56	0.933	0.03571	2142.86	14.00	10.75
	6	0.37	2	2000	65	1.083	0.03077	1846.15	10.75	8.25
	8	0.38	2	2000	86	1.433	0.02326	1395.35	8.25	4.50
	8.9	0.40	0.85	850	82	1.367	0.01037	621.95	4.50	1.75
Notes:										

500 um NETTING + 1 um NOMINAL FILTER (Bag 6) - Run 7										
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)
Raw Water	0	23.3	0	0	0	0	#DIV/0!	0		16.50
	2	0.37	2	2000	47	0.783	0.04255	2553.19	16.50	15.00
	4	0.47	2	2000	55	0.917	0.03636	2181.82	15.00	12.00
	6	0.42	2	2000	63	1.050	0.03175	1904.76	12.00	9.50
	8	0.38	2	2000	83	1.383	0.02410	1445.78	9.50	6.00
	9.5	0.36	1.45	1450	138	2.300	0.01051	630.43	6.00	2.50
Notes:										

500 um NETTING + 1 um NOMINAL FILTER (Bag 6) - Run 8										
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)
Raw Water	0		0	0	0	0	#DIV/0!	0		16.25
	2	0.63	2	2000	44	0.733	0.04545	2727.27	16.25	14.25
	4	0.58	2	2000	50	0.833	0.04000	2400.00	14.25	12.00
	6	0.44	2	2000	59	0.983	0.03390	2033.90	12.00	9.50
	8	0.69	2	2000	74	1.233	0.02703	1621.62	9.50	5.50
	9	0.46	1	1000	50	0.833	0.02000	1200.00	5.50	3.50
Notes:										

500 um NETTING + 1 um NOMINAL FILTER (Bag 6) - Run 9										
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)
Raw Water	0		0	0	0	0	#DIV/0!	0		16.00
	2	0.49	2	2000	47	0.783	0.04255	2553.19	16.00	14.00
	4	0.62	2	2000	53	0.883	0.03774	2264.15	14.00	11.50
	6	0.39	2	2000	62	1.033	0.03226	1935.48	11.50	9.50
	8	0.53	2	2000	78	1.300	0.02564	1538.46	9.50	5.00
	9	0.42	1	1000	53	0.883	0.01887	1132.08	5.00	2.50
Notes:										

500 um NOMINAL + 1 um NOMINAL FILTER (Bag 6) - Run 10										
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)
Raw Water	0		0	0	0	0	#DIV/0!	0		16.75
	2	0.74	2	2000	48	0.800	0.04167	2500.00	16.75	14.50
	4	0.45	2	2000	56	0.933	0.03571	2142.86	14.50	12.00
	6	0.40	2	2000	65	1.083	0.03077	1846.15	12.00	9.25
	8	0.37	2	2000	83	1.383	0.02410	1445.78	9.25	6.00
	9	0.35	1	1000	59	0.983	0.01695	1016.95	6.00	4.00
	10	0.34	1	1000	104	1.733	0.00962	576.92	6.00	1.75
Notes:										

500 um NETTING + 1 um NOMINAL FILTER (Bag 6) - Run 11										
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)
Raw Water	0	416	0	0	0	0	#DIV/0!	0		16.50
	2	1.05	2	2000	62	1.033	0.03226	1935.48	16.50	14.00
	4	0.43	2	2000	80	1.333	0.02500	1500.00	14.00	12.00
	6	0.41	2	2000	85	1.417	0.02353	1411.76	12.00	9.25
	8	0.40	2	2000	118	1.967	0.01695	1016.95	9.25	5.00
	8.7	0.43	0.7	700	75	1.250	0.00933	560.00	5.00	3.00
Notes:										

500 um NETTING + 1 um NOMINAL FILTER (Bag 6) - Run 12										
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)
Raw Water	0	411	0	0	0	0	#DIV/0!	0		17.00
	2.1	2.28	2	2100	74	1.233	0.02838	1702.70	17.00	15.00
	4.1	1.95	2	2000	83	1.383	0.02410	1445.78	15.00	12.00
	6.1	0.75	2	2000	98	1.633	0.02041	1224.49	12.00	9.50
	8.1	0.86	2	2000	125	2.083	0.01600	960.00	9.50	6.50
	9	0.89	1	1000	120	2.000	0.00833	500.00	6.50	3.00
Notes:										

EXPERIMENT B-1

EXTERNAL FILTER (Bag 2) - Run 1

Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)
Raw Water	0		0	0	0	0	#DIV/0!	0		35.50
	0.1		0.1	100	3.7	0.062	0.02703	1621.62	35.50	
	0.2		0.1	100	2.3	0.038	0.04348	2608.70		
	0.3		0.1	100	3	0.050	0.03333	2000.00		
	0.4		0.1	100	2	0.033	0.05000	3000.00		
	0.5		0.1	100	4	0.067	0.02500	1500.00		
	0.6		0.1	100	3	0.050	0.03333	2000.00		
	0.7		0.1	100	2.5	0.042	0.04000	2400.00		
	0.8		0.1	100	3.5	0.058	0.02857	1714.29		
	0.9		0.1	100	2	0.033	0.05000	3000.00		
	1.65	1.62	0.75	750	30	0.500	0.02500	1500.00		33.50
	2.9	1.14	1.25	1250	36.3	0.605	0.03444	2066.12	33.50	31.50
	4	1.27	1.1	1100	31	0.517	0.03548	2129.03	31.50	29.50
	5	1.42	1	1000	25.3	0.422	0.03953	2371.54	29.50	28.50
	6	1.49	1	1000	26	0.433	0.03846	2307.69	28.50	27.00
	7	1.38	1	1000	27.8	0.463	0.03597	2158.27	27.00	25.50
	8	1.21	1	1000	28.6	0.477	0.03497	2097.90	25.50	23.50
	9	1.20	1	1000	31	0.517	0.03226	1935.48	23.50	21.00
	9.7	1.48	0.7	700	37.3	0.622	0.01877	1126.01	21.00	20.50

Notes: 30 mL leaked from left corner front of bag

EXTERNAL FILTER (Bag 2) - Run 2

Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)
Raw Water	0		0	0	0	0	#DIV/0!	0		N/M
	1		1	1000	26	0.432	0.03860	2315.71		N/M
	2		1	1000	24	0.400	0.04167	2500.00		N/M
	3		1	1000	16	0.267	0.06250	3750.00		N/M
	4		1	1000	36	0.600	0.02778	1666.67		N/M
	5		1	1000	27	0.450	0.03704	2222.22		N/M
	6		1	1000	27	0.450	0.03704	2222.22		N/M
	7		1	1000	29	0.483	0.03448	2068.97		N/M
	8		1	1000	29	0.483	0.03448	2068.97		N/M
	9		1	1000	32	0.533	0.03125	1875.00		N/M
	9.7	1.41	0.7	700	25	0.417	0.02800	1680.00		N/M

Notes: Last 700 mL seemed to be coming out of external bag

EXTERNAL FILTER (Bag #2) - Run 3

Water	Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)
Raw Water	0		0	0	0	0	#DIV/0!	0		33.00
	2	0.69	2	2000	60	1.000	0.03333	2000.00	33.00	30.50
	4	0.68	2	2000	27	0.450	0.07407	4444.44	30.50	28.50
	6	0.67	2	2000	28	0.467	0.07143	4285.71	28.50	25.00
	8	0.71	2	2000	61	1.017	0.03279	1967.21	25.00	19.50
	10	0.70	2	2000	93	1.550	0.02151	1290.32	19.50	19.50

Notes: flipped filter to run from outside to inside; BAD IDEA because the inside of the filter was filled with 20 L worth of floc; this caused a high initial turbidity. Initial flow rate was really low due to a kink in the tubing. No change in head as last 2 liters drained out of external pouch.

