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Evaluation of Small System Filtration Technologies for the Treatment of Color, Disinfection Byproducts, and Microbial Contaminants in Surface Waters

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EVALUATION OF SMALL SYSTEM FILTRATION TECHNOLOGIES FOR THE TREATMENT OF COLOR, DISINFECTION BYPRODUCTS AND MICROBIOLOGICAL CONTAMINANTS IN SURFACE WATERS

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Notice

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Mr. John Olszewski and Mr. Stephen M. Harmon were the EPA Quality Assurance Managers, and were responsible for the quality assurance review of the document.

Abstract

The U.S. Environmental Protection Agency (EPA) National Risk Management Research Laboratory (NRMRL) evaluated various filtration systems at the EPA T&E Facility in Cincinnati, Ohio and at a field site in Ely, Minnesota (MN) in collaboration with the Minnesota Department of Health (MDH). Color and organic matter are often present in lake water and these constituents are difficult to remove using conventional treatment technologies. The organic matter can also serve as a precursor to the formation of disinfection byproducts (DBPs). This report documents the results of tests conducted on the following four filtration systems for the removal of turbidity, color, organic matter, microorganisms and their surrogates from surface water:

1) Fyne Technology units manufactured by ITT Corporation (Zelienople, PA) that incorporate tubular membranes which are periodically cleaned by a foam-ball
2) GE Pentair unit that utilizes capillary hollow fiber membranes
3) Virex Pro unit manufactured by Seccua GmbH (Steingaden, Germany) that consists of hollow fiber membranes in a stainless steel housing.
4) A radial flow fluidized filtration (R3f) unit followed by polishing membrane filters (microfilter and ultrafilter modules manufactured by NOK).

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Acronyms and Abbreviations

APHA	American Public Health Association
B. subtilis	*Bacillus subtilis*
CR	complete removal
C. parvum	*Cryptosporidium Parvum*
DBP	disinfection byproduct
E. coli	*Escherichia coli*
GE	General Electric Company (Fairfield, Connecticut)
gpm	gallons per minute
ITT	ITT Corporation (Zelienople, PA)
L	liter
Lpm	liters per minute
MDH	Minnesota Department of Health
MF	microfilter
MS2	MS2 bacteriophage
MWCO	molecular weight cutoff
MWE	Midwest Water Engineering, LLC (East Bethel, Minnesota)
N/A	not available
N/D	not detected
NOK	NOK Corporation (Tokyo, Japan)
NRMRL	National Risk Management Research Laboratory
NTU	Nephelometric Turbidity Unit
psi	pounds per square inch
PSL	polystyrene latex
QA	quality assurance
QAPP	Quality Assurance Project Plan
R3f	Radial Flow Fluidized Filter
SDWA	Safe Drinking Water Act
Shaw	Shaw Environmental & Infrastructure (E&I), Inc.
Std. Dev.	standard deviation
SWAMP	Safe Water for All Minnesota People
T&E	Test and Evaluation
TOC	total organic carbon
UF	ultrafilter
µg	microgram
µm	microns
WSWRD	Water Supply and Water Resources Division

1.0 Introduction

The Water Supply and Water Resources Division (WSWRD) of the U.S. Environmental Protection Agency (EPA) National Risk Management Research Laboratory (NRMRL) has been conducting tests on small drinking water treatment systems since 1997 in response to the 1996 Reauthorization of the Safe Drinking Water Act (SDWA). The SDWA established standards for drinking water systems and required EPA to assess treatment technologies for small systems serving fewer than 10,000 people. Initial tests were focused on packaged bag and cartridge filtration systems. Subsequently, the program has been expanded to test a variety of filtration systems for the removal of turbidity, chemical contaminants, and microbial contaminants. Under contract to EPA, Shaw Environmental and Infrastructure (E&I), Inc. (Shaw) has been providing technical support in the evaluation of various filtration systems at the EPA's T&E Facility in Cincinnati, OH and at a number of field locations.

Color and organic matter are often present in lake water and these constituents are difficult to remove using conventional treatment technologies. The organic matter can also serve as a precursor to the formation of disinfection byproducts (DBPs). This report documents the results of tests conducted on the following four filtration systems for the removal of turbidity, color, organic matter, microorganisms and their surrogates from surface water:

5) Fyne Technology units manufactured by ITT Corporation (Zelienople, PA) that incorporate tubular membranes which are periodically cleaned by a foam-ball
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7) Virex Pro unit manufactured by Seccua GmbH (Steingaden, Germany) that consists of hollow fiber membranes in a stainless steel housing.
8) A radial flow fluidized filtration (R3f) unit followed by polishing membrane filters (microfilter and ultrafilter modules manufactured by NOK).

The tests were conducted at the EPA T&E Facility in Cincinnati, OH and at a field site in Ely, Minnesota (MN) in collaboration with the Minnesota Department of Health (MDH).

2.0 System Description, Operation and Testing Procedures

This section provides a summary description of the systems evaluated and the associated operation and testing procedures employed at the field site in Ely, MN and at the T&E Facility in Cincinnati, OH. The test procedures employed are presented in the following EPA-endorsed Quality Assurance Project Plans (QAPPs):

- EPA QA ID No. 627-Q-10-0 (EPA and Shaw, 2007)
- Amendment 1 to EPA QA ID No. 627-Q-10-0 (EPA and Shaw, 2008)
- QA ID No. 627-Q-11-0 (EPA and Shaw, 2009)

2.1 Field Test Site

The field test site was located on the grounds of the Outdoor Learning Center just outside the town of Ely, MN. The learning center also houses the Safe Water for All Minnesota People (SWAMP) that includes classroom facilities and a laboratory. Color and turbidity measurements were performed by MDH in this laboratory as a part of this study. The tested units were installed in the test trailer owned and operated by MDH. Shaw contracted with Midwest Water Engineering (MWE) to provide power to the test trailer and install the lake water pump to supply the trailer with test water. MWE also provided services for the installation of the systems and for the construction of a skid that facilitated the testing of the NOK modules. MDH operated the systems to gather data for turbidity removal and color removal. EPA and Shaw conducted a series of tests to evaluate the test systems for the removal of microorganisms.

2.2 ITT Fyne Technology Filtration System

The Fyne Process refers to a family of treatment systems that were originally developed in the United Kingdom to treat waters with high concentrations of organic materials. Membrane Specialists LLC provides the Fyne Packaged Systems in the US as the exclusive distributor of ITT PCI Membranes Tubular technology. The ITT Fyne Process uses a tubular semi-permeable membrane to allow clean filtered water to pass through the membrane while retaining microbial contaminants and most of the color-producing organic material dissolved in water, thus reducing the potential for formation of DBPs. Its small footprint and modular construction makes the ITT Fyne Technology filtration system ideal for many small communities.

One unique aspect of the ITT Fyne Technology System is the use of an automated foam ball cleaning process to remove accumulated filter cake and organic and inorganic foulants. In this process, a small foam ball is forced through the tubular filtration elements via water pressure flowing in the opposite direction of normal flow. The foam ball scours the tubular membrane surface removing the accumulated foulants. "Filter-catchers" (small, perforated plates installed

in the module inlet and outlet lines) retain the foam-balls in the system. The cleaning frequency is adjustable and the entire process is fully automated.

Figure 2-1 shows a process flow diagram for the ITT Fyne Process pilot skid that was employed at the Ely, MN field site and at the T&E Facility. This unit was fitted with two modules constructed of ABS plastic in a vertical position. One module contained the PCI Membrane type ES404 while the other module contained the PCI Membrane type CA2PF for the first series of tests conducted in 2008. For the tests conducted in 2009, the CA2PF membrane was replaced by an AFC30 membrane and a new ES404 membrane was installed. The ES404 has a molecular weight cutoff (MWCO) of approximately 4,000 Daltons, the CA2PF has a MWCO of approximately 2,000 Daltons, and the AFC30 membrane has a MWCO of 1000 Daltons. Each module was 3 feet long and contained thirty-six individual membrane tubes. Each membrane tube was ½ inch in diameter. The 36 membrane tubes were fed in series through the module with U-Bends linking one tube with the next. One of the particular features of the tubular design is the lack of need for pre-filtration. A coarse screen is placed before the system to protect both the pump and membranes from larger materials. The maximum operating pressure of the module was 175 pounds per square inch (psi) at 70°F. Figures 2-2, 2-3, and 2-4 are photographs showing various features of the system.