EXTERNAL FILTER (Bag #2) - Run 4

Water	Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)
Raw Water	0		0	0	0	0	#DIV/0!	0		34.00
	2	0.62	2	2000	30	0.500	0.06667	4000.00	34.00	31.50
	4	0.57	2	2000	30	0.500	0.06667	4000.00	31.50	29.25
	6	0.67	2	2000	36	0.600	0.05556	3333.33	29.25	26.50
	8	0.41	2	2000	35	0.583	0.05714	3428.57	26.50	22.75
	10	0.48	2	2000	45	0.750	0.04444	2666.67	22.75	18.50

Notes:

EXTERNAL FILTER (Bag #2) - Run 5

Water	Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)
Raw Water	0		0	0	0	0	#DIV/0!	0		33.75
	2	0.44	2	2000	30	0.500	0.06667	4000.00	33.75	31.75
	4	0.56	2	2000	30	0.500	0.06667	4000.00	31.75	29.25
	6	0.48	2	2000	36	0.600	0.05556	3333.33	29.25	26.50
	8	0.53	2	2000	35	0.583	0.05714	3428.57	26.50	22.75
	10	0.53	2	2000	45	0.750	0.04444	2666.67	22.75	19.50

Notes:

EXPERIMENT B-2

OUT --> IN FILTER - Run 1										
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)
Raw Water	0	499	0	0	0	0	#DIV/0!	0		37.00
	2	1.20	2	2000	133	2.217	0.01504	902.26	37.00	35.00
	4	1.08	2	2000	187	3.117	0.01070	641.71	35.00	33.00
	6	0.98	2	2000	275	4.583	0.00727	436.36	33.00	28.00
	7	1.29	1	1000	n/a	#VALUE!	#VALUE!	#VALUE!	28.00	26.00
Notes:										

OUT --> IN FILTER - Run 2										
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)
Raw Water	0	419	0	0	0	0	#DIV/0!	0		36.00
	2	0.90	2	2000	83	1.383	0.02410	1445.78	36.00	33.50
	4	0.95	2	2000	159	2.650	0.01258	754.72	33.50	30.00
	6	0.98	2	2000	245	4.083	0.00816	489.80	30.00	26.50
	6.25	1.18	0.25	250	124	2.067	0.00202	120.97	26.50	26.00
Notes:										

OUT --> IN FILTER - Run 3										
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)
Raw Water	0	461	0	0	0	0	#DIV/0!	0		36.50
	2	0.86	2	2000	85	1.417	0.02353	1411.76	36.50	34.00
	4	0.93	2	2000	87	1.450	0.02299	1379.31	34.00	31.00
	6	0.82	2	2000	91	1.517	0.02198	1318.68	31.00	28.00
	6.95	0.93	0.95	950	124	2.067	0.00766	459.68	28.00	26.50
Notes:										

OUT --> IN FILTER - Run 4										
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)
Raw Water	0	440	0	0	0	0	#DIV/0!	0		36.00
	2	1.02	2	2000	69	1.150	0.02899	1739.13	36.00	34.50
	4	0.92	2	2000	72	1.200	0.02778	1666.67	34.50	32.00
	6	0.96	2	2000	81	1.350	0.02469	1481.48	32.00	28.50
	8	1.15	2	2000	253	4.217	0.00791	474.31	28.50	25.00
Notes:										

OUT --> IN FILTER - Run 5										
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)
Raw Water	0	511	0	0	0	0	#DIV/0!	0		36.00
	2	1.75	2	2000	77	1.283	0.02597	1558.44	36.00	34.50
	4	1.06	2	2000	73	1.217	0.02740	1643.84	34.50	32.50
	6	0.94	2	2000	82	1.367	0.02439	1463.41	32.50	29.25
	8	1.01	2	2000	144	2.400	0.01389	833.33	29.25	26.00
Notes:										

OUT --> IN FILTER - Run 6										
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)
Raw Water	0	478	0	0	0	0	#DIV/0!	0		36.75
	2	1.11	2	2000	67	1.117	0.02985	1791.04	36.75	34.75
	4	0.97	2	2000	76	1.267	0.02632	1578.95	34.75	32.50
	6	0.91	2	2000	85	1.417	0.02353	1411.76	32.50	28.75
	8	0.96	2	2000	122	2.033	0.01639	983.61	28.75	25.00
	8.45	0.89	0.45	450	93	1.550	0.00484	290.32	25.00	24.50
Notes:										

OUT --> IN FILTER - Run 7										
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)
Raw Water	0	457	0	0	0	0	#DIV/0!	0		36.00
	2	1.11	2	2000	86	1.433	0.02326	1395.35	36.00	35.00
	4	0.94	2	2000	106	1.767	0.01887	1132.08	35.00	32.00
	6	0.54	2	2000	98	1.633	0.02041	1224.49	32.00	28.00
	8	0.88	2	2000	170	2.833	0.01176	705.88	28.00	24.00
Notes:										

OUT --> IN FILTER - Run 8										
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)
Raw Water	0	409	0	0	0	0	#DIV/0!	0		37.00
	2	0.59	2	2000	78	1.300	0.02564	1538.46	37.00	33.50
	4	0.66	2	2000	72	1.200	0.02778	1666.67	33.50	30.50
	6	0.39	2	2000	105	1.750	0.01905	1142.86	30.50	26.50
	7	0.47	1	1000	80	1.333	0.01250	750.00	26.50	23.50
Notes:										

OUT --> IN FILTER - Run 9										
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)
Raw Water	0	391	0	0	0	0	#DIV/0!	0		37.00
	2	0.42	2	2000	79	1.317	0.02532	1518.99	37.00	35.50
	4	0.54	2	2000	93	1.550	0.02151	1290.32	35.50	33.50
	6	0.55	2	2000	90	1.500	0.02222	1333.33	33.50	30.00
	7.7	0.42	1.70	1700	270	4.500	0.00630	377.78	30.00	28.00
Notes:										

OUT --> IN FILTER - Run 10										
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)
Raw Water	0	531	0	0	0	0	#DIV/0!	0		37.00
	2	0.65	2	2000	81	1.350	0.02469	1481.48	37.00	35.00
	4	0.64	2	2000	91	1.517	0.02198	1318.68	35.00	32.00
	6	0.64	2	2000	111	1.850	0.01802	1081.08	32.00	29.00
	7.35	1.03	1.35	1350	240	4.000	0.00563	337.50	29.00	26.00
Notes:										

OUT --> IN FILTER - Run 11										
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)
Raw Water	0	520	0	0	0	0	#DIV/0!	0		36.50
	2	0.65	2	2000	67	1.117	0.02985	1791.04	36.50	35.50
	4	0.91	2	2000	79	1.317	0.02532	1518.99	35.50	33.50
	6	0.90	2	2000	91	1.517	0.02198	1318.68	33.50	30.00
	8	0.83	2	2000	147	2.450	0.01361	816.33	30.00	27.00
Notes:										