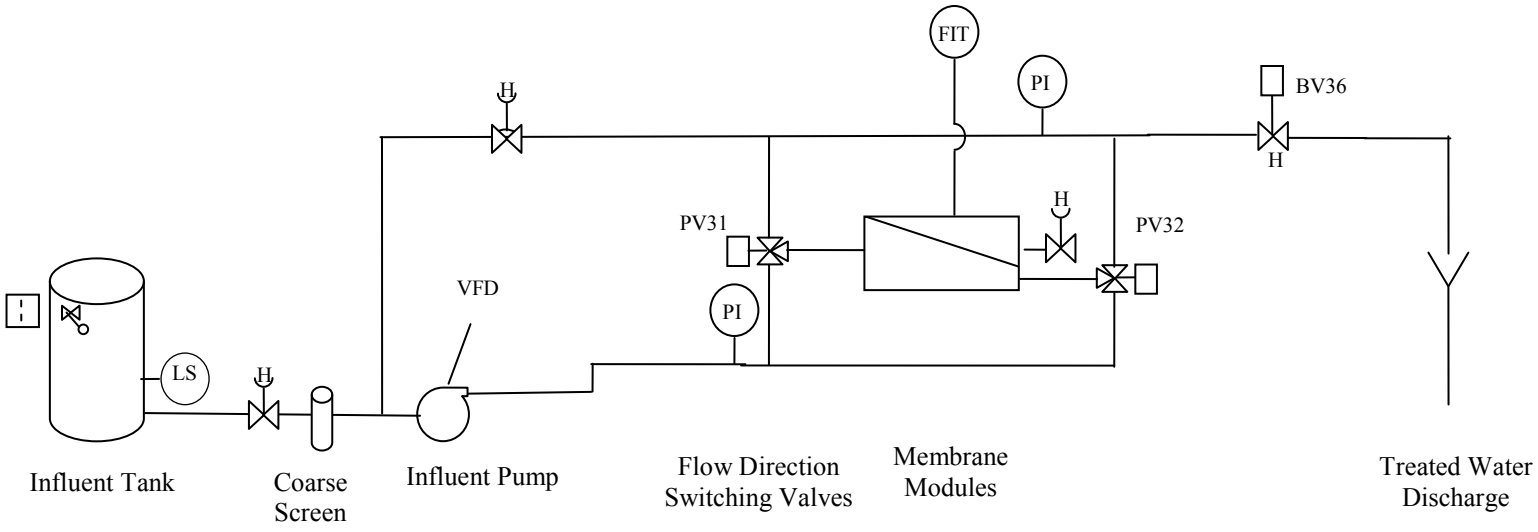

Figure 2-1. Process Flow Diagram for the ITT Fyne Technology System

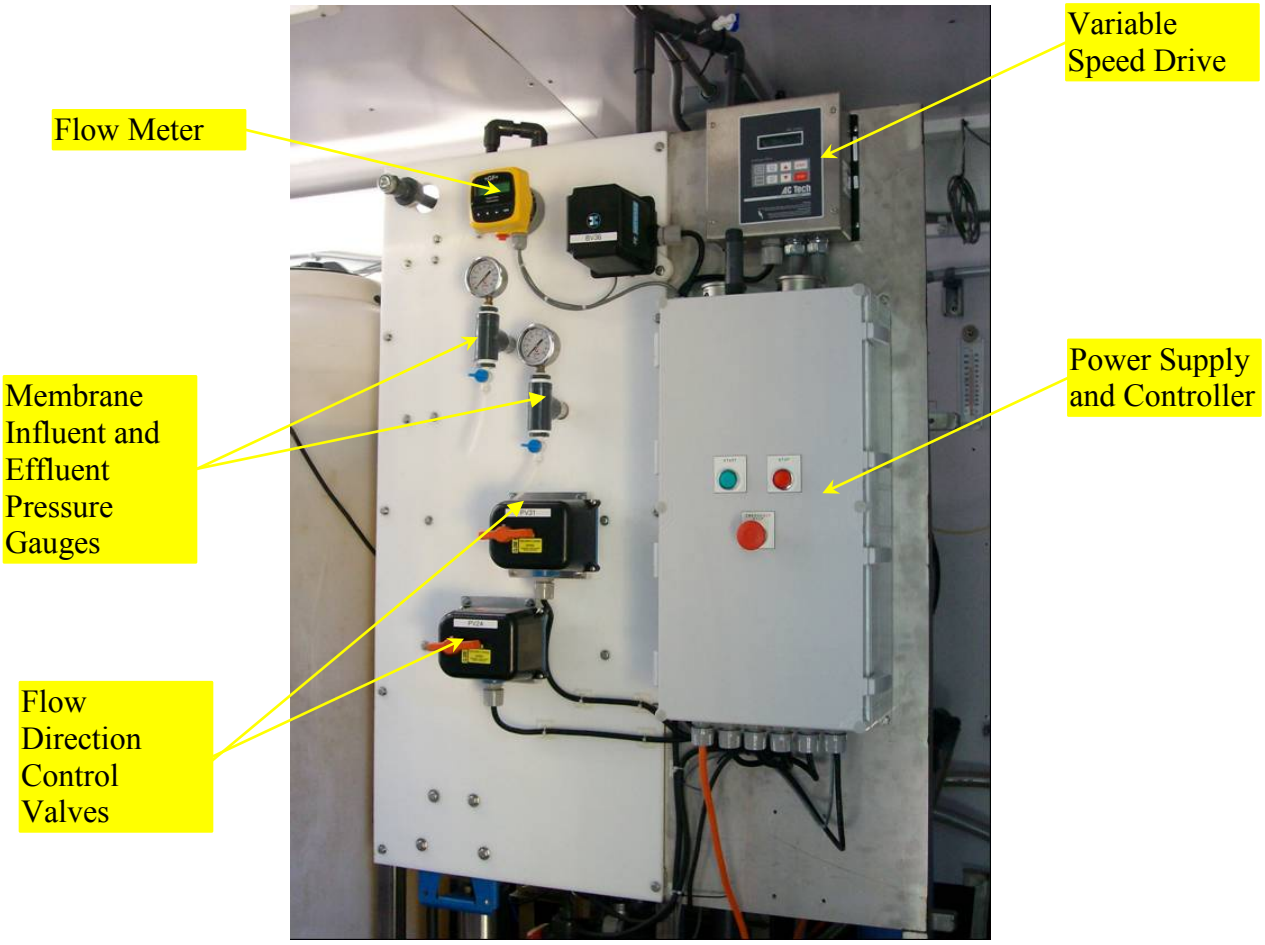

Figure 2-2. Fyne Technology System Control Panel 3-Foot Module

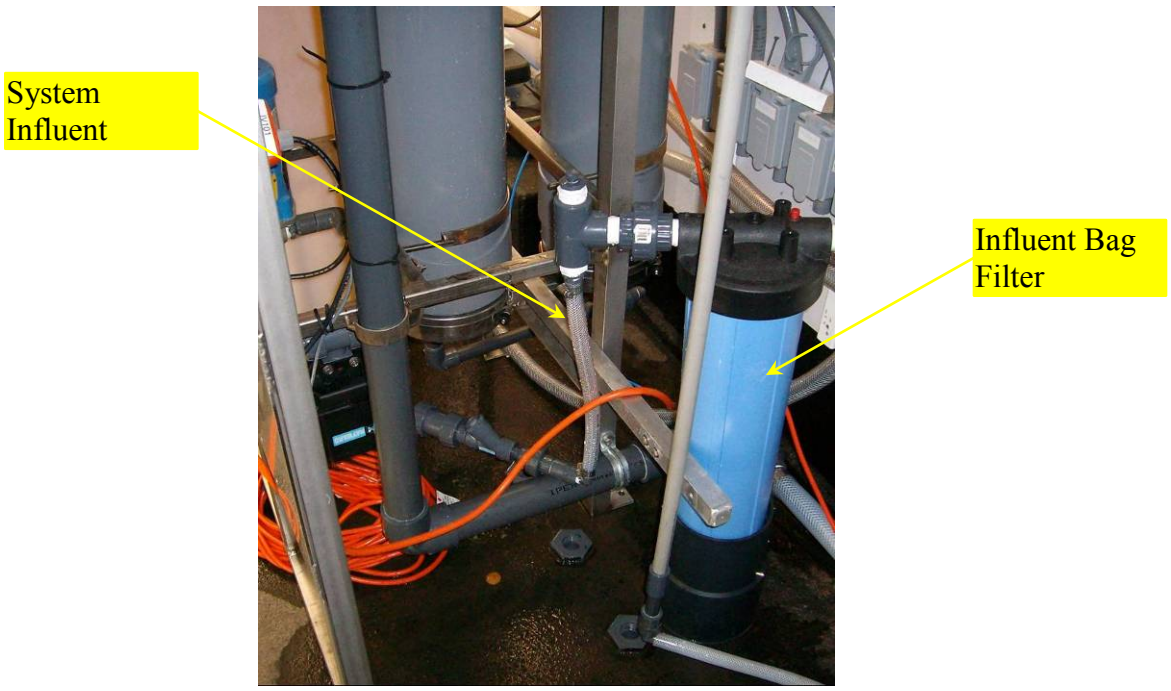

Figure 2-3. ITT Fyne Technology System Influent 3-Foot Module

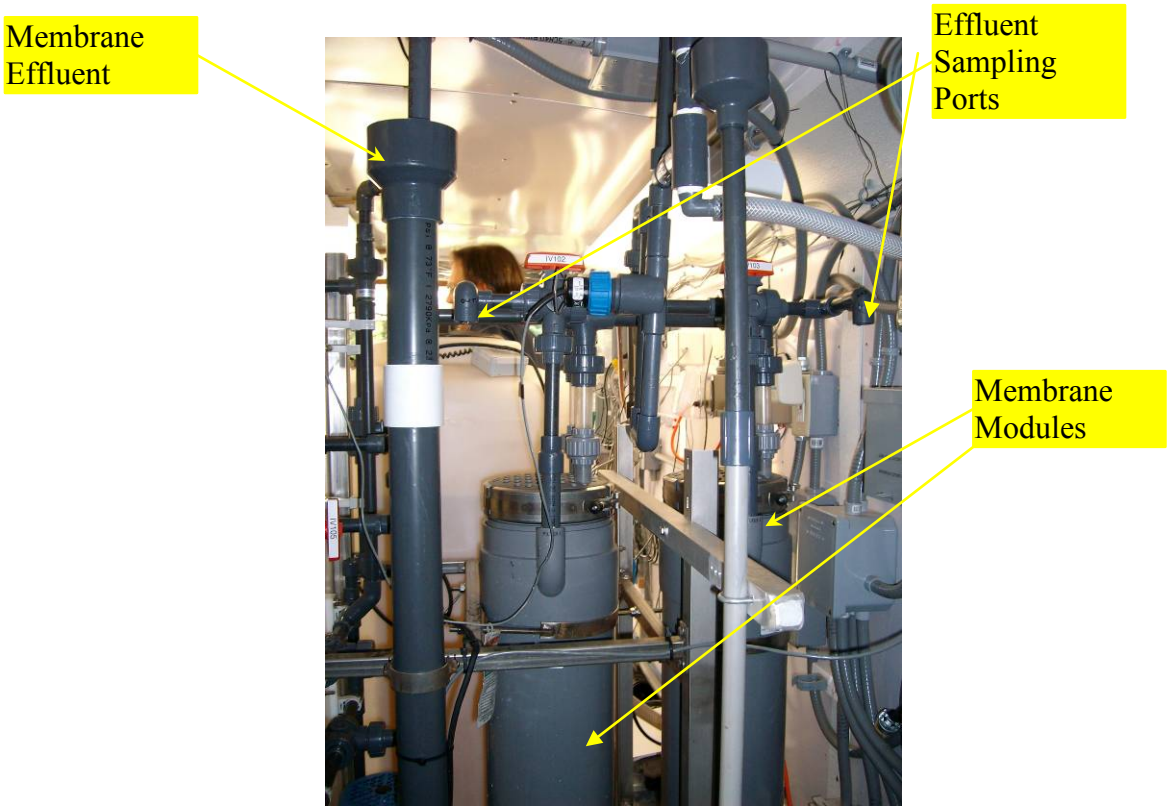

Figure 2-4. ITT Fyne Technology System Effluent 3-Foot Module

In addition to the aforementioned 3-foot vertical module, a 12-foot horizontal module of the ITT Fyne Technology system was also tested at the T&E Facility. The horizontal module consists of

CA2PF membrane with a MWCO of 2000 Daltons. Figures 2-5 and 2-6 are photographs showing the various features of this unit.

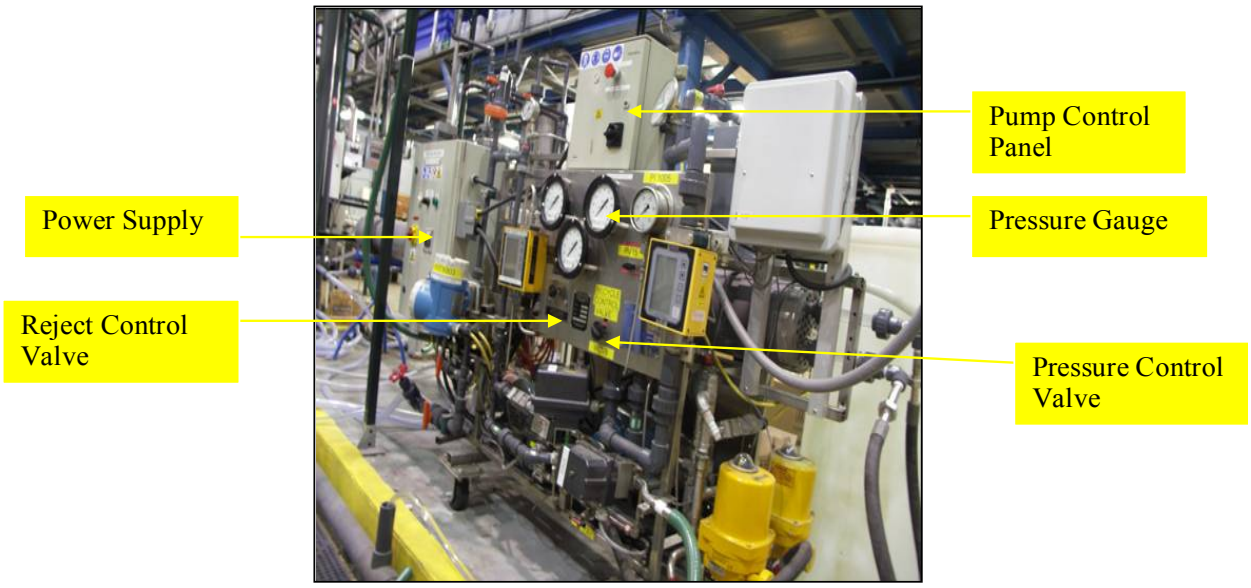

Figure 2-5. Control Panel for the ITT Fyne Technology 12-Foot Module

Figure 2-6. ITT Fyne Technology System 12-Foot Module Effluent

2.3 GE Pentair Filtration System

The GE Pentair membrane unit is an off-the-shelf commercial water filtration unit that consists of 48.5 square feet of capillary hollow-fiber membrane surface area in a single housing. The system is operated in a dead-end mode without a reject stream. Any material that does not pass through the membrane remains accumulated in the housing. The system design incorporates a timer that shuts off the production water flow at preset intervals and backflushes the membrane housing to remove the concentrated material accumulated therein. Finished water that has been accumulated in a tank is used for backwash (or the system can be designed for forward flush only). The system is designed to operate at standard domestic water pressure of up to 60 psi. Figure 2-7 shows a photograph of the GE Pentair System.

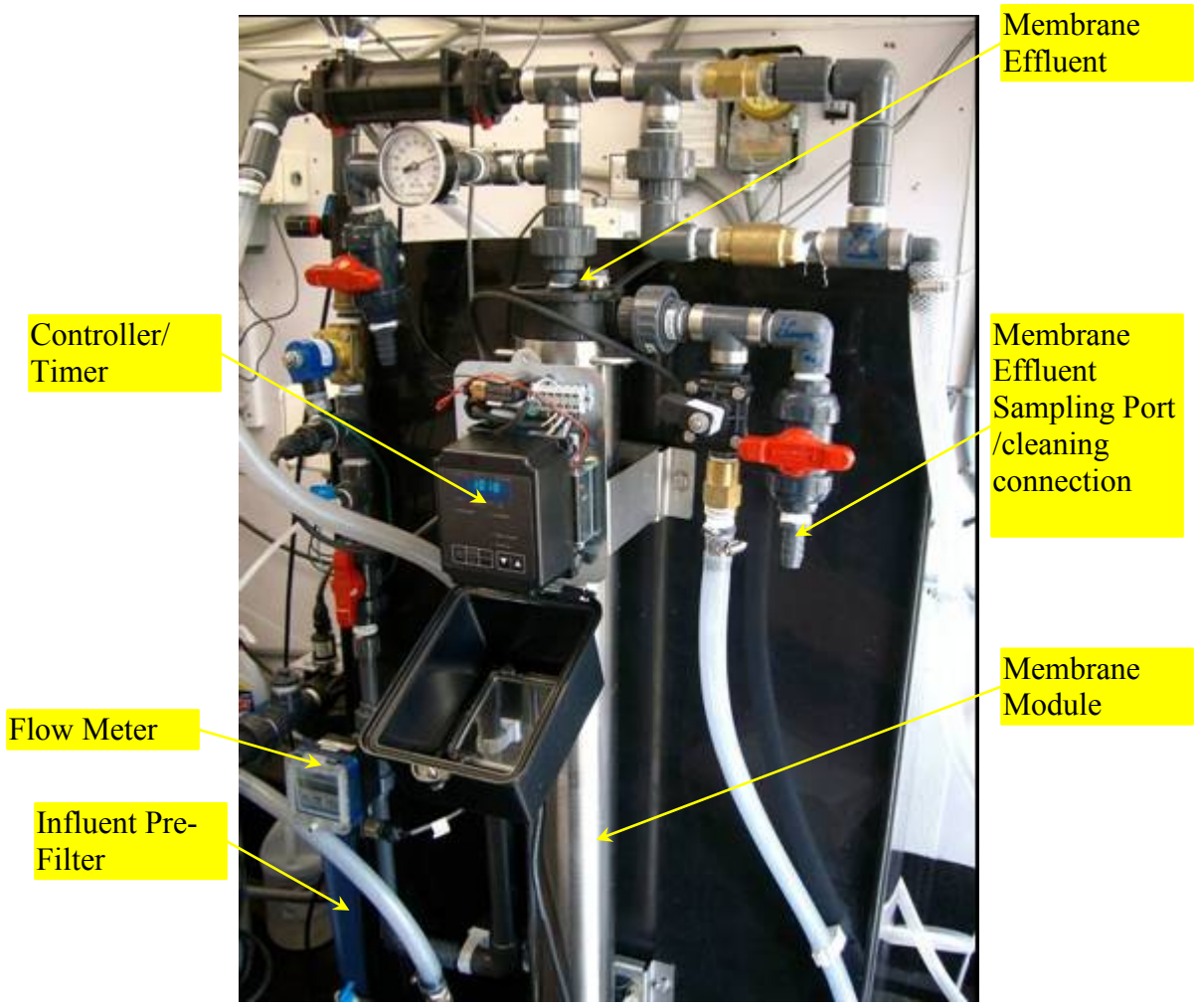

Figure 2-7. GE Pentair Membrane System

2.4 Virex Pro Filtration System

The Virex Pro unit is manufactured by Seccua GmbH in Germany and is a water filtration unit that consists of dual hollow fiber membrane modules with a nominal pore size of 15 nanometers. The system is operated in a dead-end mode without a reject stream. The system can be cleaned at specific intervals, time-of-day or fouling-based frequency. Combinations of forward flushes with backwashes are possible. The cleaning efficiency can be enhanced by the use of chemicals. The system is commercially available in two maximum filtration flow rate capacities – 9.7 gpm and 17.8 gpm. The pilot-scale system was operated between 2.5-3.5 gpm (10 Lpm). Figure 2-8 shows the various features of the system.

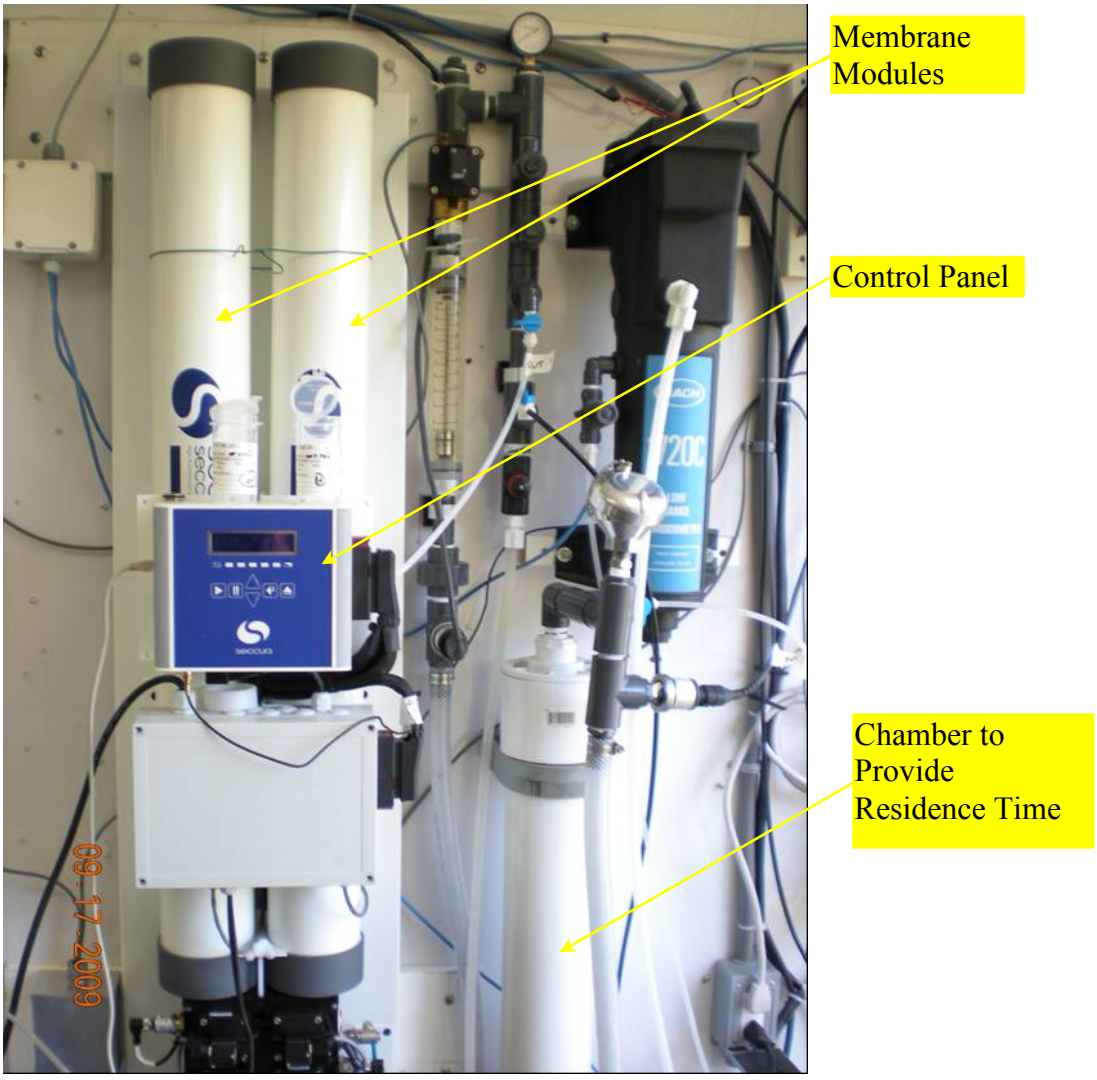

Figure 2-8. Virex Pro Filtration System

2.5 Radial Flow Fluidized Filter (R3f) with NOK Membrane Polishing Filters

The radial flow fluidized filtration (R3f) system utilizes radial flow (similar to the flow pattern of a cartridge filter) through use of non-bonded garnet media that can be fluidized and backwashed. The technology uses fine garnet media (33 microns) for depth filtration. The filter system housing consists of an upper chamber and a lower chamber. The upper chamber provides the necessary head for flow through the media and for backwashing. Water to be treated enters the system through the annular section at the top of the inner core. The lower chamber contains the media and water travels radially from the annular section through the media to the bottom inner core as a plug flow. The treated water then flows out of the system through the pipe connected at the bottom of the inner core. The plug in the inner core prevents any reverse flow. A typical R3f system is 150 mm (6 inches) in diameter and 1.8 m (6 feet) high as shown in Figure 2-9. The media can be fluidized and backwashed very quickly resulting in backwash volumes significantly lower than other technologies. The R3f system is suitable for small community potable water systems. It can also serve as pre-filter to membranes or disposable final filtration system. The R3f system is operated at 5 gpm flow rate as a pre-filter to Shelco NOK membrane filters in this study.