OUT --> IN FILTER - Run 12										
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)
Raw Water	0	424	0	0	0	0	#DIV/0!	0		35.50
	2	0.56	2	2000	84	1.400	0.02381	1428.57	35.50	33.00
	4	0.59	2	2000	84	1.400	0.02381	1428.57	33.00	31.00
	6	0.60	2	2000	98	1.633	0.02041	1224.49	31.00	27.00
	7.55	0.55	1.55	1550	180	3.000	0.00861	516.67	27.00	25.00
Notes:										

EXPERIMENT B-3

IN --> OUT FILTER - Run 1										
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)
Raw Water	0	499	0	0	0	0	#DIV/0!	0		38.00
	2	1.06	2	2000	140	2.333	0.01429	857.14	38.00	36.50
	4	1.06	2	2000	206	3.433	0.00971	582.52	36.50	34.00
	6	1.71	2	2000	390	6.500	0.00513	307.69	34.00	30.50
	8	1.29	2	2000	n/a	#VALUE!	#VALUE!	#VALUE!	30.50	26.00
Notes:										

IN --> OUT FILTER - Run 2										
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)
Raw Water	0	419	0	0	0	0	#DIV/0!	0		37.00
	2	1.04	2	2000	203	3.383	0.00985	591.13	37.00	35.00
	4	0.72	2	2000	110	1.833	0.01818	1090.91	35.00	32.00
	6	0.80	2	2000	100	1.667	0.02000	1200.00	32.00	27.50
	8	1.07	2	2000	115	1.917	0.01739	1043.48	27.50	23.00
	8.75	0.82	0.75	750	75	1.250	0.01000	600.00	23.00	21.00
Notes:										

IN --> OUT FILTER - Run 3										
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)
Raw Water	0	461	0	0	0	0	#DIV/0!	0		37.00
	2	1.32	2	2000	83	1.383	0.02410	1445.78	37.00	34.00
	4	1.89	2	2000	76	1.267	0.02632	1578.95	34.00	31.50
	6	0.79	2	2000	86	1.433	0.02326	1395.35	31.50	27.75
	8	0.77	2	2000	155	2.583	0.01290	774.19	27.75	22.25
	8.7	0.92	0.7	700	180	3.000	0.00389	233.33	22.25	20.75
Notes:										

IN --> OUT FILTER - Run 4										
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)
Raw Water	0	440	0	0	0	0	#DIV/0!	0		37.00
	2	0.80	2	2000	77	1.283	0.02597	1558.44	37.00	35.00
	4	0.68	2	2000	77	1.283	0.02597	1558.44	35.00	32.50
	6	0.65	2	2000	95	1.583	0.02105	1263.16	32.50	29.00
	8	0.73	2	2000	158	2.633	0.01266	759.49	29.00	24.50
	8.6	0.73	0.6	600	163	2.717	0.00368	220.86	24.50	22.25
Notes: steady drip out of bag, unsure if from filter bag or possibly hole in Cascade bag, covered in duct tape										

IN --> OUT FILTER - Run 5										
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)
Raw Water	0	511	0	0	0	0	#DIV/0!	0		36.00
	2	1.00	2	2000	80	1.333	0.02500	1500.00	36.00	34.50
	4	1.13	2	2000	75	1.250	0.02667	1600.00	34.50	31.00
	6	0.85	2	2000	90	1.500	0.02222	1333.33	31.00	27.00
	8	0.86	2	2000	162	2.700	0.01235	740.74	27.00	22.00
	8.4	0.78	0.4	400	66	1.100	0.00606	363.64	22.00	21.50
Notes: steady drip out of bag, unsure if from filter bag or possibly hole in Cascade bag, covered in duct tape										

IN --> OUT FILTER - Run 6										
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)
Raw Water	0	478	0	0	0	0	#DIV/0!	0		37.00
	2	0.67	2	2000	77	1.283	0.02597	1558.44	37.00	34.00
	4	0.68	2	2000	80	1.333	0.02500	1500.00	34.00	31.00
	6	1.09	2	2000	101	1.683	0.01980	1188.12	31.00	26.75
	8	0.73	2	2000	165	2.750	0.01212	727.27	26.75	21.75
	8.45	0.66	0.45	450	75	1.250	0.00600	360.00	21.75	20.75
Notes:										

IN --> OUT FILTER - Run 7										
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)
Raw Water	0	457	0	0	0	0	#DIV/0!	0		38.00
	2	0.99	2	2000	77	1.283	0.02597	1558.44	38.00	37.00
	4	0.62	2	2000	85	1.417	0.02353	1411.76	37.00	32.00
	6	0.68	2	2000	105	1.750	0.01905	1142.86	32.00	27.50
	8	0.70	2	2000	174	2.900	0.01149	689.66	27.50	22.50
	8.7	0.38	0.7	700	135	2.250	0.00519	311.11	22.50	21.00
Notes: metal clamp opened after 4 liters drawn out of bag										

IN --> OUT FILTER - Run 8										
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)
Raw Water	0	409	0	0	0	0	#DIV/0!	0		37.00
	2	14.50	2	2000	75	1.250	0.02667	1600.00	37.00	34.00
	4	0.95	2	2000	100	1.667	0.02000	1200.00	34.00	30.00
	6	0.72	2	2000	95	1.583	0.02105	1263.16	30.00	25.00
	7.1	0.64	1	1100	200	3.333	0.00550	330.00	25.00	22.00
Notes: metal clamp opened after 4 liters drawn out of bag										

IN --> OUT FILTER - Run 9										
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)
Raw Water	0	391	0	0	0	0	#DIV/0!	0		36.00
	2	0.82	2	2000	92	1.533	0.02174	1304.35	36.00	35.00
	4	0.78	2	2000	98	1.633	0.02041	1224.49	35.00	31.50
	6	0.65	2	2000	116	1.933	0.01724	1034.48	31.50	27.00
	8	0.69	2	2000	290	4.833	0.00690	413.79	27.00	24.00
	8.2	0.54	0.2	200	84	1.400	0.00238	142.86	24.00	21.00
Notes:										

IN --> OUT FILTER - Run 10										
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)
Raw Water	0	531	0	0	0	0	#DIV/0!	0		36.50
	2	1.22	2	2000	100	1.667	0.02000	1200.00	36.50	34.00
	4	0.72	2	2000	108	1.800	0.01852	1111.11	34.00	30.00
	6	0.63	2	2000	160	2.667	0.01250	750.00	30.00	25.00
	7.5	0.63	1.50	1500	257	4.283	0.00584	350.19	25.00	23.00
Notes:										

IN --> OUT FILTER - Run 11										
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)
Raw Water	0	520	0	0	0	0	#DIV/0!	0		37.00
	2	0.59	2	2000	91	1.517	0.02198	1318.68	37.00	35.00
	4	0.51	2	2000	102	1.700	0.01961	1176.47	35.00	31.50
	6	0.62	2	2000	134	2.233	0.01493	895.52	31.50	27.50
	8	0.55	2	2000	200	3.333	0.01000	600.00	27.50	23.00
Notes:										

IN --> OUT FILTER - Run 12										
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)
Raw Water	0	424	0	0	0	0	#DIV/0!	0		37.00
	2	0.88	2	2000	90	1.500	0.02222	1333.33	37.00	34.50
	4	0.81	2	2000	108	1.800	0.01852	1111.11	34.50	32.00
	6	0.84	2	2000	118	1.967	0.01695	1016.95	32.00	28.50
	8	0.73	2	2000	191	3.183	0.01047	628.27	28.50	23.50
Notes:										

EXPERIMENT C-1

In --> Out, parallel bulk heads FILTER - Run 1										
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)
Raw Water	0	451	0	0	0	0	#DIV/0!	0		37.00
	2	0.90	2	2000	160	2.667	0.01250	750.00	37.00	36.00
	4	0.88	2	2000	125	2.083	0.01600	960.00	36.00	34.00
	6	0.72	2	2000	155	2.583	0.01290	774.19	34.00	30.50
	8	0.59	2	2000	323	5.383	0.00619	371.52	30.50	26.00
Notes:										

In --> Out, parallel bulk heads FILTER - Run 2										
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)
Raw Water	0	427	0	0	0	0	#DIV/0!	0		38.50
	2	0.71	2	2000	121	2.017	0.01653	991.74	38.50	37.00
	4	0.69	2	2000	105	1.750	0.01905	1142.86	37.00	34.00
	6	0.61	2	2000	123	2.050	0.01626	975.61	34.00	31.00
	8	0.55	2	2000	157	2.617	0.01274	764.33	31.00	26.00
	8.8	0.65	0.8	800	210	3.500	0.00381	228.57	26.00	23.50
Notes:										

In --> Out, parallel bulk heads FILTER - Run 3										
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)
Raw Water	0	367	0	0	0	0	#DIV/0!	0		36.50
	2	0.60	2	2000	124	2.067	0.01613	967.74	36.50	34.00
	4	0.50	2	2000	120	2.000	0.01667	1000.00	34.00	30.50
	6	0.39	2	2000	134	2.233	0.01493	895.52	30.50	28.00
	8	0.57	2	2000	259	4.317	0.00772	463.32	28.00	26.00
Notes:										

In --> Out, parallel bulk heads FILTER - Run 4										
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)
Raw Water	0	389	0	0	0	0	#DIV/0!	0		37.00
	2	0.65	2	2000	125	2.083	0.01600	960.00	37.00	34.50
	4	0.38	2	2000	120	2.000	0.01667	1000.00	34.50	30.00
	6	0.39	2	2000	134	2.233	0.01493	895.52	30.00	27.00
	7.5	0.28	2	1500	244	4.067	0.00615	368.85	27.00	25.00
Notes:										

In --> Out, parallel bulk heads FILTER - Run 5										
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)
Raw Water	0	394	0	0	0	0	#DIV/0!	0		38.00
	2	0.70	2	2000	118	1.967	0.01695	1016.95	38.00	34.00
	4	0.59	2	2000	119	1.983	0.01681	1008.40	34.00	30.00
	6	0.38	2	2000	138	2.300	0.01449	869.57	30.00	26.50
	6.2	0.40	0.20	200	154	2.567	0.00130	77.92	26.50	25.00
Notes:										

In --> Out, parallel bulk heads FILTER - Run 6										
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)
Raw Water	0	447	0	0	0	0	#DIV/0!	0		38.00
	2	0.75	2	2000	122	2.033	0.01639	983.61	38.00	35.00
	4	0.58	2	2000	120	2.000	0.01667	1000.00	35.00	31.00
	6	0.39	2	2000	129	2.150	0.01550	930.23	31.00	29.00
	8	0.37	2	2000	198	3.300	0.01010	606.06	29.00	26.00
Notes:										

In --> Out, parallel bulk heads FILTER - Run 7										
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)
Raw Water	0	423	0	0	0	0	#DIV/0!	0		37.50
	2	0.45	2	2000	95	1.583	0.02105	1263.16	37.50	36.00
	4	0.27	2	2000	110	1.833	0.01818	1090.91	36.00	32.00
	6	0.34	2	2000	130	2.167	0.01538	923.08	32.00	29.00
	8	0.41	2	2000	245	4.083	0.00816	489.80	29.00	25.00
Notes:										

In --> Out, parallel bulk heads FILTER - Run 8										
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)
Raw Water	0	531	0	0	0	0	#DIV/0!	0		37.00
	2	0.43	2	2000	150	2.500	0.01333	800.00	37.00	35.25
	4	0.48	2	2000	127	2.117	0.01575	944.88	35.25	33.00
	6	0.05	2	2000	147	2.450	0.01361	816.33	33.00	29.50
	8	0.58	2	2000	186	3.100	0.01075	645.16	29.50	26.75
	9	0.63	1	1000	107	1.783	0.00935	560.75	26.75	25.00
Notes:										

In --> Out, parallel bulk heads FILTER - Run 9										
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)
Raw Water	0	479	0	0	0	0	#DIV/0!	0		37.00
	2	0.63	2	2000	131	2.183	0.01527	916.03	37.00	35.00
	4	0.52	2	2000	111	1.850	0.01802	1081.08	35.00	32.00
	6	0.53	2	2000	127	2.117	0.01575	944.88	32.00	30.00
	8	0.36	2	2000	166	2.767	0.01205	722.89	30.00	28.00
	9.8	0.56	1.8	1800	212	3.533	0.00849	509.43	28.00	25.00
Notes:										

In --> Out, parallel bulk heads FILTER - Run 10										
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)
Raw Water	0	475	0	0	0	0	#DIV/0!	0		38.00
	2	0.65	2	2000	138	2.300	0.01449	869.57	38.00	34.50
	4	0.65	2	2000	111	1.850	0.01802	1081.08	34.50	32.50
	6	0.58	2	2000	130	2.167	0.01538	923.08	32.50	30.00
	8	0.57	2	2000	170	2.833	0.01176	705.88	30.00	27.00
	9	0.61	1	1000	120	2.000	0.00833	500.00	27.00	25.00
Notes:										

In --> Out, parallel bulk heads FILTER - Run 11										
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)
Raw Water	0	479	0	0	0	0	#DIV/0!	0		38.00
	2	0.63	2	2000	140	2.333	0.01429	857.14	38.00	35.00
	4	0.64	2	2000	115	1.917	0.01739	1043.48	35.00	33.00
	6	0.56	2	2000	145	2.417	0.01379	827.59	33.00	30.25
	8	0.51	2	2000	180	3.000	0.01111	666.67	30.25	26.50
	9	0.62	1	1000	100	1.667	0.01000	600.00	26.50	22.00
Notes:										

In --> Out, parallel bulk heads FILTER - Run 12										
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)
Raw Water	0	535	0	0	0	0	#DIV/0!	0		37.50
	2	0.71	2	2000	150	2.500	0.01333	800.00	37.50	35.00
	4	0.68	2	2000	115	1.917	0.01739	1043.48	35.00	33.25
	6	0.63	2	2000	120	2.000	0.01667	1000.00	33.25	31.25
	8	0.84	2	2000	143	2.383	0.01399	839.16	31.25	28.00
	9.25	0.64	1.25	1250	120	2.000	0.01042	625.00	28.00	25.00
Notes:										

EXPERIMENT C-2-Filter #1

In --> Out, McMaster Carr bulk heads FILTER 1 - Run 1										
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)
Raw Water	0		0	0	0	0	#DIV/0!	0		33.50
	2		2	2000	168	2.800	0.01190	714.29	33.50	30.00
	4		2	2000	123	2.050	0.01626	975.61	30.00	27.50
	6		2	2000	112	1.867	0.01786	1071.43	27.50	23.50
	8		2	2000	173	2.883	0.01156	693.64	23.50	19.00
	8.5		0.5	500	49	0.817	0.01020	612.24	19.00	17.50
Notes:										