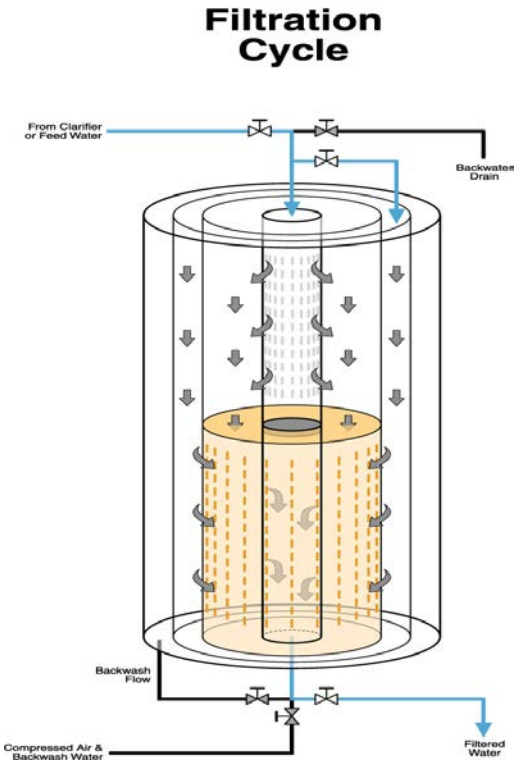

Figure 2-9. Conceptual Flow Diagram of the R3f System

The NOK polishing filters were tested by placing them in a 7-cartridge Shelco Multifilter Cartridge Housing (see Figure 2-10). Two Shelco housings were placed in series – the first housing contained microfilter (MF) cartridges while the second housing contained ultrafilter (UF) cartridges. The system was configured so that both Shelco housing units could be backwashed at the same frequency as the R3f system.

Figure 2-10. NOK Filters Placed in a 7-Cartridge Shelco Multi-Cartridge Housing Unit

2.6 System Operation and Test Conditions

2.6.1 Turbidity, Color and Microbial Challenges

Tests were carried out to evaluate the performance of the different systems in removing turbidity, color, organic matter, bacteria, virus, and protozoa using the following test matrix, organisms or surrogates:

- For turbidity challenges at the field site, the systems were operated using surface water from the lake as the feed source with as-received turbidity levels. Samples were collected for turbidity, total organic carbon (TOC), and color during the operation of the system.
- At the T&E Facility, the systems were evaluated for color and TOC removal but not for turbidity removal. For evaluating removal of TOC and color, the systems were challenged using dechlorinated potable water spiked with Bio-hume to achieve a target TOC concentration of 10 mg/L.

- For bacteria removal, the systems were challenged with *Bacillus subtilis* (*B. subtilis*) endospores at the T&E Facility and at the field site. Additionally, the ITT system and the R3f system were tested with *Escherichia coli* (*E. coli*) at the T&E Facility.
- For protozoa removal, the systems were challenged with 3.0 µm Polystyrene Latex (PSL) beads as a surrogate for *Cryptosporidium Parvum* (*C. parvum).* These tests were conducted at the T&E Facility.
- For a preliminary evaluation of virus removal potential, the systems were challenged with MS2 bacteriophage (a surrogate for enteric viruses) at the field site.

For *B. subtilis*, *E. coli,* MS2 bacteriophage and PSL beads, 1 mL of stock suspension with an approximate concentration of 10^9 cells/surrogates per mL was mixed with 500 mL of 0.01% Tween 20 in a 1-L glass beaker. A sub-sample was collected to determine the actual concentration of the injection suspension. The 500 mL suspension and the rinseate were added into the influent stream of the system using a peristaltic pump. The total injection time was approximately 60 minutes. Detailed descriptions of *B. subtilis*, *E. coli* and PSL bead stocks and their suppliers are described in the QAPPs for this project. MS2 bacteriophage stock was obtained from BioVir laboratory (Benicia, CA).

Tests were conducted on the ITT Fyne Technology system in the recycle mode and in the dead-end mode of operation. In the recycle mode, the modules were operated with approximately 20% reject water; there was no reject water during the dead-end mode of operation. The proportion of reject water flow was controlled by a valve. In the tests conducted at Ely, MN there was no reject stream other than during foam ball cleanings. The reject water valve was closed during the tests conducted in the dead-end mode of operation at the T&E Facility. The GE Pentair and the Virex Pro systems were operated in the dead-end mode only.

2.6.2 Sampling and Analytical Procedures

The sampling and analytical procedures are described in project QAPPs. PSL beads samples (1 L) were collected following a grab sampling method instead of the membrane sampling method because the effluent water pressure was insufficient to allow the water to pass through the collection membrane.

3.0 Test Results

This section summarizes the results of tests conducted on the ITT Fyne, GE Pentair, Virex Pro and R3f-NOK systems to evaluate the performance in removing different microbiological contaminants, color, organic matter, particle count, and turbidity. Table 3-1 presents a summary of the challenge tests that were conducted on the four filtration systems at the T&E Facility and at the MN field site. In addition to the challenge tests, MDH monitored turbidity, color, conductivity, and particle count on an ongoing basis for the systems at the field site.

Table 3.1. Summary of Challenge Tests Conducted on Different Systems

Date	Test ID	Membrane Configuration	Mode of Operation
Field Study 2008: ITT Fyne 3-Foot Module and GE Pentair Systems			
8/20/08	*B. subtilis* Test 1	ITT Fyne: ES404 + CA2PF	Recycle
8/20/08	*B. subtilis* Test 2	GE Pentair	Dead-end
8/20/08	*B. subtilis* Test 3	ITT Fyne: ES404 + CA2PF	Recycle
8/20/08	*B. subtilis* Test 4	GE Pentair	Dead-end
8/21/08	*B. subtilis* Test 5	ITT Fyne: ES404 + CA2PF	Dead-end
8/21/08	*B. subtilis* Test 6	ITT Fyne: ES404 + CA2PF	Dead-end
Field Test 2009: ITT Fyne 3-Foot Module and Virex Pro Systems			
9/15/09	*B. subtilis* Test 1	Virex Pro	Dead-end
9/15/09	*B. subtilis* Test 2	ITT Fyne: ES404 + AFC30	Recycle
9/16/09	*B. subtilis* Test 3	Virex Pro	Dead-end
9/16/09	*B. subtilis* Test 4	ITT Fyne: ES404 + AFC30	Recycle
9/16/09	*B. subtilis* Test 5	ITT Fyne: ES404 + AFC30	Recycle
9/15/09	MS2 bacteriophage Test 1	Virex Pro	Dead-end
9/16/09	MS2 bacteriophage Test 2	ITT Fyne: ES404 + AFC30	Recycle
9/16/09	MS2 bacteriophage Test 3	ITT Fyne: ES404 + AFC30	Recycle
9/16/09	MS2 bacteriophage Test 4	ITT Fyne: ES404 + AFC30	Recycle
Field Test 2009: R3f –NOK Systems			
9/17/09	*B. subtilis* Test 1	R3f + NOK MF + NOK UF	-
9/18/09	*B. subtilis* Test 2	R3f + NOK MF + NOK UF	-
9/18/09	*B. subtilis* Test 3	R3f + NOK MF + NOK UF	-
9/17/09	MS2 bacteriophage Test 1	R3f + NOK MF + NOK UF	-
Pilot Study at the U.S. EPA T&E Facility: ITT Fyne 3-Foot and 12-Foot Modules			
5/7/09	*B. subtilis* Test 1	CA2PF 12-Foot	Recycle
5/7/09	*B. subtilis* Test 2	CA2PF 12-Foot	Dead-end
5/8/09	*B. subtilis* Test 3	CA2PF 12-Foot	Recycle
6/3/09	*B. subtilis* Test 4	ES404 + CA2PF 3-Foot	Recycle
6/4/09	*B. subtilis* Test 5	ES404 + CA2PF 3-Foot	Recycle
6/5/09	*B. subtilis* Test 6	ES404 + CA2PF 3-Foot	Dead-end

6/16/09	*B. subtilis* Test 7	ES404 + AFC30 3-Foot	Recycle
6/17/09	*B. subtilis* Test 8	ES404 + AFC30 3-Foot	Recycle
6/17/09	*B. subtilis* Test 9	ES404 + AFC30 3-Foot	Dead-end
6/8/09	*E. coli* Test 1	ES404 + CA2PF 3-Foot	Recycle
7/16/09	*E. coli* Test 2	ITT Fyne: CA2PF 12-Foot	Recycle
7/20/09	*E. coli* Test 3	ITT Fyne: CA2PF 12-Foot	Recycle
7/22/09	*E. coli* Test 4	ITT Fyne: CA2PF 12-Foot	Dead-end
8/4/09	PSL Bead Test 1	ITT Fyne: CA2PF 12-Foot	Recycle
8/5/09	PSL Bead Test 2	ITT Fyne: CA2PF 12-Foot	Recycle
8/6/09	PSL Bead Test 3	ITT Fyne: CA2PF 12-Foot	Dead-end
6/3/09	TOC & Color Test 1	ES404 + CA2PF 3-Foot	Recycle
6/4/09	TOC & Color Test 2	ES404 + CA2PF 3-Foot	Recycle
6/5/09	TOC & Color Test 3	ES404 + CA2PF 3-Foot	Dead-end
6/16/09	TOC & Color Test 4	ES404 + AFC30 3-Foot	Recycle
6/17/09	TOC & Color Test 5	ES404 + AFC30 3-Foot	Recycle
6/17/09	TOC & Color Test 6	ES404 + AFC30 3-Foot	Dead-end
7/1/09	TOC & Color Test 7	CA2PF 12-Foot	Recycle
7/2/09	TOC & Color Test 8	CA2PF 12-Foot	Dead-end
7/06/09	TOC & Color Test 9	CA2PF 12-Foot	Recycle

3.1 B. subtilis Field Test Results

The following test runs were conducted on the 3-foot ITT Fyne Technology system and the GE Pentair system in 2008 to evaluate the removal of *B. subtilis*:

- Test 1 – ITT Fyne Technology System (Membrane 1: ES404 and Membrane 2: CA2PF) in Recycle Mode
- Test 2 – GE Pentair System in Dead-End Mode
- Test 3 – ITT Fyne Technology System (Membrane 1: ES404 and Membrane 2: CA2PF) in Recycle Mode (Replicate of Test 1)
- Test 4 – GE Pentair System in Dead-End Mode (Replicate of Test 2)
- Test 5 – ITT Fyne Technology System (Membrane 1: ES404 and Membrane 2: CA2PF) in Dead-End Mode
- Test 6 – ITT Fyne Technology System (Membrane 1: ES404 and Membrane 2: CA2PF) in Dead-End Mode (Replicate of Test 5)

The following test runs were conducted on the 3-foot ITT Fyne Technology system and the Virex Pro system in 2009 to evaluate the removal of *B. subtilis*:

- Test 1 – Virex Pro System in Dead-End Mode
- Test 2 – ITT Fyne Technology System (Membrane 1: ES404 and Membrane 2: AFC30) in Recycle Mode
- Test 3 – Virex Pro System in Dead-End Mode (Replicate of Test 1)
- Test 4 – ITT Fyne Technology System (Membrane 1: ES404 and Membrane 2: AFC30) in Recycle Mode (Replicate of Test 2)
- Test 5 – ITT Fyne Technology System (Membrane 1: ES404 and Membrane 2: AFC30) in Recycle mode (Replicate of Test 2)

The test results are organized by system in the following sections. The performance of a system at a particular sampling event was evaluated by comparing the influent and effluent concentrations of the contaminant and calculating an average log removal value was determined comparing the average influent and effluent concentrations of the contaminant during a particular test.

3.1.1 B. subtilis Test Results for the ITT Fyne Technology System

Table 3-2 presents the *B. subtilis* analytical results for four tests conducted on the 3-foot ITT Fyne Technology system at Ely, MN in August 2008. For these tests, the *B. subtilis* suspension was injected into the system approximately 10 minutes prior to the T0 sample (which was collected when permeate was observed to discharge from the system). Injection was completed just before the T5 samples were taken (followed by a chaser solution of Tween-20 for another 15 minutes). The system accidentally went into the foam-ball cleaning mode immediately after the T30 samples had been collected. T60 samples were collected after the system was restarted. The ES404 and the CA2PF membranes both achieved complete removal of *B. subtilis* in a number of sampling events during the challenge tests. The average performance achieved by the ES404 membrane in the recycle mode ranged from 6.2 log to complete removal (> 6.9 log) and that in the dead-end mode ranged from 4.3 log to complete removal (> 6.1 log). The average performance achieved by the CA2PF membrane in the recycle mode was 5.8 log and that in the dead-end mode ranged from 4.4 log to complete removal (> 6.1 log). Thus, the ES404 membrane performed slightly better in removing *B. subtilis* than the CA2PF membrane even though the CA2PF with a MWCO of 2000 Daltons is a tighter membrane than the ES404 membrane (which has a MWCO of 4000 Daltons).

Table 3-3 presents the *B. subtilis* analytical results for the three tests conducted on the 3-foot ITT Fyne Technology system in Ely, MN in September 2009. Collection of effluent samples started at 15 minutes after the start of the injection as there was a lag time of 15 minutes between the

influent and effluent for filling the system shroud. The ES404 and the CA2PF membranes both achieved complete removal of *B. subtilis* in a number of sampling events during the challenge tests. The average performance of the ES404 membrane in three tests in the recycle mode ranged from 5.0 log to complete removal (> 5.8 log). The average log removal value achieved by the AFC30 membrane in three tests in the recycle mode was 4.8. Thus, the ES404 membrane performed slightly better in removing *B. subtilis* than the AFC30 membrane even though the AFC30 with a MWCO of 1000 Daltons is a tighter membrane than the ES404 membrane.

Table 3.2. *B. subtilis* Analytical Results for ITT Fyne Technology System (ES404 and CA2PF) at Ely, MN in August 2008

Sampling Time (min)	No. Cells/100 ml			Log Removal		Average Log Removal
	IN	Out 1 (ES404)	Out 2 (CA2PF)	ES404	CA2PF	
Test 1: Recycle Mode						
T0	N/A[b]	N/D[c]	275	-	-	ES404: 6.2 CA2PF: 5.8
T5	7.2×10^6	N/D[c]	N/D[c]	CR (> 6.9)	CR (> 6.9)	
T15	7.6×10^6	N/D[c]	10	CR (> 6.9)	5.9	
T15 Dup	7.3×10^6	20	N/D[c]	5.6	CR (> 6.9)	
T30	7.9×10^6	N/D[c]	20	CR (> 6.9)	5.6	
T60	3.4×10^5	N/D[c]	20	CR (> 5.5)	4.2	
Test 3: Recycle Mode						
T0	N/A[b]	N/D[c]	30	-	-	ES404: CR (> 6.9) CA2PF: 5.7
T5	8.8×10^6	N/D[c]	30	CR (> 6.9)	5.5	
T15	7.6×10^6	N/D[c]	10	CR (> 6.9)	5.9	
T15 Dup	8.2×10^6	N/D[c]	20	CR (> 6.9)	5.6	
T30	7.4×10^6	N/D[c]	N/D[c]	CR (> 6.9)	CR (> 6.9)	
T60	N/A[b]	N/D[c]	N/D[c]	-	-	
Test 5: Dead-End Mode						
T0	1.4×10^6	N/D[c]	N/D[c]	CR (> 6.2)	CR (> 6.2)	ES404: 4.3 CA2PF: 4.4
T5	1.0×10^5	N/D[c]	200	CR (> 5.0)	2.7	
T15	2.5×10^6	N/D[c]	N/D[c]	CR (> 6.4)	CR (> 6.4)	
T15 Dup[a]	8.0×10^4	N/D[c]	N/D[c]	CR (> 4.9)	CR (> 4.9)	
T30	8.0×10^5	100	N/D[c]	3.9	CR (> 5.9)	
T60	2.8×10^5	160	N/D[c]	3.2	CR (> 5.5)	
Test 6: Dead-End Mode						
T0	3.6×10^5	N/D[c]	N/D[c]	CR (> 5.6)	CR (> 5.6)	ES404: CR (> 6.1) CA2PF: CR (> 6.1)
T5	1.9×10^6	N/D[c]	N/D[c]	CR (> 6.3)	CR (> 6.3)	
T15	3.6×10^5	N/D[c]	N/D[c]	CR (> 5.6)	CR (> 5.6)	
T15 Dup	3.1×10^6	N/D[c]	N/D[c]	CR (> 6.5)	CR (> 6.5)	
T30	3.0×10^5	N/D[c]	N/D[c]	CR (> 5.5)	CR (> 5.5)	
T60[a]	4.0×10^4	N/D[c]	N/D[c]	CR (> 4.6)	CR (> 4.6)	

[a]Data not considered for performance evaluation due to low influent concentration; [b]Not Available, samples were underdiluted;
[c]Not detected, no plaques were observed on any of the 10 plates for the sample
CR – Complete Removal, log removal value was based on the influent concentration

Table 3.3. *B. subtilis* Analytical Results for ITT Fyne Technology System (ES404 and AFC30) at Ely, MN in September 2009

Sampling Time (min)	No. Cells/100 ml			Log Removal		Average Log Removal
	IN	Out 1 (ES404)	Out 2 (AFC 30)	ES404	AFC30	
Test 2: Recycle Mode						
T0[a]	N/D[c]	N/D[c]	N/D[c]	-		ES404: CR (> 5.8) AFC30: 4.9
T5	1.5×10^5	N/D[c]	N/D[c]	CR (> 5.2)	CR (> 5.2)	
T15	5.0×10^5	N/D[c]	5	CR (> 5.7)	5.0	
T15 Dup	5.9×10^5	N/D[c]	10	CR (> 5.8)	4.8	
T30	1.1×10^6	N/D[c]	20	CR (> 6.0)	4.8	
T60[a]	30	N/D[c]	10	-		
Test 4: Recycle Mode						
T0[a]	7.0×10^2	5	5	-	-	ES404: 5.0 AFC30: 4.4
T5	2.0×10^4	5	5	3.6	3.6	
T15	3.5×10^5	N/D[c]	10	CR (> 5.5)	4.5	
T15 Dup	3.9×10^5	N/D[c]	10	CR (> 5.6)	4.6	
T30	3.6×10^5	5	20	4.9	4.3	
T60	N/A[b]	N/D[c]	10	-	-	
Test 5: Recycle Mode						
T0[a]	1.0×10^3	N/D[c]	N/D[c]	-	-	ES404: CR (> 5.7) AFC30: 5.0
T5	7.6×10^4	N/D[c]	5	CR (> 4.9)	4.2	
T15	5.3×10^5	N/D[c]	N/D[c]	CR (> 5.7)	CR (> 5.7)	
T15 Dup	5.2×10^5	N/D[c]	10	CR (> 5.7)	4.7	
T30	9.8×10^5	N/D[c]	5	CR (> 6.0)	5.3	
T60	N/A[b]	N/D[c]	5	-	-	

[a]Data not considered for performance evaluation due to lower influent concentration; [b]Not Available, samples were underdiluted;
[c]Not detected, no plaques were observed on any of the 10 plates for the sample
CR – Complete Removal, log removal value was based on the influent concentration

3.1.2 B. subtilis Test Results for the GE Pentair System

Table 3-4 presents the *B. subtilis* analytical results for two tests conducted on the GE Pentair System at Ely, MN in August 2008. For these tests, the injection was started just prior to taking the T0 sample and completed at T30. The chaser solution was then started and the injection was completed at T60. The system averaged a log removal of 5.0 based on these two tests.

Table 3.4. *B. subtilis* Analytical Results for GE Pentair System at Ely, MN in August 2008

Sampling Time (min)	No. Cells/100 ml		Log Removal	Average Log Removal
	IN	Out		
Test 2: Dead-End Mode				
T0	N/A[b]	35	-	4.7
T5	7.6×10^6	100	4.9	
T15	3.8×10^6	300	4.1	
T15 Dup	7.0×10^6	30	5.4	
T30	3.4×10^6	20	5.2	
T60[a]	2.0×10^3	N/D[c]	CR (> 3.3)	
Test 4: Dead-End Mode				
T0[a]	8.0×10^4	N/D[c]	CR (> 4.9))	5.3
T5	3.0×10^6	40	4.9	
T15	2.1×10^6	N/D[c]	CR (> 6.3)	
T15 Dup	6.4×10^6	10	5.8	
T30	3.0×10^6	30	5.0	
T60[a]	1.6×10^4	N/D[c]	CR (> 4.2)	

[a]Data not considered for performance evaluation due to low influent concentration; [b]Not Available, sample was underdiluted;
[c]Not detected, no plaques were observed on any of the 10 plates for the sample
CR – Complete Removal, log removal value was based on the influent concentration

3.1.3 B. subtilis Tests Results for the Virex Pro System

Table 3-5 presents the *B. subtilis* analytical results for two tests conducted on the Virex Pro system at Ely, MN in 2009. For these tests, the *B. subtilis* injection was completed at T30 and injection of the chaser solution injection completed at T60. The Virex Pro system achieved complete removal (> 4.7 log) of *B. subtilis* in two tests conducted in the dead-end mode of operation.

Table 3.5. *B. subtilis* Analytical Results for Virex Pro System at Ely, MN in September 2009

Sampling Time (min)	No. Cells/100 ml		Log Removal	Average Log Removal
	IN	Out		
Test 1: Dead-End Mode				
T0[a]	N/D[c]	N/D[c]	-	CR (> 4.7)
T5	N/A[b]	N/D[c]	-	
T15	4.0×10^4	N/D[c]	CR (> 4.6)	
T15 Dup	4.0×10^4	N/D[c]	CR (> 4.6)	
T30	8.0×10^4	N/D[c]	CR (> 4.9)	
T60[a]	1.6×10^3	N/D[c]	CR (> 3.2)	
Test 3: Dead-End Mode				
T0[a]	N/D[c]	N/D[c]	-	CR (> 4.6)
T5	7.5×10^4	N/D[c]	-	
T15	8.5×10^4	N/D[c]	CR (> 4.9)	
T15 Dup	7.0×10^4	N/D[c]	CR (> 4.8)	
T30	1.2×10^5	N/D[c]	CR (> 5.1)	
T60	2.2×10^4	N/D[c]	CR (> 4.3)	

[a]Data not considered for performance evaluation due to low influent concentration; [b]Not Available, sample was overdiluted;
[c]Not detected, no plaques were observed on any of the 10 plates for the sample
CR – Complete Removal, log removal value was based on the influent concentration.

3.2 MS2 bacteriophage Field Test Results

The following test runs were conducted on the 3-foot ITT Fyne Technology system and the Virex Pro system at the field site in September 2009 to evaluate the removal of MS2 bacteriophage:

- Test 1 – Virex Pro System in Dead-End Mode
- Test 2 – ITT Fyne Technology System (Membrane 1: ES404 and Membrane 2: AFC30) in Recycle Mode
- Test 3 – ITT Fyne Technology System (Membrane 1: ES404 and Membrane 2: AFC30) in Recycle Mode (Replicate of Test 2)
- Test 4 – ITT Fyne Technology System (Membrane 1: ES404 and Membrane 2: AFC30) in Recycle Mode (Replicate of Test 2)

3.2.1 MS2 bacteriophage Results for Virex Pro System

Table 3-6 presents the MS2 bacteriophage analytical results for the single test conducted on the Virex Pro system at Ely, MN in September 2009. For this test, the MS2 bacteriophage injection was completed at T30 and injection of the chaser solution injection completed at T60. Complete

removal (> 4.7 log) of MS2 bacteriophage was achieved by the Virex Pro system in the single test conducted in the dead-end mode of operation.

Table 3.6. MS2 bacteriophage Analytical Results for Virex Pro System at Ely, MN in September 2009

Sampling Time (min)	No. Cells/100 ml		Log Removal	Average Log Removal
	IN	Out		
T0	N/A[b]	N/D[c]	-	CR (> 4.7)
T5	5.0×10^4	N/D[c]	CR (> 4.7)	
T15	5.0×10^4	N/D[c]	CR (> 4.7)	
T15 Dup	6.0×10^4	N/D[c]	CR (> 4.8)	
T30	2.0×10^4	N/D[c]	CR (> 4.3)	
T60[a]	6.2×10^3	N/D[c]	CR (> 3.8)	

[a]Data not considered for performance evaluation due to low influent concentration; [b]Not Available, sample was underdiluted;
[c]Not detected, no plaques were observed on any of the 10 plates for the sample
CR – Complete Removal, log removal value was based on the influent concentration

3.2.2 MS2 bacteriophage Results for ITT Fyne Technology System

Table 3-7 presents the MS2 analytical results for three MS2 bacteriophage tests conducted on the 3-foot ITT Fyne Technology system in September 2009. Collection of effluent samples started at approximately 15 minutes after the start of the injection as there was a lag time of 15 minutes between the influent and effluent for filling the system shroud. The average performance of the ES404 membrane in removing MS2 bacteriophage ranged from 4.1 log to complete removal (> 5.3 log) in the three tests conducted in recycle mode of operation. A small number of MS2 bacteriophage was detected in effluent samples of AFC30 membrane and the average log removal in three tests was 4.2. Thus, the performance of the ES404 membrane is comparable to the tighter AFC30 membrane.

Table 3.7. MS2 bacteriophage Analytical Results for ITT Fyne Technology System (ES404 and AFC30) at Ely, MN in September 2009

Sampling Time (min)	No. Cells/100 ml			Log Removal		Average Log Removal
	IN	Out 1 (ES404)	Out 2 (AFC30)	ES404	AFC30	
Test 2: Recycle Mode						
T0	N/A[b]	N/D[c]	N/D[c]	-	-	ES404: CR (>5.3) AFC30: 4.5
T5[a]	8.0×10^3	N/D[c]	5	CR (>3.9)	3.2	
T15	1.2×10^5	N/D[c]	8	CR (>5.1)	4.2	
T15 Dup	1.6×10^5	N/D[c]	6	CR (>5.2)	4.4	
T30	2.8×10^5	N/D[c]	6	CR (>5.5)	4.7	
T60	N/A[b]	N/D[c]	N/D[c]	-	-	
Test 3: Recycle Mode						
T0	N/A[b]	18	16	-	-	ES404: 4.1 AFC30: 4.1
T5	2.4×10^4	6	12	3.6	3.3	
T15	1.6×10^5	26	10	3.8	4.2	
T15 Dup	1.9×10^5	18	22	4.0	3.9	
T30	3.9×10^5	10	18	4.6	4.4	
T60	N/A[b]	8	28	-	-	
Test 4: Recycle Mode						
T0	N/A[b]	-	-	-	-	ES404: 4.5 AFC30: 4.1
T5	1.2×10^4	4	12	3.5	3.0	
T15	1.7×10^5	13	13	4.1	4.1	
T15 Dup	3.7×10^5	-	-	-	-	
T30	4.0×10^5	7	31	4.8	4.1	
T60	N/A[b]	-	-	-		

[a]Data not considered for performance evaluation due to lower influent concentration; [b]Not available, sample was underdiluted;
[c]Not detected, no plaques were observed on any of the 10 plates for the sample
CR – Complete Removal, log removal value was based on the influent concentration

3.3 Microbiological Tests Results at the T&E Facility for the ITT Fyne Technology System

Microbiological tests at the T&E Facility were conducted on the ITT Fyne Technology System only.

3.3.1 *B. subtilis* Test Results for the ITT Fyne Technology System 12-Foot Module

Table 3-8 presents the *B. subtilis* test results for the following test runs conducted on the 12-foot ITT Fyne Technology systems consisting of the CA2PF membrane with a MWCO of 2000 Daltons at the T&E Facility:

- Test 1 – ITT Fyne Technology System 12-foot horizontal module (Membrane: CA2PF) in Recycle Mode
- Test 2 – ITT Fyne Technology System 12-foot horizontal module (Membrane: CA2PF) in Dead-End Mode
- Test 3 – ITT Fyne Technology System 12-foot horizontal module (Membrane: CA2PF) in Recycle Mode (Replicate of Test 1)

The system was operated at approximately 1.25 gpm in the recycle mode and approximately 1.50 gpm in the dead-end mode. The operating feed and reject pressures were ~ 90 psi and ~ 50 psi, respectively. For these tests, the *B. subtilis* injection was completed at T30 and injection of the chaser solution injection completed at T60. The unit achieved complete removal of *B. subtilis* in a number of sampling events during the two tests conducted in recycle mode of operation. The average log removal achieved by the system in two tests in the recycle mode was 4.8. The log removal achieved by the system in a single test conducted in the dead-end mode was 4.2.

Table 3.8. *B. subtilis* Analytical Results for ITT Fyne Technology System 12-Foot Horizontal Module (CA2PF) at the T&E Facility

Sampling Time (min)	No. Cells/100 ml		Log Removal	Average Log Removal
	IN	Out		
Test 1: Recycle Mode				
T0[a]	N/D[b]	N/D[b]	N/A	4.4
T5	8.0×10^5	70	4.1	
T10	1.2×10^6	30	4.6	
T20	7.0×10^5	10	4.9	
T30	1.0×10^6	30	4.5	
T60[a]	3.3×10^4	10	3.5	
Test 2: Dead-End Mode				
T0[a]	N/D[b]	N/D[b]	N/A	4.2
T5	9.0×10^5	30	4.5	
T10	8.0×10^5	15	4.7	
T20	1.1×10^6	90	4.1	
T30	8.2×10^5	80	4.0	
T60[a]	2.5×10^4	15	3.2	
Test 3: Recycle Mode				
T0[a]	15	5	N/A	5.1
T5	2.6×10^5	5	4.7	
T10	2.3×10^5	N/D[b]	CR (>5.4)	
T20	3.0×10^5	5	4.8	
T30	2.8×10^5	N/D[b]	CR (>5.5)	
T60	1.7×10^5	N/D[b]	CR (>5.2)	

[a]Data not considered for performance evaluation due to lower influent concentration
[b]Not detected, no plaques were observed on any of the 10 plates for the sample
CR – Complete Removal, log removal value was based on the influent concentration

3.3.2 B. subtilis Test Results for ITT Fyne Technology System 3-Foot Modules

Table 3-9 presents the *B. subtilis* analytical results for the following three tests conducted on the 3-foot ITT Fyne Technology system consisting of ES404 membrane with MWCO of 4000 Daltons and CA2PF membrane with a MWCO of 2000 Daltons.

- Test 4 – ITT Fyne Technology 3-foot vertical modules (Membrane 1: ES404 and Membrane 2: CA2PF) in Recycle mode
- Test 5 – ITT Fyne Technology System 3-foot vertical modules (Membrane 1: ES404 and Membrane 2: CA2PF) in Recycle Mode (Replicate of Test 4)
- Test 6 – ITT Fyne Technology System 3-foot vertical module (Membrane 1: ES404 and Membrane 2: CA2PF) in Dead-End Mode

The system was operated at approximately 0.70 gpm in the recycle mode and approximately 0.90 gpm in the dead-end mode. The operating feed and reject pressures were approximately 80 psi and approximately 30 psi, respectively. For these tests, the *B. subtilis* injection was completed at T30 and injection of the chaser solution injection completed at T60. The CA2PF membrane (MWCO: 2000 Daltons) in the 3 feet vertical module achieved complete removal of *B. subtilis* in both recycle (> 6.2 log) and dead-end (> 5.8 log) modes of operations. The ES404 membrane (MWCO: 4000 Daltons) achieved an average log removal value of 3.4 in two tests conducted in the recycle mode of operation. The log removal value achieved by the ES404 membrane in a single test in the dead-end mode was 4.1.