In --> Out, McMaster Carr bulk heads FILTER 1 - Run 2										
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)
Raw Water	0		0	0	0	0	#DIV/0!	0		33.00
	2		2	2000	99	1.650	0.02020	1212.12	33.00	31.00
	4		2	2000	108	1.800	0.01852	1111.11	31.00	27.75
	6		2	2000	110	1.833	0.01818	1090.91	27.75	24.00
	8		2	2000	176	2.933	0.01136	681.82	24.00	19.25
	9		1	1000	120	2.000	0.00833	500.00	19.25	16.25
Notes: let filter bag fill with water, closed clamp a 1/2 turn before 2nd draw out of bag to reduce flow rate										

EXPERIMENT C-2: Filter #2

In --> Out, McMaster Carr bulk heads FILTER 2 - Run 1										
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)
Raw Water	0		0	0	0	0	#DIV/0!	0		36.50
	2		2	2000	124	2.067	0.01613	967.74	36.50	34.00
	4		2	2000	120	2.000	0.01667	1000.00	34.00	30.50
	6		2	2000	134	2.233	0.01493	895.52	30.50	28.00
	8		2	2000	259	4.317	0.00772	463.32	28.00	26.00
Notes: 1/2 turn release on metal clamp before 2nd draw out of bag.										

EXPERIMENT C-2: Filter #3

In --> Out McMaster Carr Bulkheads FILTER 3 (Bag 1) - Run 1										
PUR Serial #: 0015032231 Mfg. 1/10 Exp: 12/12										
Recipe: Chilledtap, dust, I.O., humic, pH adjustment, and spheres										
pH: 9.08 Temp: 7°C										
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)
Raw Water	0	491	0	0	0	0	#DIV/0!	0		31.50
Pre-Filter	0	5	0	0	0	0	#DIV/0!	0		31.50
	2	4.89	2	2000	164	2.733	0.01220	731.71	31.50	28.50
	4	4.22	2	2000	200	3.333	0.01000	600.00	28.50	26.00
	6	4.37	2	2000	175	2.917	0.01143	685.71	26.00	21.50
Notes: slight yellowish tint (too much humic), no floc attop, flow rate slowed: need spacer to keep outlet off plastic & filter, no flow after 6L; not enough head										

EXPERIMENT C-2: Filter #4

In --> Out McMaster Carr Bulkheads FILTER 4 (Bag 2) - Run 1										
PUR Serial #: 0015032231 Mfg. 1/10 Exp: 12/12										
Recipe: Chilledtap, dust, I.O., humic, pH adjustment, and spheres										
pH: 7.02 Temp: 9°C										
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)
Raw Water	0	434	0	0	0	0	#DIV/0!	0		29.50
Pre-Filter	0	6.98	0	0	0	0	#DIV/0!	0		29.50
	2	3.31	2	2000	200	3.333	0.01000	600.00	29.50	27.00
	4	3.00	2	2000	284	4.733	0.00704	422.54	27.00	24.00
Notes: Shasta held outlet up, off the filter for more consistent flow, maybe extend length of pouch so it puffs out; right now plastic is suctioned to filter										

EXPERIMENT C-2: Filter #5

In --> Out McMaster Carr Bulkheads FILTER 5 (Bag 1) - Run 1										
PUR Serial #: 7223032202 Mfg. 8/07 Exp: 7/10										
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)
Raw Water	0	508	0	0	0	0	#DIV/0!	0		37.00
	2	1.72	2	2000	146	2.433	0.01370	821.92	37.00	33.50
	4	1.81	2	2000	180	3.000	0.01111	666.67	33.50	29.50
	6	1.79	2	2000	N/M	#VALUE!	#VALUE!	#VALUE!	29.50	N/M
	8	1.64	2	2000	254	4.233	0.00787	472.44	N/M	20.50

Notes: yellow-ish tint to effluent, flow ceased after 8 L

In --> Out McMaster Carr Bulkheads FILTER 5 (Bag 1) - Run 2										
PUR Serial #: 7223032202 Mfg. 8/07 Exp: 7/10										
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)
Raw Water	0	464	0	0	0	0	#DIV/0!	0		37.00
	2	2.97	2	2000	96	1.600	0.02083	1250.00	37.00	33.50
	4	2.98	2	2000	93	1.550	0.02151	1290.32	33.50	30.50
	6	2.66	2	2000	155	2.583	0.01290	774.19	30.50	27.00
	8	2.53	2	2000	125	2.083	0.01600	960.00	27.00	24.00
	8.8	2.58	0.8	800	61	1.017	0.01311	786.89	24.00	21.25

Notes:

In --> Out McMaster Carr Bulkheads FILTER 5 (Bag 1) - Run 3										
PUR Serial #: 7223032202 Mfg. 8/07 Exp: 7/10										
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)
Raw Water	0	430	0	0	0	0	#DIV/0!	0		35.00
	2	1.95	2	2000	98	1.633	0.02041	1224.49	35.00	32.50
	4	3.25	2	2000	106	1.767	0.01887	1132.08	32.50	31.00
	6	1.89	2	2000	123	2.050	0.01626	975.61	31.00	26.50
	7.8	1.92	1.8	1800	172	2.867	0.01047	627.91	26.50	20.00

Notes:

EXPERIMENT C-2: Filter #6

In --> Out McMaster Carr Bulkheads FILTER 6 (Bag 2) - Run 1										
PUR Serial #: 7223032202 Mfg. 8/07 Exp: 7/10										
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)
Raw Water	0	476	0	0	0	0	#DIV/0!	0		35.00
	2	2.51	2	2000	102	1.700	0.01961	1176.47	35.00	32.50
	4	2.62	2	2000	80	1.333	0.02500	1500.00	32.50	29.50
	6	2.58	2	2000	120	2.000	0.01667	1000.00	29.50	25.50
	8	2.59	2	2000	103	1.717	0.01942	1165.05	25.50	21.00

Notes: yellow-ish tint to effluent, filter pouch REALLY puffed up, maybe led to higher Q?

In --> Out McMaster Carr Bulkheads FILTER 6 (Bag 2) - Run 2										
PUR Serial #: 7223032202 Mfg. 8/07 Exp: 7/10										
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)
Raw Water	0	464	0	0	0	0	#DIV/0!	0		36.25
	2	2.21	2	2000	93	1.550	0.02151	1290.32	36.25	34.50
	4	2.29	2	2000	78	1.300	0.02564	1538.46	34.50	29.25
	6	2.31	2	2000	103	1.717	0.01942	1165.05	29.25	26.00
	8	2.19	2	2000	99	1.650	0.02020	1212.12	26.00	21.50

Notes:

In --> Out McMaster Carr Bulkheads FILTER 6 (Bag 2) - Run 3										
PUR Serial #: 7223032202 Mfg. 8/07 Exp: 7/10										
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)
Raw Water	0	430	0	0	0	0	#DIV/0!	0		35.00
	2	1.99	2	2000	94	1.567	0.02128	1276.60	35.00	33.00
	4	2.12	2	2000	130	2.167	0.01538	923.08	33.00	30.50
	6	1.94	2	2000	125	2.083	0.01600	960.00	30.50	26.50
	8	2.06	2	2000	125	2.083	0.01600	960.00	26.50	22.00
Notes:										

EXPERIMENT E-1

In --> Out McMaster Carr Bulkheads FILTER (Bag 1) - Run 1											
PUR Serial #: 0015032231 Mfg. 1/10 Exp: 12/12											
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)	Cyst Count
Raw Water	0	499	0	0	0	0	#DIV/0!	0		39.00	TNTC
	2	4.36	2	2000	100	1.667	0.02000	1200.00	39.00	35.00	
	4	4.42	2	2000	93	1.550	0.02151	1290.32	35.00	30.75	440
	6	4.05	2	2000	114	1.900	0.01754	1052.63	30.75	27.00	
	8	3.91	2	2000	121	2.017	0.01653	991.74	27.00	23.50	
Notes:											

EXPERIMENT F-1

In --> Out 1 Ply Absolute FILTER - Run 1										
PUR Serial #: 0015032231 Mfg. 1/10 Exp: 12/12										
Recipe: tap water, dust, I.O., humic, and spheres (15 L made)										
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)
Raw Water	0	53.9	0	0	0	0	#DIV/0!	0		37.50
	2	1.90	2	2000	1560	26	0.00128	76.92	37.50	35.00
	3.15	1.63	1.15	1150	1200	20	0.00096	57.50	35.00	33.50
Notes: during 2L pull: red-tab valve closed after 2 min. b/c flow too slow, filter needed to wet and water needed to build up in the filter pouch for flow, had to open both red-tab valves all the way.										

In --> Out 1 Ply Absolute FILTER - Run 2											
PUR Serial #: 0015032231 Mfg. 1/10 Exp: 12/12											
Recipe: tap water, dust, I.O., humic, and spheres (15 L made)											
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)	Cyst Count
Raw Water	0	58.1	0	0	0	0	#DIV/0!	0		N/M	TNTC
	2	2.44	2	2000	591	9.850	0.00338	203.05	TNTC	62.00	
	4	1.77	2	2000	1590	26.500	0.00126	75.47	0.00	59.50	162.00
Notes: flow ceased b/c filter clogged, confirmed with tap water											

EXPERIMENT F-3

In --> Out 2 Ply Nominal inside Absolute FILTER											
Recipe: tap water (for flow curve)											
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)	Cyst Count
Raw Water	0		0	0	0	0	#DIV/0!	0		64.00	
	2		2	2000	163	2.717	0.01227	736.20	64.00	60.75	
	4		2	2000	119	1.983	0.01681	1008.40		58.00	
	6		2	2000	129	2.150	0.01550	930.23		53.50	
	8		2	2000	138	2.300	0.01449	869.57		49.00	
	8.925		0.925	925	79	1.317	0.01171	702.53	60.75	49.00	
Notes:											

In --> Out 2 Ply Nominal inside Absolute FILTER - Run 1											
PUR Serial #: 0015032231 Mfg. 1/10 Exp: 12/12											
Recipe: tap water, dust, I.O., humic, and spheres (15 L made)											
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)	Cyst Count
Raw Water	0	59	0	0	0	0	#DIV/0!	0		65.50	TNTC
	2	2.24	2	2000	174	2.900	0.01149	689.66	65.50	63.00	
	4	2.04	2	2000	173	2.883	0.01156	693.64	63.00	60.75	54
	6	1.82	2	2000	323	5.383	0.00619	371.52	60.75	58.25	
	8	1.37	2	2000	1029	17.150	0.00194	116.62	58.25	54.00	
Notes: at 6L, brown floc started to appear along seams											

EXPERIMENT G-1

In --> Out 2 Ply Nominal Filter, 5 Min. Mix - Run 1											
PUR Serial #: 0015032231 Mfg. 1/10 Exp: 12/12											
Recipe: tap water, dust, I.O., humic, and spheres (70 L made in trash can with sump pump)											
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)	Cyst Count
Raw Water	0	60.6	0	0	0	0	#DIV/0!	0		37.00	TNTC
	2	5.33	2	2000	211	3.517	0.00948	568.72	37.00	34.00	
	4	5.77	2	2000	216	3.600	0.00926	555.56	34.00	30.50	>1000
	6	5.62	2	2000	330	5.500	0.00606	363.64	30.50	27.00	
	8	4.78	2	2000	564	9.400	0.00355	212.77	27.00	21.50	
Notes: turbidimeter was correctly calibrated, confirmed with tap water (read 0.72 NTU), during 6L pull the filter plastic suctioned to the filter pouch outlet bulkhead; reduced flow, possible that sump pump heated up water too much; resulting in higher than normal treated water turbidity											

In --> Out 2 Ply Nominal Filter, 5 Min. Mix - Run 2											
PUR Serial #: 0015032231 Mfg. 1/10 Exp: 12/12											
Recipe: tap water, dust, I.O., humic, and spheres (15 L)											
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)	Cyst Count
Raw Water	0	46.5	0	0	0	0	#DIV/0!	0		37.00	TNTC
	2	3.99	2	2000	163	2.717	0.01227	736.20	37.00	34.00	
	4	3.79	2	2000	263	4.383	0.00760	456.27	34.00	30.50	170
	6	3.80	2	2000	189	3.150	0.01058	634.92	30.50	27.00	
	8	3.72	2	2000	240	4.000	0.00833	500.00	27.00	21.50	
Notes: filter pouch inlet and outlet red-tab valves set to 2.5 hatch mark											

In --> Out 2 Ply Nominal Filter, 5 Min. Mix - Run 3											
PUR Serial #: 0015032231 Mfg. 1/10 Exp: 12/12											
Recipe: tap water, dust, I.O., humic, and spheres (15 L)											
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)	Cyst Count
Raw Water	0	47.4	0	0	0	0	#DIV/0!	0		39.50	TNTC
	2	2.95	2	2000	232	3.867	0.00862	517.24	39.50	37.00	
	4	2.72	2	2000	235	3.917	0.00851	510.64	37.00	35.25	>1000
	6	2.77	2	2000	225	3.750	0.00889	533.33	35.25	32.50	
	8	2.59	2	2000	260	4.333	0.00769	461.54	32.50	29.25	
Notes: filter pouch inlet and outlet red-tab valves set to 2.5 hatch mark											

In --> Out 2 Ply Nominal Filter, 5 Min. Mix - Run 4											
PUR Serial #: 0015032231 Mfg. 1/10 Exp: 12/12											
Recipe: tap water, dust, I.O., humic, and spheres (15 L)											
Water Temp: N/M											
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)	Cyst Count
Raw Water	0	59.3	0	0	0	0	#DIV/0!	0		39.00	TNTC
Pre-Filter	0	6.14	0								
	2	4.86	2	2000	200	3.333	0.01000	600.00	39.00	35.00	
Pre-Filter	4	5.39									TNTC
	4	4.66	2	2000	185	3.083	0.01081	648.65	35.00	32.25	3121
	6	4.80	2	2000	256	4.267	0.00781	468.75	32.25	27.75	
	8	N/M	2	2000	208	3.467	0.00962	576.92	27.75	N/M	
Notes: spheres in 4L Pre-Filter sample were TNTC but were less than Raw											