The poor log removal achieved by the ES404 membrane led to the speculation that the membrane may have been damaged and the ES404 membrane was replaced with a new membrane while the CA2PF membrane was replaced with an AFC30 membrane with a MWCO of 1000 Daltons. Table 3-10 presents the *B. subtilis* results for the following three tests conducted with the ES404 membrane and the AFC30 membrane:

- Test 7 – ITT Fyne Technology System 3-foot vertical modules in Recycle Mode (Membrane 1: ES404 New and Membrane 2: AFC30)
- Test 8 - ITT Fyne Technology System 3-foot vertical modules in Recycle Mode (Membrane 1: ES404 New and Membrane 2: AFC30) (Replicate of Test 7)
- Test 9 - ITT Fyne Technology System 3-foot vertical modules (Membrane 1: ES 404 New and Membrane 2: AFC30) in Dead-End Mode

The system was operated at approximately 0.42 gpm in the recycle mode and approximately 0.52 gpm in the dead-end mode. The operating feed and reject pressures were approximately 80 psi and approximately 30 psi, respectively. For these tests, the *B. subtilis* injection was completed at T30 and injection of the chaser solution injection completed at T60. Both, the AFC30 membrane and the ES404 membrane achieved complete removal of *B. subtilis* in both the recycle (> 6.3 log) and dead-end mode (> 6.0 log) of operations. The results on the new ES404 membrane confirm that the ES404 membrane used in Test Nos. 4, 5 and 6 had been compromised.

Table 3.9. *B. subtilis* Analytical Results for ITT Fyne Technology System 3-Foot Modules (ES404 and CA2PF) at the T&E Facility

Sampling Time (min)	No. Cells/100 ml			Log Removal		Average Log Removal
	IN	Out 1 (ES404)	Out 2 (CA2PF)	ES404	CA2PF	
Test 4: Recycle Mode						
T0[a]	N/D[b]	N/D[b]	N/D[b]	-	-	ES404: 3.4 CA2PF: CR (>6.2)
T5	7.0×10^5	2.1×10^2	N/D[b]	3.5	CR (>5.9)	
T10	1.0×10^6	3.2×10^2	N/D[b]	3.5	CR (>6.0)	
T20	1.7×10^6	9.3×10^2	N/D[b]	3.3	CR (>6.2)	
T30	2.1×10^6	1.0×10^3	N/D[b]	3.3	CR (>6.3)	
T60[a]	4.4×10^4	N/D[b]	N/D[b]	CR (>4.6)	CR (>4.6)	
Test 5: Recycle Mode						
T0[a]	10	10	N/D[b]	-	-	ES404: 3.3 CA2PF: CR (>6.2)
T5	3.0×10^5	1.3×10^2	N/D[b]	3.4	CR (>5.5)	
T10	7.5×10^5	3.9×10^2	N/D[b]	3.3	CR (>5.9)	
T20	3.0×10^6	1.1×10^3	N/D[b]	3.4	CR (>6.5)	
T30	2.0×10^6	1.3×10^3	N/D[b]	3.2	CR (>6.3)	
T60[a]	1.1×10^4	2.0×10^2	N/D[b]	1.7	CR (>4.0)	
Test 6: Dead-End Mode						
T0[a]	100	300	N/D[b]	-	-	ES404: 4.1 CA2PF: approximately CR (>5.8)
T5	2.1×10^6	1.2×10^2	20	4.2	5.0	
T10	1.5×10^6	4.5×10^2	N/D[b]	3.5	CR (>6.2)	
T20	4.2×10^6	1.7×10^2	N/D[b]	4.4	CR (>6.6)	
T30	4.6×10^6	3.6×10^2	N/D[b]	4.1	CR (>6.7)	
T60[a]	1.0×10^4	15	N/D[b]	2.8	CR (>4.2)	

[a]Data not considered for performance evaluation due to lower influent concentration

[b]Not detected, no plaques were observed on any of the 10 plates for the sample

CR – Complete Removal, log removal value was based on the influent concentration

Table 3.10. *B. subtilis* Analytical Results for ITT Fyne Technology System 3-Foot Vertical Modules (ES404 and AFC30) at the T&E Facility

Sampling Time (min)	No. Cells/100 ml			Log Removal		Average Log Removal
	IN	Out 1 (ES404)	Out 2 (AFC30)	ES404	AFC30	
Test 7: Recycle Mode						
T0[a]	N/D[b]	N/D[b]	N/D[b]	-	-	ES404: CR (> 5.7) AFC30: CR (> 6.0)
T5	3.0×10^5	10	5	4.5	4.8	
T10	9.0×10^5	N/D[b]	N/D[b]	CR (> 6.0)	CR (> 6.0)	
T20	1.4×10^6	N/D[b]	N/D[b]	CR (> 6.2)	CR (> 6.2)	
T30	2.7×10^6	N/D[b]	N/D[b]	CR (> 6.4)	CR (> 6.4)	
T60[a]	1.1×10^4	N/D[b]	N/D[b]	CR (> 4.0)	CR (> 4.0)	
Test 8: Recycle Mode						
T0[a]	5	N/D[b]	N/D[b]	-	-	ES404: CR (> 6.3) AFC30: CR (> 6.3)
T5	1.0×10^5	N/D[b]	N/D[b]	CR (> 5.0)	CR (> 5.0)	
T10	7.0×10^5	N/D[b]	N/D[b]	CR (> 5.8)	CR (> 5.8)	
T20	3.2×10^6	N/D[b]	N/D[b]	CR (> 6.5)	CR (> 6.5)	
T30	4.0×10^6	N/D[b]	N/D[b]	CR (> 6.6)	CR (> 6.6)	
T60[a]	N/D[b]	N/D[b]	N/D[b]	-	-	
Test 9: Dead-End Mode						
T0[a]	140	N/D[b]	N/D[b]	-	-	ES404: CR (> 6.0) AFC30: CR (> 6.0)
T5	1.0×10^5	N/D[b]	N/D[b]	CR (> 5.0)	CR (> 5.0)	
T10	3.0×10^5	N/D[b]	N/D[b]	CR (> 5.5)	CR (> 5.5)	
T20	1.3×10^6	N/D[b]	N/D[b]	CR (> 6.1)	CR (> 6.1)	
T30	2.0×10^6	N/D[b]	N/D[b]	CR (> 6.3)	CR (> 6.3)	
T60[a]	N/D[b]	N/D[b]	N/D[b]	-	-	

[a]Data not considered for performance evaluation due to lower influent concentration

[b]Not detected, no plaques were observed on any of the 10 plates for the sample

CR – Complete Removal, log removal value was based on the influent concentration

3.3.3 E. coli Test Results for the ITT Fyne Technology System 12-Foot Module

Table 3-11 presents the analytical results for the following three tests conducted on the 12-foot ITT Fyne Technology system to evaluate the removal of *E. coli*:

- Test 2 – ITT Fyne Technology System 12-foot horizontal module (Membrane: CA2PF) in the Recycle Mode
- Test 3 – ITT Fyne Technology System 12-foot horizontal module (Membrane: CA2PF) in the Recycle Mode (Replicate of Test1)

- Test 4 – ITT Fyne Technology System 12-foot horizontal module (Membrane: CA2PF) in the Dead-End Mode

The system was operated at approximately 1.50 gpm in both the recycle mode and the dead-end mode of operation. The operating feed and reject pressures were approximately 90 psi and approximately 50 psi, respectively. For these tests, the *E. coli* injection was completed at T30 and injection of the chaser solution injection completed at T60. The system achieved complete removal of *E. coli* in both the recycle mode (>7.4 log) and the dead-end mode (> 6.0 log) of operations.

Table 3.11. *E. coli* Analytical Results for ITT Fyne Technology System 12-Foot Horizontal Module (CA2PF) at the T&E Facility

Sampling Time (min)	No. Cells/100 ml		Log Removal	Average Log Removal
	IN	Out		
Test 2: Recycle Mode				
T0[a]	N/D[c]	N/D[c]	-	CR (> 5.9)
T5	1.4×10^5	N/D[c]	CR (> 5.2)	
T10	N/A[b]	N/D[c]	-	
T20	8.3×10^5	N/D[c]	CR (> 5.9)	
T30	1.3×10^5	N/D[c]	CR (> 5.1)	
T60	2.4×10^6	N/D[c]	CR (> 6.4)	
Test 3: Recycle Mode				
T0[a]	291	N/D[c]	-	CR (> 7.4)
T5	8.7×10^6	N/D[c]	CR (> 6.9)	
T10	2.4×10^7	N/D[c]	CR (> 7.4)	
T20	2.4×10^7	N/D[c]	CR (> 7.4)	
T30	2.4×10^7	N/D[c]	CR (> 7.4)	
T60	2.4×10^7	N/D[c]	CR (> 7.4)	
Test 4: Dead-End Mode				
T0[a]	N/D[c]	N/D[c]	-	CR (> 6.0)
T5	4.7×10^5	N/D[c]	CR (> 5.7)	
T10	1.3×10^6	N/D[c]	CR (> 6.1)	
T20	1.2×10^6	N/D[c]	CR (> 6.1)	
T30	1.2×10^6	N/D[c]	CR (> 6.1)	
T60	4.0×10^5	N/D[c]	CR (> 5.6)	

[a]Data not considered for performance evaluation due to lower influent concentration; [b]Not available, sample spilled during analysis; [c]Not detected, no plaques were observed on any of the 10 plates for the sample

CR – Complete Removal, log removal value was based on the influent concentration

3.3.4 *E. coli* Tests for ITT Fyne Technology System 3-Foot Modules

Table 3-12 presents the *E. coli* analytical results for the single test conducted on the 3-foot ITT Fyne Technology system with the ES404 membrane and CA2PF membrane. The system was operated at approximately 0.70 gpm in recycle mode of operation. The operating feed and reject pressures were approximately 80 psi and approximately 30 psi, respectively. For this test, the *E. coli* injection was completed at T30 and injection of the chaser solution injection completed at T60. The CA2PF in achieved a log removal of 4.2 while the ES404 achieved a log removal of 3.5. This test was conducted on the ES 404 membrane that was suspected faulty during *B. subtilis* tests.

Table 3.12. *E. coli* Analytical Results for ITT Fyne Technology System 3-Foot Vertical Modules (ES404 and CA2PF) at the T&E Facility

Sampling Time (min)	No. Cells/100 ml			Log Removal		Average Log Removal
	IN	Out 1 (ES404)	Out 2 (CA2PF)	ES404	CA2PF	
Test 1: Recycle Mode						
T0[a]	N/D[b]	N/D[b]	N/D[b]	-	-	ES404: 3.5 CA2PF: 4.2
T5	3.1×10^4	1	11	4.5	3.5	
T10	8.2×10^4	72	N/D[b]	3.1	CR (> 4.9)	
T20	3.5×10^4	5	2	3.8	4.2	
T30	7.3×10^4	1	1	4.9	4.9	
T60[a]	2.4×10^3	6	N/D[b]	2.6	CR (> 3.4)	

[a]Data not considered for performance evaluation due to lower influent concentration
[b]Not detected, no plaques were observed on any of the 10 plates for the sample
CR – Complete Removal, log removal value was based on the influent concentration

3.3.5 PSL Beads Test Results for the ITT Fyne Technology System 12-Foot Module

Table 3-13 presents the analytical results for the following three tests using PSL beads (a non-biological surrogate for *Cryptosporidium)* conducted on the 12-foot ITT Fyne Technology system with the CA2PF membrane:

- Test 1 – ITT Fyne Technology System 12-foot horizontal module (Membrane: CA2PF) in Recycle Mode
- Test 2 – ITT Fyne Technology System 12-foot horizontal module (Membrane: CA2PF) in Recycle Mode (Replicate of Test1)
- Test 3 – ITT Fyne Technology System 12-foot horizontal module (Membrane: CA2PF) in Dead-End Mode

The system was operated at approximately 1.50 gpm in both recycle and dead-end modes of operation. The operating feed and reject pressures were approximately 90 psi and approximately

50 psi, respectively. For these tests, the PSL beads injection was completed at T30 and injection of the chaser solution injection completed at T60. The system achieved complete removal of PSL beads in a number of sampling events during the two tests conducted in the recycle mode of operation. The average log removal achieved by the system in the recycle mode was 2.7. The log removal achieved by the system in a single test in the dead-end mode was 2.2. The relatively inferior removal of PSL beads may possibly be attributed to the surface characteristics of membrane as well as solution properties, such as pH and ionic strength, which may impact removal.

Table 3.13. PSL Beads Analytical Results for the ITT Fyne Technology System 12-Foot Horizontal Module (CA2PF) at the T&E Facility

Sampling Time (min)	No. of Beads/1000 ml		Log Removal	Average Log Removal
	IN	Out		
Test 1: Recycle Mode				
T0[a]	1.3×10^4	5.8×10^2	1.4	2.6
T5	3.6×10^5	4.2×10^3	1.9	
T15	2.8×10^5	1.7×10^3	2.2	
T30	1.9×10^6	N/D[b]	CR (> 6.3)	
T60[a]	3.2×10^4	N/D[b]	CR (> 4.5)	
Test 2: Recycle Mode				
T0[a]	8.3×10^2	N/D[b]	CR (> 2.9)	2.8
T5	7.9×10^5	2.5×10^3	2.5	
T15	6.5×10^5	N/D[b]	CR (> 5.8)	
T30	2.7×10^5	N/D[b]	CR (> 5.4)	
T60[a]	2.9×10^4	1.7×10^4	0.2	
Test 3: Dead-end Mode				
T0[a]	8.3×10^2	N/D[b]	CR (> 2.9)	2.2
T5	3.5×10^5	5.8×10^3	1.8	
T15	9.3×10^5	2.5×10^3	2.6	
T30	8.9×10^5	5.0×10^3	2.3	
T60[a]	9.2×10^3	1.7×10^3	0.7	

[a]Data not considered for performance evaluation due to lower influent concentration
[b]Not detected, no beads were observed in the sample
CR – Complete Removal, log removal value was based on the influent concentration

3.4 TOC and Color Test Results at the T&E Facility

The following test runs were conducted on the ITT Fyne Technology systems at the T&E Facility to evaluate the removal of TOC and Color:

- Test 1 – ITT Fyne Technology 3-foot vertical modules (Membrane 1: ES404 and Membrane 2: CA2PF) in Recycle Mode
- Test 2 – ITT Fyne Technology System 3-foot vertical modules (Membrane 1: ES404 and Membrane 2: CA2PF) in Recycle Mode (Replicate of Test 4)
- Test 3 – ITT Fyne Technology System 3-foot vertical module (Membrane 1: ES404 and Membrane 2: CA2PF) in Dead-End Mode
- Test 4 – ITT Fyne Technology System 3-foot vertical modules in Recycle Mode (Membrane 1: ES404 New and Membrane 2: AFC30)
- Test 5 - ITT Fyne Technology System 3-foot vertical modules in Recycle Mode (Membrane 1: ES404 New and Membrane 2: AFC30) (Replicate of Test 7)
- Test 6 - ITT Fyne Technology System 3-foot vertical modules in Recycle Mode (Membrane 1: ES404 New and Membrane 2: AFC30) in Dead-End Mode
- Test 7 – ITT Fyne Technology System 12-foot horizontal module (Membrane: CA2PF-2000) in Recycle Mode
- Test 8 – ITT Fyne Technology System 12-foot horizontal module (Membrane: CA2PF) in Recycle Mode (Replicate of Test 1)
- Test 9 – ITT Fyne Technology System 12-foot horizontal module (Membrane: CA2PF) in Dead-End Mode

3.4.1 TOC and Color Test Results for the ITT Fyne Technology System 12-Foot Module

Tables 3-14 and 3-15 present the TOC and Color analytical results, respectively for three tests conducted on the ITT Fyne Technology system 12-foot horizontal module consisting of the CA2PF membrane with a MWCO of 2000 Daltons. The system was operated at approximately 1.50 gpm in both recycle and dead-end modes of operation. The operating feed and reject pressures were approximately 90 psi and approximately 50 psi, respectively. For these tests, feed water with a target TOC concentration of 10 mg/L was prepared by mixing Bio-hume in dechlorinated potable water. The system removed 83.6% of the TOC in the recycle mode and 80.8% in the dead-end mode. For color, the system achieved an average percent removal 96.3% in the recycle mode and 93.4% in the dead-end mode.