In --> Out 2 Ply Nominal Filter, 5 Min. Mix - Run 5											
PUR Serial #: 0015032231 Mfg. 1/10 Exp: 12/12											
Recipe: tap water, dust, I.O., humic, and spheres (15 L)											
Water Temp: 21oC											
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)	Cyst Count
Raw Water	0	46.4	0	0	0	0	#DIV/0!	0		37.25	N/M
Pre-Filter	0	N/M	0								
	2	2.71	2	2000	225	3.750	0.00889	533.33	37.25	33.75	
Pre-Filter	4	N/M									N/M
	4	3.17	2	2000	146	2.433	0.01370	821.92	33.75	30.00	N/M
	6	2.87	2	2000	187	3.117	0.01070	641.71	30.00	27.50	
	8	2.60	2	2000	260	4.333	0.00769	461.54	27.50	21.50	
Notes:											

EXPERIMENT G-2

In --> Out 2 Ply Nominal Filter, 10 Min. Mix - Run 1											
PUR Serial #: 0015032231 Mfg. 1/10 Exp: 12/12											
Recipe: tap water, dust, I.O., humic, and spheres (70 L made in trash can with sump pump)											
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)	Cyst Count
Raw Water	0	60.6	0	0	0	0	#DIV/0!	0		37.50	TNTC
	2	6.24	2	2000	345	5.750	0.00580	347.83	37.50	35.00	
	4	6.49	2	2000	316	5.267	0.00633	379.75	35.00	32.50	54
	6	6.31	2	2000	308	5.133	0.00649	389.61	32.50	28.00	
	8	6.06	2	2000	645	10.750	0.00310	186.05	28.00	24.00	
Notes: turbidimeter was correctly calibrated, confirmed with tap water (read 0.72 NTU), during 6L pull the filter plastic suctioned to the filter pouch outlet bulkhead; reduced flow, possible that sump pump heated up water too much; resulting in higher than normal treated water turbidity											

In --> Out 2 Ply Nominal Filter, 10 Min. Mix - Run 2											
PUR Serial #: 0015032231 Mfg. 1/10 Exp: 12/12											
Recipe: tap water, dust, I.O., humic, and spheres (15 L)											
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)	Cyst Count
Raw Water	0	51.3	0	0	0	0	#DIV/0!	0		N/M	TNTC
	2	4.62	2	2000	298	4.967	0.00671	402.68	N/M	35.75	
	4	4.67	2	2000	337	5.617	0.00593	356.08	35.75	33.25	>1000
	6	4.25	2	2000	174	2.900	0.01149	689.66	33.25	28.50	
	8	4.15	2	2000	173	2.883	0.01156	693.64	28.50	26.00	
Notes: filter pouch inlet and outlet red-tab valves set to 2.5 hatch mark											

In --> Out 2 Ply Nominal Filter, 10 Min. Mix - Run 3											
PUR Serial #: 0015032231 Mfg. 1/10 Exp: 12/12											
Recipe: tap water, dust, I.O., humic, and spheres (15 L)											
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)	Cyst Count
Raw Water	0	52.8	0	0	0	0	#DIV/0!	0		37.50	TNTC
	2	4.02	2	2000	221	3.683	0.00905	542.99	37.50	36.25	
	4	3.96	2	2000	129	2.150	0.01550	930.23	36.25	33.00	>1000
	6	3.96	2	2000	175	2.917	0.01143	685.71	33.00	30.25	
	8	4.05	2	2000	264	4.400	0.00758	454.55	30.25	27.00	
Notes: filter pouch inlet and outlet red-tab valves set to 2.5 hatch mark											

In --> Out 2 Ply Nominal Filter, 10 Min. Mix - Run 4											
PUR Serial #: 0015032231 Mfg. 1/10 Exp: 12/12											
Recipe: tap water, dust, I.O., humic, and spheres (15 L)											
Water Temp: 21oC											
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)	Cyst Count
Raw Water	0	53.6	0	0	0	0	#DIV/0!	0		38.50	TNTC
Pre-Filter	0	6.76	0								
	2	5.90	2	2000	209	3.483	0.00957	574.16	38.50	36.50	
Pre-Filter	4	6.58									TNTC
	4	5.92	2	2000	217	3.617	0.00922	553.00	36.50	34.75	3074
	6	5.87	2	2000	144	2.400	0.01389	833.33	34.75	31.50	
	8	5.70	2	2000	190	3.167	0.01053	631.58	31.50	26.00	
Notes:											

EXPERIMENT G-3

In --> Out 2 Ply Nominal Filter, 15 Min. Mix in 5 Min. Bag - Run 1											
PUR Serial #: 0015032231 Mfg. 1/10 Exp: 12/12											
Recipe: tap water, dust, I.O., humic, and spheres (15 L)											
Water Temp: 22oC											
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)	Cyst Count
Raw Water	0	55.1	0	0	0	0	#DIV/0!	0		39.25	N/M
Pre-Filter	0	5.45	0								
	2	4.32	2	2000	163	2.717	0.01227	736.20	39.25	37.50	
Pre-Filter	4	5.26									N/M
	4	4.18	2	2000	189	3.150	0.01058	634.92	37.50	35.75	N/M
	6	3.97	2	2000	165	2.750	0.01212	727.27	35.75	29.50	
	8	4.11	2	2000	259	4.317	0.00772	463.32	29.50	31.75	
Notes: bag suction caused water level to rise, resulting in higher head											

In --> Out 2 Ply Nominal Filter, 15 Min. Mix in 10 Min. Bag - Run 2											
PUR Serial #: 0015032231 Mfg. 1/10 Exp: 12/12											
Recipe: tap water, dust, I.O., humic, and spheres (15 L)											
Water Temp: 21.5oC											
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)	Cyst Count
Raw Water	0	52.1	0	0	0	0	#DIV/0!	0		37.50	N/M
Pre-Filter	0	5.11	0								
	2	4.53	2	2000	186	3.100	0.01075	645.16	37.50	34.00	
Pre-Filter	4	5.09									N/M
	4	4.58	2	2000	258	4.300	0.00775	465.12	34.00	31.00	N/M
	6	1.56	2	2000	213	3.550	0.00939	563.38	31.00	27.50	
	8	4.61	2	2000	174	2.900	0.01149	689.66	27.50	23.25	
Notes:											

EXPERIMENT H-1

In --> Out 1 Ply Nominal Filter, 5 Min. Mix - Run 1											
PUR Serial #: 0015032231 Mfg. 1/10 Exp: 12/12											
Recipe: tap water, dust, I.O., humic, and spheres (15 L)											
Water Temp: 23oC											
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)	
Raw Water	0	51.3	0	0	0	0	#DIV/0!	0			37.75
Pre-Filter	0	7.59	0								
	2	3.80	2	2000	175	2.917	0.01143	685.71	37.75	33.25	
Pre-Filter	4	3.70									
	4	3.68	2	2000	155	2.583	0.01290	774.19	33.25	N/M	
	6	3.39	2	2000	207	3.450	0.00966	579.71	N/M	27.50	
	8	3.51	2	2000	216	3.600	0.00926	555.56	27.50	23.50	
Notes:											