Table 3.14. TOC Analytical Results for ITT Fyne Technology System 12-Foot Horizontal Module (CA2PF) at the T&E Facility

Sampling Time (min)	TOC (mg/L)		Percent Removal	Average Percent Removal
	IN	Out		
Test 7: Recycle Mode				
T0[a]	-1.47	2.46	N/A[b]	83.8
T10[a]	1.54	0.87	N/A[b]	
T30	5.60	0.70	87.5	
T60	5.16	1.03	80.0	
Test 8: Recycle Mode				
T0	9.77	1.57	83.9	83.3
T10	10.40	1.67	83.9	
T30	10.50	1.78	83.0	
T60	10.67	1.90	82.8	
Test 9: Dead-End Mode				
T0	9.16	2.20	76.0	80.8
T10	9.13	1.59	82.6	
T30	9.22	1.61	82.5	
T60	9.91	1.76	82.2	

[a]Data not considered for performance evaluation due to lower influent concentration; [b]Not Available

Table 3.15. Color Analytical Results for ITT Fyne Technology System 12-Foot Horizontal Module (CA2PF) at the T&E Facility

Sampling Time (min)	Color (Pt-Co Unit)		Percent Removal	Average Percent Removal
	IN	Out		
Test 7: Recycle Mode				
T0[a]	approximately 2	approximately 2	N/A[b]	99.6
T10[a]	286	approximately 2	N/A[b]	
T30	586	approximately 2	99.6	
T60	546	approximately 2	99.6	
Test 8: Recycle Mode				
T0	736	35	95.2	92.9
T10	734	61	91.7	
T30	754	67	91.2	
T60	796	52	93.5	
Test 9: Dead-End Mode				
T0	662	48	92.7	93.4
T10	682	47	93.2	
T30	736	41	94.4	
T60	724	49	93.3	

[a]Data not considered for performance evaluation due to lower influent concentration; [b]Not Available

3.4.2 TOC and Color Test Results for ITT Fyne Technology System 3-Foot Modules

Tables 3-16 and 3-17 present the TOC and color analytical results for three tests conducted on the 3-foot ITT Fyne Technology system with the ES404 and CA2PF membranes. The system was operated at approximately 0.70 gpm and approximately 0.90 gpm in recycle and dead-end modes, respectively. The operating feed and reject pressures were approximately 80 psi and approximately 30 psi, respectively. The ES404 membrane removed approximately 89% of the TOC in the recycle mode and 96% in the dead-end mode. The CA2PF membrane removed approximately 67% of the TOC in the recycle mode and 86% in the dead-end mode. The ES404 and CA2PF membranes both removed approximately 98% of the color.

Tables 3-18 and 3-19 present the TOC and color analytical results for three tests conducted on the 3-foot ITT Fyne Technology system consisting of the ES404 membrane and the AFC30 membrane. The system was operated at approximately 0.42 gpm and approximately 0.52 gpm in recycle and dead-end modes, respectively. The operating feed and reject pressures were approximately 80 psi and approximately 30 psi, respectively. The ES404 removed approximately 90% of the TOC in both recycle mode and dead-end mode of operations while the

AFC30 membrane removed approximately 92% of the TOC in the recycle mode and 95% in the dead-end mode. The ES404 removed approximately 97% of the color while the AFC30 membrane removed approximately 99% of the color in both recycle and dead-end modes.

Table 3.16. TOC Analytical Results for ITT Fyne Technology System 3-Foot Vertical Modules (ES404 and CA2PF) at the T&E Facility

Sampling Time (min)	TOC (mg/L)			Percent Removal		Average Percent Removal
	IN	Out 1 (ES404)	Out 2 (CA2PF)	ES404	CA2PF	
Test 1: Recycle Mode						
T0	5.12	0.67	1.52	86.9	70.3	
T10	6.40	0.85	2.28	86.7	64.3	ES404: 86.4
T30	5.19	0.83	2.57	84.0	50.5	CA2PF: 62.2
T60	6.07	0.72	2.20	88.1	63.7	
Test 2: Recycle Mode						
T0	5.68	0.53	1.36	90.7	76.1	
T10	6.82	0.64	-	90.6	N/A	ES404: 90.9
T30	7.92	0.70	2.62	91.2	66.9	CA2PF: 70.8
T60	6.22	0.55	1.89	91.2	69.6	
Test 3: Dead-end Mode						
T0	10.33	0.62	1.17	94.0	88.7	
T10	12.16	0.44	1.92	96.4	84.2	ES404: 95.9
T30	15.93	0.57	2.60	96.4	83.6	CA2PF: 85.9
T60	14.25	0.44	1.82	96.9	87.3	

Table 3.17. Color Analytical Results for ITT Fyne Technology System 3-Foot Vertical Modules (ES404 and CA2PF) at the T&E Facility

Sampling Time (min)	Color (Pt-Co Unit)			Percent Removal		Average Percent Removal
	IN	Out 1 (ES404)	Out 2 (CA2PF)	ES404	CA2PF	
Test 1: Recycle Mode						
T0	401	11	approximately 2	97.3	99.5	ES404: 98.3 CA2PF: 98.5
T10	734	approximately 2	27	99.7	96.3	
T30	888	33	15	96.2	98.3	
T60	654	approximately 2	approximately 2	99.7	99.7	
Test 2: Recycle Mode						
T0	648	15	approximately 2	97.7	99.6	ES404: 96.9 CA2PF: 97.0
T10	770	4	58	99.5	92.5	
T30	770	33	15	95.7	98.1	
T60	910	48	19	94.7	97.8	
Test 3: Dead-End Mode						
T0	586	40	49	93.2	91.7	ES404: 97.4 CA2PF: 95.9
T10	668	2	8	99.7	98.8	
T30	1006	2	40	99.8	96.0	
T60	980	33	40	96.7	95.9	

Table 3.18. TOC Analytical Results for ITT Fyne Technology System 3-Foot Vertical Modules (ES404 New and AFC30) at the T&E Facility

Sampling Time (min)	TOC (mg/L)			Percent Removal		Average Percent Removal
	IN	Out 1 (ES404)	Out 2 (AFC30)	ES404	AFC30	
Test 4: Recycle Mode						
T0	5.96	1.03	0.97	82.7	83.7	ES404: 89.7 AFC30: 90.7
T10	15.77	1.17	0.97	92.6	93.8	
T30	19.16	1.44	0.88	92.4	95.4	
T60	13.52	1.22	1.38	90.9	89.8	
Test 5: Recycle Mode						
T0	10.90	0.87	0.88	92.0	91.9	ES404: 89.6 AFC30: 93.7
T10	16.10	1.64	0.82	89.8	94.9	
T30	18.74	2.03	0.81	89.2	95.7	
T60	9.72	1.24	0.75	87.3	92.3	
Test 6: Dead-end Mode						
T0	9.96	1.22	0.56	87.8	94.4	ES404: 89.6 AFC30: 95.4
T10	12.91	1.42	0.57	89.0	95.6	
T30	13.53	1.37	0.51	89.8	96.2	
T60	14.21	1.15	0.64	91.9	95.5	

Table 3.19. Color Analytical Results for ITT Fyne Technology System 3-Foot Vertical Modules (ES404 New and AFC30) at the T&E Facility

Sampling Time (min)	Color (Pt-Co Unit)			Percent Removal		Average Percent Removal
	IN	Out 1 (ES404)	Out 2 (AFC30)	ES404	AFC30	
Test 4: Recycle Mode						
T0	320	2	2	99.4	99.4	ES404: 98.9 AFC30: 98.9
T10	942	5	23	99.5	97.6	
T30	1400	19	19	98.6	98.6	
T60	900	14	2	98.4	99.8	
Test 5: Recycle Mode						
T0	640	60	approximately 2	90.6	99.7	ES404: 92.4 AFC30: 98.3
T10	700	30	23	95.7	96.7	
T30	920	39	7	95.7	99.3	
T60	524	65	14	87.6	97.3	
Test 6: Dead-End Mode						
T0	688	13	2	98.1	99.7	ES404: 97.2 AFC30: 99.5
T10	692	22	2	96.8	99.7	
T30	1048	24	2	97.7	99.8	
T60	1080	43	14	96.0	98.7	

3.5 Test Results for the R3f System and NOK Polishing Filters

3.5.1 B. subtilis Test Results

Table 3-20 present the results of the three *B. subtilis* tests conducted on the R3f pre-filters and NOK post-filters at Ely, MN in September 2009. The corresponding log removal values for the different sampling locations are summarized in Table 3-21. The lead NOK polishing filter was a microfilter and the lag NOK polishing filter was an ultrafilter. The R3f-NOK filtration system achieved complete removal of *B. subtilis*. The R3f had a l.0 log removal while the NOK MF showed an approximately 3.0 log removal. Thus, there was negligible influent *B. subtilis* concentration for the final NOK UF. Table 3-22 presents the pressure buildup in the system during this test.

Table 3.20. *B. subtilis* Analytical Results for R3f – NOK Filters at Ely, MN in September 2009

Sample ID	B. subtilis Conc./100 mL				
	Influent	Out 1 (Lead Filter)	Out 2 (Lag Filter)	Out 3 (NOK MF)	Out 4 (NOK UF)
Test 1					
T0[a]	20	1.3×10^2	20	N/D[c]	N/D[c]
T5[a]	5.0×10^3	6.0×10^2	70	N/D[c]	N/D[c]
T15	4.6×10^4	2.0×10^4	8.1×10^3	N/D[c]	N/D[c]
T15 Dup	5.2×10^4	3.0×10^4	6.3×10^3	N/D[c]	N/D[c]
T30	6.0×10^4	3.8×10^4	5.5×10^3	N/D[c]	N/D[c]
T60[a]	6.0×10^2	N/A[b]	4.6×10^2	N/D[c]	N/D[c]
Test 2: Replicate of Test 1					
T0[a]	20	80	1.0×10^2	N/D[c]	N/D[c]
T5	3.6×10^4	1.6×10^3	5.2×10^2	N/D[c]	N/D[c]
T15	3.8×10^4	3.3×10^4	1.6×10^3	N/D[c]	N/D[c]
T15 Dup	4.2×10^4	4.9×10^4	1.0×10^3	N/D[c]	N/D[c]
T30	7.0×10^4	2.2×10^4	6.6×10^2	N/D[c]	N/D[c]
T60[a]	1.2×10^2	9.0×10^2	1.6×10^2	N/D[c]	N/D[c]
Test 3: Replicate of Test 1					
T0[a]	50	3.0×10^2	1.5×10^2	N/D[c]	N/D[c]
T5	2.2×10^4	7.0×10^3	1.6×10^2	N/D[c]	N/D[c]
T15	3.2×10^4	1.7×10^4	9.3×10^3	10	N/D[c]
T15 Dup	3.0×10^4	1.7×10^4	9.3×10^3	5	N/D[c]
T30	2.6×10^4	1.7×10^4	1.2×10^4	20	N/D[c]
T60[a]	30	1.2×10^3	1.1×10^4	5	N/D[c]

[a]Data not considered for performance evaluation due to low influent concentration

[b]Not available, colonies were not visible due to turbid materials on the filter

[c]Not detected, no plaques were observed on any of the 10 plates for the sample

Table 3.21. Performance of R3f and NOK Filters

Test No.	Log Removal				
	R3f Lead Filter	R3f Lag Filter	NOK MF	NOK NF	Overall
1	0.2	0.7	3.8	-	CR (> 4.7)
2	0.3	1.4	3.0	-	CR (> 4.7)
3	0.3	0.3	2.9	1.0	CR (>4.5)

Table 3.22. System Pressure Buildup During the *B. subtilis* Challenge Tests at Ely, MN in September 2009

Time	Flow (gpm)	Pressure (psi)					Pressure (psi)					
		R3f Inlet	R3f Lead Filter	R3F Lag Filter	ΔP1	ΔP2	MF in	MF out	UF in	UF out	ΔP MF	ΔP UF
B. Subtilis Test 1												
13:58		92.8	45.0	42.0	47.8	3.0	36.0	36.0	32.0	14.0	0	18.0
14:01							28.0	28.0	26.0	11.0	0	15.0
14:04							24.0	22.0	22.0	10.0	2.0	12.0
14:07	2.1	95.7	30.0	28.0	65.7	2.0						
14:10							22.0	21.0	20.0	10.0	1.0	10.0
14:16							18.0	18.0	17.0	9.0	0	8.0
14:20							17.5	16.5	16.0	9.0	1.0	7.0
14:21	1.4	96.7	22.0	22.0	74.7	0						
14:25							16.0	15.5	14.5	9.0	0.5	5.5
14:28	1.2	97.1	19.0	19.0	78.1	0						
14:30							14.5	14.0	14.0	9.0	0.5	5.0
14:36							12.5	13.0	12.0	8.5	-0.5	3.5
14:37	1.0	97.6	17.5	18.0	80.1	-0.5						
14:43							12.0	12.0	11.0	8.5	0	2.5
B. Subtilis Test 2												
14:57	Backwash											
	3.4	87.7	80.0	78.0	7.7	2.0	72.0	72.0	69.0	43.0	0	26.0
15:15	2.4	91.8	55.0	53.0	36.8	2.0	47.0	47.0	45.0	26.0	0	19.0
17:45	Feed pump started											
17:46	3.2	39.0	32.0	28.0	7.0	4.0	23.0	23.0	21.0	14.0	0	7.0
17:51	3.1	40.8	32.0	28.0	8.8	4.0	24.0	23.0	22.0	14.0	1.0	8.0
17:57	3.0	44.3	33.0	30.0	11.3	3.0	24.0	24.0	22.0	14.0	0	8.0
18:02	2.9	46.0	33.0	30.0	13.0	3.0	24.5	24.0	23.0	14.0	0.5	9.0
18:09	2.8	48.1	34.0	31.0	14.1	3.0	25.0	24.5	23.0	14.0	0.5	9.0
18:17	2.8	50.8	34.0	31.0	16.8	3.0	26.0	26.0	24.0	14.0	0	10.0
18:25	2.8	52.8	34.0	31.5	18.8	2.5	26.0	26.0	24.0	14.0	0	10.0
18:38	2.6	56.5	34.0	32.0	22.5	2.0	27.0	26.0	25.0	14.5	1.0	10.5
18:52	2.5	58.0	36.0	33.0	22.0	3.0	28.0	28.0	26.0	13.0	0	13.0
B. Subtilis Test 3												
9:18	Backwash R3F											
9:30	NOK on-line											
9:37	3.1	66.0	58.0	55.0	8.0	3.0	50.0	50.0	47.0	16.0	0	31.0
9:45	Feed pump started											
9:48	3.1	68.9	58.0	55.0	10.9	3.0	50.0	50.0	47.0	15.0	0	32.0
9:57	2.9	71.2	58.0	56.0	13.2	2.0	51.0	50.0	48.0	14.5	1.0	33.5
10:05	2.9	72.6	58.0	56.0	14.6	2.0	51.0	50.0	48.0	14.0	1.0	34.0
10:15	2.6	74.5	58.0	56.0	16.5	2.0	51.5	50.0	48.0	14.0	1.5	34.0
10:23	2.7	75.6	58.0	56.0	17.6	2.0	51.0	50.5	48.5	14.0	0.5	34.5
10:33	2.6	76.9	58.0	56.0	18.9	2.0	51.0	50.0	48.5	14.0	1.0	34.5
10:42	2.4	77.8	58.0	56.0	19.8	2.0	51.0	50.0	48.5	13.5	1.0	35.5

3.5.2 MS2 bacteriophage Test Results

A single MS2 bacteriophage test was conducted on the R3f system followed by the NOK polishing filters at Ely, MN in September 2009 and the results are presented in Table 3-23. The R3f-NOK filtration system achieved almost complete removal of MS2 bacteriophage with a log removal value of approximately 3.7. As expected based on filtration capabilities, all the treatment was provided by the NOK UF system. Table 3-24 presents the pressure buildup in the system during this test.