EXPERIMENT H-2

In --> Out 2 Ply Nominal Filter, 65 mL/min										
PUR Serial #: 0015032231 Mfg. 1/10 Exp: 12/12										
Recipe: tap water, dust, I.O., humic, and spheres (15 L)										
Water Temp: 14oC										
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)
Raw Water	0	47	0	0	0	0	#DIV/0!	0		39.25
Pre-Filter	0	3.74	0							
	2	3.40	2	2000	1840	30.667	0.00109	65.22	39.25	34.75
Pre-Filter	4	3.47								
	4	3.29	2	2000	1756	29.267	0.00114	68.34	34.75	31.50
Notes:										

EXPERIMENT H-3 (50 mL/min)

In --> Out 2 Ply Nom.-Abs. Filter, 50-mL/min										
PUR Serial #: 9289032230 Mfg. Exp:										
Recipe: tap water, dust, I.O., humic, and spheres (15 L)										
Water Temp: 14oC										
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)
Raw Water	0	49.4	0	0	0	0	#DIV/0!	0		64.50
Pre-Filter	0	2.11	0							
	2	0.88	2	2000	1386	23.100	0.00144	86.58	64.50	61.25
Pre-Filter	4	1.95								
	4	0.85	2	2000	3009	50.150	0.00066	39.88	61.25	58.00
Notes:										

In --> Out 2 Ply Nom.-Abs. Filter, 50-mL/min										
PUR Serial #: 9289032230 Mfg. Exp:										
Recipe: tap water, dust, I.O., humic, and spheres (15 L)										
Water Temp: 11oC										
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)
Raw Water	0	48.9	0	0	0	0	#DIV/0!	0		65.00
Pre-Filter	0	4.66	0							
	2	2.70	2	2000	2378	39.633	0.00084	50.46	65.00	62.00
Pre-Filter	4	3.88								
	4	2.90	2	2000	2383	39.717	0.00084	50.36	62.00	59.00
Notes: PUR pack was clumped and didn't break up so settled to bottom of bag before mixing, more interruptions b/c tubing came off and Tryg taking pictures.										

EXPERIMENT H-3 (20 mL/min)

In --> Out 2 Ply Nom.-Abs. Filter, 20-mL/min and port screen										
PUR Serial #: 9289032230 Mfg. Exp:										
Recipe: tap water, dust, I.O., humic, and spheres (15 L)										
Water Temp: 9oC										
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)
Raw Water	0	46.5	0	0	0	0	#DIV/0!	0		65.00
Pre-Filter	0.1	2.64	0							
	2	1.17	2	2000	5700	95.000	0.00035	21.05	65.00	63.00
Pre-Filter	4	2.28								
	4.1	1.13	2	2000	5940	99.000	0.00034	20.20	63.00	61.00
Notes:										

In --> Out 2 Ply Nom.-Abs. Filter, 20-mL/min and port screen										
PUR Serial #: 9289032230 Mfg. Exp:										
Recipe: tap water, dust, I.O., humic, and spheres (15 L)										
Water Temp: 9.5oC										
Water	Total Vol. Filtered (L)	Turbidity (NTU)	Vol. of Water Discharged (L)	Volume of Water (mL)	Time (sec)	Time (min)	Flowrate (L/sec)	Flowrate (mL/min)	Ho (inch)	Hn (inch)
Raw Water	0	48.9	0	0	0	0	#DIV/0!	0		65.25
Pre-Filter	0.1	2.31	0							
	2	1.38	2	2000	5970	99.500	0.00034	20.10	65.25	62.00
Pre-Filter	4	2.18								
	4.1	1.31	2	2000	5740	95.667	0.00035	20.91	62.00	59.50
Notes:										

APPENDIX D: BIOVIR REPORT (2012)

Test report from BioVir Laboratories, Inc. for experiment I-1, performed August 17, 2012.

TEST REPORT

Project Title	Polytech Waterbag Challenge
Project No.	121132
Sponsor:	Cal Poly Corporation
C/O:	Prof. Tryg Lundquist California Polytechnic State University Civil & Environmental Engineering Department San Luis Obispo, CA 93407
Date:	September 6, 2012
From:	Robert C. Cooper, VP

Introduction: The Cal Poly Corp contracted with BioVir Laboratories to perform microbiological challenges of the *Polytech Waterbag* device being developed by Professor Lundquist and his students. Three bags were challenged with the bacterium *Escherichia coli* (ATCC11229), two coliphage types (MS2 ATCC 15597-B1) and fr (ATCC15767-B1) and with 3.1µm diameter fluorescent microspheres as a surrogate for *Cryptosporidium* oocysts (Duke Scientific Corp, Palo Alto, CA.) On August 17, 2012 Professor Lundquist and two graduate students arrived at BioVir Labs with three test bags and the necessary ancillary equipment needed to operate the treatment units.

The challenge water (40L of Test water #2) was prepared by BioVir staff and had the quality shown in Table 1 below:

Table 1. Challenge Water #2	
Parameter	Value-
Volume	40 L
pH	9.1
Chlorine	ND Non Detect
TDS	1450 mg/L
NTU	33*
TOC	12.6 mg/L
Temperature	4° C
*Before Humic acid added	

Just prior to the challenge the test water was inoculated with the challenge microorganisms and

microspheres. The seed microorganisms were prepared as per standard BioVir protocols. The test water was constantly mixed using a magnetic stirring device. Each bag was filled with 10L of the seeded test water at which point the Cal Poly group performed the treatment operation. The product water from each unit, produced over time, was collected into 10L cubitainers and a sub-sample of one L taken from each of the cubitainers at the end of the test run. The one liter sample was collected in sterile bottles containing enough sterile sodium thiosulfate to neutralize any residual disinfectant that might be present in the sample. A one liter influent sample) was collected from the 40 L seed reservoir.

The influent and product water samples were kept refrigerated until assayed, with the exception of the microspheres, a period of no more than 3 hours. The *E.coli* assays were performed using the membrane filter method and employing mFC agar incubated for 20 to 24 hours at 45°C; the results being reported as colony forming units (Cfu) per mL. The combined bacteriophage were assayed using the Adams double agar overlay method and reported as plaque forming units (Pfu) per mL. The microspheres were enumerated by direct microscopic count using epi-fluorescent microscopy and reported as spheres per L.

Results: The results of the challenges are shown in the following Tables.

Table 2. <i>E.coli</i> Results Cfu/ 100 mL						
Influent	Test Unit #1		Test Unit #2		Test Unit #3	
	Bag Effluent	Post Filter Effluent	Bag Effluent	Post Filter Effluent	Bag Effluent	Post Filter Effluent
7.3×10^6	<1	<1	<1	<1	1.5×10^4	2.2×10^2
Log Reduction :	>6.7				2.6	4.5

Table 3. Coliphage Results Pfu/ mL						
Influent	Test Unit #1		Test Unit #2		Test Unit #3	
	Bag Effluent	Post Filter Effluent	Bag Effluent	Post Filter Effluent	Bag Effluent	Post Filter Effluent
1.3×10^5	<1	<1	<1	<1	9	4
Log Reduction:	>5.1				≥ 4.3	

Table 4 Microsphere Results. Beads/Liter						
Influent	Test Unit #1		Test Unit #2		Test Unit #3	
	Bag Effluent	Post Filter Effluent	Bag Effluent	Post Filter Effluent	Bag Effluent	Post Filter Effluent
5.6×10^5	7.7×10^3	<50/L	7.0×10^3	1.2×10^2	4.4×10^3	2.2×10^3
Log Reduction:	1.9	>4.1	1.9	3.7	2.1	2.4