Table 3.23. MS2 bacteriophage Analytical Results for R3f – NOK Filters at Ely, MN in September 2009

Sample ID	MS2 bacteriophage Concentration/100 mL					Overall Log Removal
	Influent	Out 1 (R3f Lead Filter)	Out 2 (R3f Lag Filter)	Out 3 (NOK MF)	Out 4 (NOK UF)	
Test 1						
T0[a]	2	3	9	N/D[d]	1	3.7
T5[a]	5.4×10^3	2.1×10^3	1.0×10^2	8	2	
T15	2.7×10^4	4.4×10^4	7.0×10^4	N/A[b]	9	
T15 Dup	7.3×10^4	7.9×10^4	6.9×10^4	N/A[b]	6	
T30	2.1×10^4	3.6×10^4	3.9×10^4	1.6×10^3	9	
T60[c]	-	-	-	-	-	

[a]Data not considered for performance evaluation due to low influent concentration; [b]Not available, sample was underdiluted; [c]Test stopped for backwashing of the R3f filter; [d] Not detected, no plaques were observed on any of the 10 plates for the sample

Table 3.24. System Pressure Buildup During the MS2 bacteriophage Challenge at Ely, MN in September 2009

Time	Flow (gpm)	R3f Pressure (psi)					NOK Pressure (psi)					
		R3F Inlet	R3F Lead Filter	R3F Lag Filter	ΔP1	ΔP2	MF in	MF out	UF in	UF out	ΔP MF	ΔP UF
19:12	3.3	62.8	52.0	49.0	10.8	3.0	43.0	43.0	41.0	21.0	0	20.0
19:15	Feed pump started											
19:20	3.2	64.2	52.0	45.0	12.2	7.0	41.0	41.0	38.0	15.0	0	23.0
19:27	3.1	66.5	50.0	45.0	16.5	5.0	40.0	40.0	38.0	15.0	0	23.0
19:33	3.0	68.4	50.0	45.0	18.4	5.0	40.0	40.0	38.0	14.5	0	23.5
19:41	2.9	70.6	48.0	44.0	22.6	4.0	40.0	40.0	38.0	14.0	0	24.0
19:51	2.8	73.2	48.0	44.0	25.2	4.0	40.0	39.0	38.0	14.0	1.0	24.0
20:05	2.6	76.0	47.0	44.0	29.0	3.0	40.0	38.5	37.5	14.0	1.5	23.5
End Test												
20:12	2.5	77.0	46.0	44.0	31.0	2.0	39.0	38.0	37.0	14.0	1.0	23.0

3.6 Raw Water and Backwash Samples

To confirm that there were negligible *B. subtilis* spores in the lake water, an untreated lake water sample was analyzed. The results of analysis on two lake water samples (Sample 1 – 0 cells/mL; Sample 2 – 0.2 cells/mL) confirmed that there was negligible *B. subtilis* in the lake water.

A sample was also collected from the GE Pentair System backflush water. The *B. subtilis* count in this sample could not be quantified because they were too many to count **(**TMTC).

3.7 Particle Count, Turbidity and Color Data from Ely, MN in August, 2008

Table 3-25 presents the removal of particles in the 2 micron (μm) and the 3 μm range, the same size range as that of *B. subtilis* and *Cryptosporidium*, for the two ITT Fyne Technology system membranes and the GE Pentair system. The influent water had an average particle count of about 3,450/mL for both size ranges. For this influent water, the GE Pentair system produced effluent with an average particle count of 75/mL over these two size ranges, or about a 98% removal. The ES404 membrane of the ITT Fyne Technology system produced effluent with an average particle count of 14/mL (99.6% removal). The CA2PF membrane of the ITT Fyne Technology system produced an effluent with an average particle count of 17/mL (99.5% removal).

Tests were not specifically conducted by EPA to evaluate the removal of turbidity and color by the two systems tested. However, the MDH collected this information on an ongoing basis for the two membranes comprising the ITT Fyne Technology system. This data is summarized in Table 3-26. The average influent turbidity was 2.18 NTU and the average effluent turbidity for

ES404 membrane was 0.17 NTU and that for the CA2PF membrane was 0.18 NTU. The average turbidity removal by the ES404 and CA2PF membranes was 91.8%. Color was spectrophotometrically measured in terms of the APHA color index. The color index of the influent water was 85.5 while the color index of the effluent from the ES404 membrane was 1.3 and that from the CA2PF membrane was 11.5 (for reference, the APHA color index for distilled water is 0). The average color removal by the ES404 membrane was 98.5% while the average color removal by the CA2PF membrane was 87.0%. The conductivity of the influent water was 57.1 milliSiemens per cm (mS/cm) while that for the effluent from the ES404 membrane was 44.7 mS/cm and 47.3 mS/cm from the CA2PF membrane

The turbidity and particle count data represented here were obtained using grab samples and bench top instruments. Readings at the low end of the range for the instruments are typically higher than results obtained from an in-line turbidity meter or particle counter.

Table 3.25. Particle Count Data for the GE Pentair System and the ITT Fyne Technology System at Ely, MN in August 2008

Date	Particle Counts/mL							
	Raw		GE-Pentair		ES404 Membrane		CA2PF Membrane	
	2µ	3µ	2µ	3µ	2µ	3µ	2µ	3µ
7/10/2008	3094	3650	N/A[a]	N/A[a]	N/A[a]	N/A[a]	N/A[a]	N/A[a]
7/11/2008	2879	3272	N/A[a]	N/A[a]	N/A[a]	N/A[a]	N/A[a]	N/A[a]
7/15/2008	3608	4783	289	519	N/A[a]	N/A[a]	N/A[a]	N/A[a]
7/16/2008	3587	4657	108	97	N/A[a]	N/A[a]	N./A[a]	N/A[a]
7/17/2008	3455	4558	75	76	N/A[a]	N/A[a]	N/A[a]	N/A[a]
7/18/2008	3391	4725	185	208	14	14	12	11
7/21/2008	2738	3396	32	34	83	81	32	40
7/22/2008	2744	3771	41	40	18	21	18	27
7/23/2008	2881	3563	36	35	29	36	61	52
7/24/2008	2476	3021	24	26	34	34	29	14
7/25/2008	2712	3378	37	37	14	15	30	22
7/28/2008	3484	4909	60	79	13	12	14	13
7/29/2008	2864	3632	34	45	7	5	15	15
7/30/2008	2871	3876	61	72	7	8	8	12
7/31/2008	2907	4332	85	106	8	9	7	7
8/1/2008	3570	4961	94	104	10	9	33	41
8/4/2008	2961	3441	106	112	12	11	29	20
8/5/2008	2723	3405	37	33	16	19	23	24
8/6/2008	2775	3964	66	56	16	15	17	16
8/7/2008	3381	4654	48	42	12	12	11	11
8/8/2008	3723	5067	88	85	7	6	8	7
8/11/2008	2195	2489	70	74	13	6	25	11
8/12/2008	2415	2988	126	115	6	5	7	7
8/13/2008	2481	3119	60	58	8	8	9	6
8/14/2008	2521	2785	38	35	8	7	8	7
8/15/2008	2492	3024	84	84	8	8	9	9
8/18/2008	2824	3564	64	81	4	3	8	6
8/19/2008	3018	3945	16	18	6	6	7	7
8/20/2008	3352	4421	21	20	5	4	11	10
8/21/2008	3228	4997	23	21	4	4	12	11
8/22/2008	3223	4321	16	17	7	5	13	13
Average (Std. Dev.)	**2986 (408)**	**3893 (738)**	**70 (57)**	**80 (94)**	**14 (16)**	**14 (16)**	**18 (12)**	**16 (12)**

[a]Not available, data was not collected

Table 3.26. Conductivity, Turbidity, and Color Data for the ITT Fyne Technology System at Ely, MN in August 2008

Influent Water						ES404 Membrane Effluent			CA2PF Membrane Effluent		
Date	**Temp**	**Cond[1]**	**Color[2]**	**pH**	**Turb[3]**	**Cond[1]**	**Color[2]**	**Turb[3]**	**Cond[1]**	**Color[2]**	**Turb[3]**
7/10/2008	21.0	58.0	89.0	7.64	1.85	N/A[a]	N/A[a]	0.12	N/A[a]	N/A[a]	0.12
7/11/2008	20.3	60.0	81.0	7.32	1.90	N/A[a]	N/A[a]	0.17	N/A[a]	N/A[a]	0.17
7/15/2008	24.1	59.0	88.0	7.3	2.11	N/A[a]	N/A[a]	0.17	N/A[a]	N/A[a]	0.17
7/16/2008	22.2	59.0	98.0	7.29	2.20	N/A[a]	N/A[a]	0.25	N/A[a]	N/A[a]	0.25
7/17/2008	23.3	65.0	71.0	7.41	2.09	N/A[a]	N/A[a]	0.26	N/A[a]	N/A[a]	0.26
7/18/2008	22.8	63.0	83.0	7.38	2.20	N/A[a]	N/A[a]	0.18	N/A[a]	N/A[a]	0.26
7/21/2008	21.5	58.0	78.0	7.35	1.99	N/A[a]	N/A[a]	0.20	N/A[a]	N/A[a]	0.25
7/22/2008	21.5	58.0	76.0	7.39	1.96	N/A[a]	N/A[a]	0.21	N/A[a]	N/A[a]	0.21
7/23/2008	22.0	57.0	73.0	6.93	1.92	N/A[a]	N/A[a]	0.23	N/A[a]	N/A[a]	0.24
7/24/2008	20.5	55.0	87.0	7.15	2.06	N/A[a]	0	0.19	N/A[a]	0	0.23
7/25/2008	22.8	55.0	87.0	7.13	2.02	N/A[a]	3.0	0.16	N/A[a]	12.0	0.16
7/28/2008	25.7	57.0	86.0	7.23	2.40	N/A[a]	0	0.12	N/A[a]	7.0	0.15
7/29/2008	25.0	56.0	81.0	7.15	1.96	N/A[a]	0	0.16	N/A[a]	2.0	0.18
7/30/2008	23.1	57.0	80.0	7.17	2.12	N/A[a]	0	0.18	N/A[a]	3.0	0.16
7/31/2008	22.1	57.0	82.0	7.16	2.17	N/A[a]	2.0	0.17	N/A	8.0	0.15
8/1/2008	23.5	57.0	91.0	7.17	2.12	N/A[a]	0	0.16	N/A[a]	3.0	0.16
8/4/2008	23.4	59.0	87.0	7.11	2.07	43.0	0	0.19	43.0	1.0	0.17
8/5/2008	22.6	59.0	92.0	7.14	2.08	41.0	0	0.17	41.0	2.0	0.16
8/6/2008	22.3	55.0	83.0	7.11	1.94	39.0	1.0	0.23	39.0	0	0.19
8/7/2008	22.1	57.0	81.0	7.17	2.29	44.0	0	0.17	44.0	3.0	0.17
8/8/2008	22.3	56.0	80.0	7.16	2.31	46.0	0	0.19	46.0	0	0.18
8/11/2008	21.6	56.0	74.0	7.62	1.63	44.0	0	0.15	44.0	7.0	0.21
8/12/2008	21.8	56.0	82.0	7.54	1.8	43.0	6.0	0.23	43.0	8.0	0.21
8/13/2008	22.8	57.0	83.0	7.41	1.91	49.0	0	0.21	49.0	4.0	0.22
8/14/2008	22.6	59.0	80.0	7.38	1.73	51.0	1.0	0.24	51.0	7.0	0.21
8/15/2008	23.3	55.0	84.0	7.63	2.11	48.0	0	0.20	48.0	8.0	0.18
8/18/2008	23.7	57.0	85.0	6.94	3.16	47.0	3.0	0.23	47.0	3.0	0.23
8/19/2008	22.6	58.0	72.0	7.78	2.31	54.0	12.0	0.21	54.0	33.0	0.20
8/20/2008	21.3	57.0	91.0	7.13	2.65	50.0	0	0.15	50.0	0	0.23
8/21/2008	24.7	56.0	86.0	7.79	2.77	41.0	0	0.13	41.0	1.0	0.20
8/22/2008	22.4	54.0	95.0	7.57	2.58	44.0	7.0	0.15	44.0	7.0	0.22
8/25/2008	22.0	57.0	84.0	7.4	2.82	41.0	0	0.24	41.0	2.0	0.23
8/26/2008	19.2	56.0	90.0	7.79	2.52	57.0	2.0	0.18	57.0	15.0	0.14
9/2/2008	21.5	55.0	105.0	7.28	2.59	46.0	-2.0	0.08	56.0	23.0	0.06
9/3/2008	N/A[a]	N/A[a]	N/A[a]	N/A[a]	N/A[a]	47.0	2.0	0.10	52.0	30.0	0.11
9/4/2008	19.3	56.0	82.0	7.37	2.05	45.0	-8.0	0.12	53.0	28.0	0.11
9/5/2008	19.4	65.0	N/A[a]	7.27	2.26	47.0	8.0	0.10	54.0	40.0	0.12
9/9/2008	20.0	49.0	100.0	N/A[a]	2.05	43.0	6.0	0.10	48.0	49.0	0.11
9/10/2008	17.8	53.0	101.0	7.91	2.26	42.0	3.0	0.09	50.0	48.0	0.11
9/11/2008	17.2	54.0	101.0	7.26	2.37	34.0	-1.0	0.20	44.0	9.0	0.14
Avg/Std Dev	**22.0/2.0**	**57.1/3.0**	**85.5/8.0**	**7.34/0.30**	**2.18/0.30**	**44.7/5.6**	**1.3/3.6**	**0.17/0.05**	**47.3/5.1**	**11.5/14.2**	**0.18/0.05**

[1]Conductivity, mS/cm; [2]Color measured in accordance with APHA color index; [3]Turbidity measured in NTU

[a]Not available, data was not collected

3.8 Particle Count, Turbidity and Color Removal Data from Ely, MN in September, 2009

Table 3-27 presents the turbidity, color and conductivity data for the ITT Fyne system. These data were collected by the MDH on an ongoing basis in 2009. For the ITT Fyne system, the average influent turbidity was 2.27 NTU. The average effluent turbidity from the ES404 membrane was 0.28 NTU (87.7% removal) and that from the AFC30 membrane was 0.25 NTU (89.0% removal). The color index of the influent water was 85.4 while the color index of the effluent from the ES404 membrane was 7.7 (91.0% removal) and that from the AFC30 membrane was 5.5 (93.6%). The conductivity of the influent water for the ITT Fyne system was 57.4 mS/cm while that for the effluent from the ES404 membrane was 52.2 mS/cm and 30.8 mS/cm from the AFC30 membrane.

Table 3-28 presents the turbidity, color and conductivity data for the Virex Pro system. The average influent turbidity for the Virex Pro system was 2.23 NTU and the average effluent turbidity was 0.29 NTU (87.0% removal). The color index of the influent water for the Virex Pro system was 83.4 while the color index of the effluent water was 38.0 (54.4%). The conductivity of the influent water for the Virex Pro system was 54.9 mS/cm while the conductivity for the effluent was 72.2 mS/cm.

Tables 3-29 and 3-30 present the conductivity, color and turbidity data for the R3f pre-filtration system and NOK MF polishing filter, respectively. The average influent turbidity for the R3f system was 1.88 NTU and the average effluent turbidity for the R3f lead filter was 0.84 NTU and that for the R3f lag filter was 0.73 NTU, showing an overall 61.1% removal percent removal of turbidity. The NOK MF filter was used as the polishing filter for the R3f system and the effluent turbidity achieved by the NOK filter was 0.10 NTU. The R3f and the NOK MF filters did not achieve any removal of color and conductivity.

Table 3.27. Conductivity, Turbidity, and Color Data for the ITT Fyne Technology System at Ely, MN in September 2009

Influent Water						ES404 Membrane Effluent			AFC30 Membrane Effluent		
Date	**Temp**	**Cond[1]**	**Color[2]**	**pH**	**Turb[3]**	**Cond[1]**	**Color[2]**	**Turb[3]**	**Cond[1]**	**Color[2]**	**Turb[3]**
7/31/2009	20.0	55.0	66.0	7.13	2.33	56.0	0	0.34	31.0	0	0.34
8/3/2009	21.1	53.0	79.0	7.06	2.49	40.0	7.5	0.40	36.0	5.5	0.62
8/4/2009	21.1	58.0	81.5	7.06	2.61	58.0	8.0	0.41	31.5	10.5	0.38
8/5/2009	20.0	57.0	79.0	7.11	2.33	52.5	8.5	0.47	31.0	11.0	0.41
8/6/2009	21.5	55.5	69.5	7.20	2.11	58.5	8.5	0.32	29.0	3.5	0.27
8/7/2009	20.6	53.0	72.5	7.20	2.36	51.5	0	0.28	31.0	6.5	0.30
8/8/2009	20.2	55.0	85.0	7.10	2.41	51.0	12.0	0.22	33.0	3.0	0.15
8/9/2009	19.9	54.0	81.0	7.00	2.22	57.0	4.0	0.34	31.0	0	0.20
8/10/2009	21.2	56.5	89.0	N/A[a]	1.94	53.5	7.0	0.23	30.5	4.5	0.23
8/11/2009	23.0	56.5	81.5	N/A[a]	1.58	58.0	8.5	0.34	31.5	10.0	0.22
8/12/2009	24.8	56.0	86.0	N/A[a]	1.79	55.0	18.0	0.22	32.5	16.5	0.23
8/13/2009	24.0	56.0	88.0	N/A[a]	2.09	54.5	15.0	0.34	30.0	21.0	0.35
8/14/2009	24.4	55.0	95.5	N/A[a]	2.30	51.0	25.0	0.46	28.5	14.5	0.38
8/15/2009	23.2	55.0	79.0	N/A[a]	2.50	59.0	13.0	0.60	30.0	7.0	0.29
8/16/2009	22.0	56.0	82.0	N/A[a]	2.01	55.0	19.0	0.44	33.0	13.0	0.20
8/17/2009	22.6	54.0	93.5	N/A[a]	2.83	52.5	16.5	0.51	30.5	11.5	0.42
8/18/2009	20.7	55.0	87.0	N/A[a]	2.88	42.5	5.0	0.38	29.0	9.0	0.35
8/19/2009	20.2	56.0	84.5	N/A[a]	2.53	54.5	7.5	0.25	32.5	10.0	0.38
8/20/2009	19.9	59.0	72.0	7.11	2.69	55.5	3.0	0.30	32.5	0	0.26
8/21/2009	19.7	53.5	99.0	7.26	3.45	46.0	8.5	0.34	26.5	0	0.29
8/24/2009	21.7	56.0	80.5	7.21	2.98	51.5	6.5	0.33	31.0	1.5	0.26
8/25/2009	21.2	55.0	91.5	7.22	3.80	51.5	16.5	0.22	29.5	9.5	0.29
8/26/2009	21.3	55.5	98.5	7.25	4.00	53.0	12.0	0.28	34.0	5.5	0.27
8/27/2009	21.3	55.5	75.5	7.27	2.37	52.0	2.5	0.31	30.5	6.0	0.27
9/2/2009	20.2	54.0	90.0	7.61	2.01	52.0	1.0	0.11	29.0	1.0	0.11
9/3/2009	21.7	54.0	92.0	7.42	1.95	44.5	3.0	0.18	26.5	0	0.10
9/4/2009	20.4	56.0	81.0	7.17	1.76	47.0	2.0	0.10	31.0	1.0	0.09
9/7/2009	23.8	54.0	82.0	7.28	1.20	53.0	3.0	0.09	30.0	0	0.09
9/8/2009	21.8	55.5	81.0	7.23	1.39	53.0	5.0	0.09	33.0	1.0	0.09
9/9/2009	20.6	57.0	89.0	7.20	2.29	57.0	3.0	0.10	32.0	0	0.09
9/15/2009	21.6	60.0	67.0	7.16	1.17	49.0	4.0	0.13	33.0	0	0.12
9/16/2009	20.7	60.0	72.0	7.37	1.17	54.0	1.0	0.09	32.0	0	0.08
9/17/2009	21.2	56.0	78.0	7.49	1.44	42.0	0	0.07	25.0	0	0.06
Average (Std Dev.)	**22.0 (1.4)**	**57.4 (1.8)**	**85.4 (8.5)**	**7.22 (0.14)**	**2.27 (0.70)**	**52.2 (4.8)**	**7.7 (6.3)**	**0.28 (0.14)**	**30.8 (2.2)**	**5.5 (5.7)**	**0.25 (0.13)**

[1]Conductivity, mS/cm; [2]Color measured in accordance with APHA color index; [3]Turbidity measured in NTU

[a]Not available, data was not collected

Table 3.28. Conductivity, Turbidity, and Color Data for the Virex Pro System at Ely, MN in September 2009

Influent Water						Virex Pro Membrane Effluent		
Date	**Temp**	**Cond[1]**	**Color[2]**	**pH**	**Turb[3]**	**Cond[1]**	**Color[2]**	**Turb[3]**
8/3/2009	21.1	53.0	79.0	7.06	2.49	83.0	25.0	0.38
8/4/2009	21.1	58.0	81.5	7.06	2.61	91.5	32.0	0.40
8/5/2009	20.0	57.0	79.0	7.11	2.33	89.0	33.0	0.35
8/6/2009	21.5	55.5	69.5	7.20	2.11	55.5	22.0	0.28
8/7/2009	20.6	53.0	72.5	7.20	2.36	57.0	52.0	0.28
8/10/2009	21.2	56.5	89.0	N/A[a]	1.94	56.0	22.0	0.26
8/11/2009	23.0	56.5	81.5	N/A[a]	1.58	62.0	30.0	0.34
8/12/2009	24.8	56.0	86.0	N/A[a]	1.79	55.0	4.0	0.19
8/13/2009	24.0	56.0	88.0	N/A[a]	2.09	84.0	61.0	0.72
8/14/2009	24.4	55.0	95.5	N/A[a]	2.30	87.0	38.5	0.44
8/15/2009	23.2	55.0	79.0	N/A[a]	2.50	85.0	45.0	0.44
8/16/2009	22.0	56.0	82.0	N/A[a]	2.01	81.0	55.0	0.52
8/17/2009	22.6	54.0	93.5	N/A[a]	2.83	69.0	43.5	0.44
8/18/2009	20.7	55.0	87.0	N/A[a]	2.88	77.5	46.5	0.63
8/19/2009	20.2	56.0	84.5	N/A[a]	2.53	58.0	46.5	0.43
8/20/2009	19.9	59.0	72.0	7.11	2.69	58.0	34.5	0.36
8/21/2009	19.7	53.5	99.0	7.26	3.45	50.5	59.0	0.22
8/24/2009	21.7	56.0	80.5	7.21	2.98	68.0	62.5	0.37
8/25/2009	21.2	55.0	91.5	7.22	3.80	81.0	44.5	0.42
8/26/2009	21.3	55.5	98.5	7.25	4.00	80.0	32.5	0.43
8/27/2009	21.3	55.5	75.5	7.27	2.37	69.5	42.0	0.35
9/2/2009	20.2	54.0	90.0	7.61	2.01	71.0	36.0	0.12
9/3/2009	21.7	54.0	92.0	7.42	1.95	80.5	29.5	0.13
9/4/2009	20.4	56.0	81.0	7.17	1.76	84.0	33.0	0.12
9/7/2009	23.8	54.0	82.0	7.28	1.20	75.0	34.0	0.12
9/8/2009	21.8	55.5	81.0	7.23	1.39	74.5	35.0	0.12
9/9/2009	20.6	57.0	89.0	7.20	2.29	76.0	32.0	0.12
9/15/2009	21.6	60.0	67.0	7.16	1.17	62.0	51.0	0.12
9/16/2009	20.7	60.0	72.0	7.37	1.17	60.0	48.0	0.09
9/17/2009	21.2	56.0	78.0	7.49	1.44	56.0	53.0	0.10
9/18/2009	20.7	58.0	88.0	7.43	1.34	79.0	40.0	0.09
9/22/2009	21.6	58.0	83.0	7.21	1.49	58.0	59.0	0.13
9/23/2009	21.1	60.0	81.0	7.46	1.82	83.5	24.0	0.13
9/24/2009	20.2	59.0	77.0	7.24	1.66	84.0	27.0	0.19
9/28/2009	16.7	60.0	93.0	7.07	2.86	83.0	32.0	0.09
9/29/2009	16.1	60.0	96.0	7.03	2.69	82.0	40.0	0.08
9/30/2009	16.2	60.0	87.0	7.14	2.44	80.0	30.0	0.06
Average (Std. Dev.)	**21.7 (1.9)**	**54.9 (2.2)**	**83.4 (8.1)**	**7.24 (0.14)**	**2.23 (0.70)**	**72.2 (12.0)**	**38.0 (12.8)**	**0.29 (0.17)**

[1]Conductivity, mS/cm; [2]Color measured in accordance with APHA color index; [3]Turbidity measured in NTU

[a]Not available, data was not collected

Table 3.29. Conductivity, Turbidity, and Color Data for the R3f System at Ely, MN in September 2009

Influent Water						Lead R3f Filter			Lag R3f Filter		
Date	**Temp**	**Cond[1]**	**Color[2]**	**pH**	**Turb[3]**	**Cond[1]**	**Color[2]**	**Turb[3]**	**Cond[1]**	**Color[2]**	**Turb[3]**
9/16/2009	20.7	60.0	72.0	7.37	1.17	61.0	60.0	0.70	62.0	64.0	0.79
9/17/2009	21.2	56.0	78.0	7.49	1.44	57.0	66.0	0.65	56.0	65.0	0.57
9/18/2009	20.7	58.0	88.0	7.43	1.34	57.0	74.0	0.60	57.0	71.0	0.51
9/22/2009	21.6	58.0	83.0	7.21	1.49	58.0	69.0	0.69	58.0	63.0	0.61
9/23/2009	21.1	60.0	81.0	7.46	1.82	59.0	69.0	0.84	59.0	64.5	1.00
9/24/2009	20.2	59.0	77.0	7.24	1.66	59.0	66.0	0.92	59.0	59.0	0.68
9/28/2009	16.7	60.0	93.0	7.07	2.86	60.0	67.0	1.06	60.0	64.0	0.85
9/29/2009	16.1	60.0	96.0	7.03	2.69	60.0	71.0	1.06	60.0	67.0	0.82
9/30/2009	16.2	60.0	87.0	7.14	2.44	60.0	67.0	1.06	61.0	63.0	0.76
Average (Std. Dev.)	**19.4 (2.3)**	**59.0 (1.4)**	**83.9 (7.8)**	**7.27 (0.17)**	**1.88 (0.60)**	**59.0 (1.4)**	**67.7 (3.9)**	**0.84 (0.20)**	**59.0 (1.9)**	**64.5 (3.3)**	**0.73 (0.15)**

[1]Conductivity, mS/cm; [2]Color measured in accordance with APHA color index; [3]Turbidity measured in NTU

Table 3.30. Conductivity, Turbidity, and Color Data for the NOK MF System at Ely, MN in September, 2009

Influent Water (Effluent from R3f Lag Filter)				NOK MF Effluent		
Date	**Cond[1]**	**Color[2]**	**Turb[3]**	**Cond[1]**	**Color[2]**	**Turb[3]**
9/18/2009	57.0	71.0	0.51	57.0	61.0	0.07
9/22/2009	58.0	63.0	0.61	58.0	55.0	0.16
9/23/2009	59.0	64.5	1.00	58.0	54.0	0.11
9/24/2009	59.0	59.0	0.68	61.0	68.0	0.14
9/28/2009	60.0	64.0	0.85	60.0	51.0	0.08
9/29/2009	60.0	67.0	0.82	60.0	55.0	0.07
9/30/2009	61.0	63.0	0.76	61.0	48.0	0.07
Average (Std. Dev.)	**59.1 (1.3)**	**64.5 (3.7)**	**0.75 (0.16)**	**59.3 (1.6)**	**56.0 (6.6)**	**0.10 (0.04)**

[1]Conductivity, mS/cm; [2]Color measured in accordance with APHA color index; [3]Turbidity measured in NTU

4.0 Conclusions

The field tests on the 3-foot ITT Fyne Technology System performed in Ely, MN showed the system to be capable of achieving a *B. subtilis* removal rate ranging from 4.3 log to complete removal (> 6.9 log). The ES404 membrane with a MWCO of 4000 Daltons showed a very similar performance to the significantly tighter CA2PF membrane (MWCO of 2000 Daltons) and the AFC30 membrane (1000 Dalton). Tests conducted at the T&E Facility on the ES404 membrane, the CA2PF membrane and the AFC30 membrane in the 3-foot ITT Fyne Technology System showed that all membranes have a similar performance with almost complete removal (> 6.0 log) of the *B. subtilis*. This indicates that the ES404 membrane is sufficient for treating bacteria down to the size of *B. subtilis*. The 12-foot ITT Fyne Technology System with the CA2PF membrane showed a slightly lower removal (approximately 4.7 log) than the corresponding 3-foot module.

When tested with MS2 bacteriophage in Ely, MN, the 3-foot ITT Fyne Technology System showed a 4.1 log to complete removal (> 5.3 log) for the ES404 membrane and a 4.2 log removal for the AFC30 membrane.

The ITT Fyne Technology System demonstrated good removal of color in tests conducted at the T&E Facility. The 3-foot ES404 membrane achieved approximately 97% color removal in both recycle and dead-end modes. The 3-foot CA2PF membrane achieved approximately 98% and approximately 96% of color removal in recycle and dead-end mode, respectively. The 12-foot CA2PF membrane achieved approximately 96% and approximately 93% of color removal in the recycle and dead-end modes, respectively. The 3-foot AFC30 membrane achieved approximately 99% of color removal in both recycle and dead-end modes, respectively.

The GE Pentair system showed an approximately 5.0 log removal and the Virex Pro system demonstrated complete removal (> 4.7 log) of *B. subtilis* during the tests conducted at field location. When tested with MS2 bacteriophage, the Virex Pro system demonstrated complete removal (> 4.7 log) at field location. The Virex Pro system demonstrated good removal of turbidity (approximately 87%) and moderate removal (approximately 54%) of color.

The ITT Fyne Technology System demonstrated good removal of *E. coli* in tests conducted at the T&E Facility. The 12-foot CA2PF membrane achieved complete removal (> 7.4 log) of *E. coli*. The 3-foot ES404 membrane and the CA2PF membrane achieved log removal values of approximately 4.0 in removing *E. coli* with both membranes showing almost complete removal of *E. coli*.

The results of PSL beads tests conducted on the 12-foot ITT Fyne Technology System with the CA2PF membrane at the T&E Facility showed relatively lower log removal (2.5 log) of the surrogate for *Cryptosporidium*. The inferior performance was probably attributed to the surface characteristics of the membrane as well as the solution properties, such as pH and ionic strength.

The ITT Fyne Technology System demonstrated good removal of TOC in tests conducted at the T&E Facility. The 3-foot ES404 membrane achieved approximately 89% and approximately 93% of TOC removal in recycle and dead-end mode, respectively. The 3-foot CA2PF achieved approximately 67% and approximately 86% of TOC removal in recycle and dead-end mode, respectively. The 12-foot CA2PF membrane achieved approximately 83% and approximately 80% of TOC removal in recycle and dead-end mode, respectively. The 3-foot AFC30 membrane achieved approximately 92% and approximately 95% of TOC removal in recycle and dead-end mode, respectively.

The ES404 and the CA2PF membranes showed nearly identical performance in turbidity removal during data collected in 2008, producing water with an average effluent turbidity of 0.17 NTU when treating lake water with an average influent turbidity of 2.18 NTU (a 92% removal of turbidity). However, the ES404 membrane showed noticeably better performance in color removal by producing water with an average effluent color of 1.3 APHA color index compared to the CA2PF membrane which produced water with an average effluent color of 11.5 APHA. Finally, the ES404 and CA2PF membranes both showed an approximately 99.5% removal efficiency for particles in the 2 μm and 3 μm size ranges (the size range for *B. subtilis* and *Cryptosporidium*).

The turbidity removals achieved by the ES404 and AFC30 membranes in treating lake water in 2009 were approximately 88% and approximately 89%, respectively. The color removals achieved by the ES404 and AFC30 membranes in treating lake water in 2009 were approximately 91% and approximately 94%, respectively.

The R3f-NOK filtration system achieved complete removal of *B. subtilis* with a calculated log removal value of approximately > 4.6 based on the influent concentration of *B. subtilis*. The R3f had a l.0 log removal while the NOK MF showed an approximately 3.0 log removal. Thus, there was negligible influent *B. subtilis* concentration for the final NOK UF. The R3f-NOK filtration system achieved almost complete removal of MS2 bacteriophage with a log removal value of approximately 3.7. The overall turbidity removal achieved by the R3f system in treating lake water with 1.88 NTU turbidity was 61%. As expected, most of the removal was achieved by the lead filter. The NOK MF membrane incorporated as a polishing unit produced effluent with 0.10 NTU turbidity. The R3f –NOK system did not achieve any removal of color.

5.0 References

EPA and Shaw (2007). "Quality Assurance Project Plan for Glass Bead R3f and Multimedia Systems", EPA QA ID: 627-Q-10-0, EPA T&E Facility, Cincinnati, Ohio.

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EPA and Shaw (2009). "Quality Assurance Project Plan for Membrane-based Small System Technologies for the Treatment of Bacteria and Reduction of Color in Surface Waters", EPA QA ID: 627-Q-11-0, EPA T&E Facility, Cincinnati, Ohio.