September 2004
NSF 04/01/EPADWCTR

Environmental Technology Verification Report

Physical Removal of Microbiological and Particulate Contaminants in Drinking Water

Separmatic™ Fluid Systems Diatomaceous Earth Pressure Type Filter System Model 12P-2

Prepared by

NSF International

Under a Cooperative Agreement with
U.S. Environmental Protection Agency

ETV ETV ETV

THE ENVIRONMENTAL TECHNOLOGY VERIFICATION PROGRAM

U.S. Environmental Protection Agency

NSF International

ETV Joint Verification Statement

TECHNOLOGY TYPE:	**DIATOMACEOUS EARTH PRESSURE TYPE FILTER USED IN DRINKING WATER TREATMENT SYSTEMS**		
APPLICATION:	**PHYSICAL REMOVAL OF MICROBIOLOGICAL AND PARTICULATE CONTAMINANTS IN DRINKING WATER**		
TECHNOLOGY NAME:	**SEPARMATIC™ DIATOMACEOUS EARTH PRESSURE TYPE FILTER SYSTEM MODEL 12P-2**		
COMPANY:	**SEPARMATIC™ FLUID SYSTEMS**		
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The U.S. Environmental Protection Agency (EPA) supports the Environmental Technology Verification (ETV) Program to facilitate the deployment of innovative or improved environmental technologies through performance verification and dissemination of information. The goal of the ETV Program is to further environmental protection by accelerating the acceptance and use of improved and more cost-effective technologies. ETV seeks to achieve this goal by providing high-quality, peer-reviewed data on technology performance to those involved in the design, distribution, permitting, purchase, and use of environmental technologies.

ETV works in partnership with recognized standards and testing organizations, stakeholder groups (consisting of buyers, vendor organizations, and permitters), and with the full participation of individual technology developers. The program evaluates the performance of innovative technologies by developing test plans that are responsive to the needs of stakeholders, conducting field or laboratory tests (as appropriate), collecting and analyzing data, and preparing peer-reviewed reports. All evaluations are conducted in accordance with rigorous quality assurance protocols to ensure that data of known and adequate quality are generated and that the results are defensible.

NSF International (NSF) in cooperation with the EPA operates the Drinking Water Systems (DWS) Center, one of seven technology areas under the ETV Program. The DWS Center evaluated the performance of a diatomaceous earth (DE) pressure type filter system for the reduction of microbiological and particulate contaminants in drinking water. This verification statement provides a summary of the test results for the Separmatic™ Fluid Systems DE Pressure Type Filter System Model 12P-2. The verification report contains a comprehensive description of the test. The University of New Hampshire (UNH), an NSF-qualified field testing organization (FTO), performed the verification testing.

ABSTRACT

The verification test of the Separmatic™ DE Pressure Type Filter System Model 12P-2 was conducted at the UNH Water Treatment Technology Assistance Center (WTTAC) in Durham, New Hampshire. Testing occurred between March 10 and May 28, 2003. The source water was finished water from the Arthur Rollins Treatment Plant that was pretreated with a 15 micron (µm) string pre-filter and stored in tanks prior to use as feed water to the system. This water source represented the high-quality water that DE systems are designed to treat. The system was operated with a 0.2 pounds per square foot (lb/ft^2) precoat of Hyflo Super Cel DE and a body feed of 2 milligrams per liter (mg/L) of Celite® 503 DE during the verification test. The system was operated for approximately 360 hours over 22 filter runs. The filter runs averaged approximately 16 hours in duration. The average flow rate ranged from 1.54 to 1.78 gallons per minute (gpm). Initial differential pressure averaged 7.9 pounds per square inch (psi), while ending differential pressure averaged 24.7 psi. The average feed water cumulative (2 to >15 µm) particle counts during the verification test were 47 counts per milliliter (mL), and the average effluent cumulative particle counts were 8 counts per mL. The average feed water online turbidity reading was 0.20 nephelometric turbidity units (NTU), and the average effluent turbidity reading was 0.13 NTU. During three of the filter runs, an initial *Cryptosporidium* oocyst challenge was performed during the first 1.5 hours of operation, and a second challenge was performed at 85% of terminal headloss (approximately 21 psi) during the filter run. The results of the six *Cryptosporidium* oocyst challenges indicated oocyst log_{10} removals ranging from 3.1 to 5.2 with an average of 4.2.

TECHNOLOGY DESCRIPTION

The following technology description was provided by the manufacturer, and has not been verified.

The equipment tested in this ETV test was the Separmatic™ DE Pressure Type Filter System Model 12P-2, serial number EXP-5. The system is a small, portable DE pressure filter unit specifically targeted for applications requiring a relatively small flow rate, such as a common supply for a small number of residences, a campground, or a small commercial operation. The system's maximum operating pressure is rated at 100 psi, but typical maximum differential pressures are 20 to 30 psi. The system is rated by the manufacturer to have 2 ft^2 of effective filter area. The system is designed to filter up to 1 gallon per minute per foot square (gpm/ft^2) or 2 gpm. Power requirements for the system are 115 volts, at 19.4 amps under full load.

The system has two tubular, plastic filter elements, each approximately 3.75 inches in diameter and 12 inches long, that are housed in a steel pressure vessel. A nylon septa in a tight weave covers the plastic filter elements. The pressure vessel has four glass portals through which the septa may be visually inspected during operation. The raw water feed connection to the system is a valved 1.25-inch PVC pipe leading to the recirculation pump. The recirculation pump is a Sta-Rite Model PLBC-178L, with a 3/8-inch PVC discharge line. The pump is powered by a 0.5 horsepower (HP) single-phase motor, operating at 3450 revolutions per minute (rpm). The full service load rating of the motor is 13.4 amps for 115 volts or 6.7 amps for 230 volts.

The system's precoat mixing vessel is an open-ended steel cauldron 18-inches in diameter and 18 inches deep. The precoat slurry is mixed by an electric mixer mounted on the precoat tank. The precoat tank is connected to the recirculation pump, and finally to the filter vessel by means of 1.25-inch diameter PVC pipes. The body feed for the system was pumped from a 100 gallon body feed tank with an outlet and mixer supplied by Separmatic™. The body feed was mixed with a Dayton 1/3 HP mixer rated at 276 rpm and pumped using a Masterflex Pump Model 7520-10 with an Easy Load II head.

The system is equipped with a drain box to catch the spent DE filter cake. The box is 14 inches square by 10 inches deep, and is designed to hold a filter bag, which will retain the spent filter cake while the flushing water is drained off.

The components of the system, except for the body feed tank, are bolted or welded onto a steel angle-iron frame. The frame is outfitted with industrial-grade casters, making the unit portable. The overall footprint of the system, except for the body feed tank, is 36 inches by 66 inches. The construction is rugged, and the unit has an estimated weight of 500 pounds (lbs). The system can be loaded into a standard pick-up truck for transport.

The DE used as precoat during the verification test was Hyflo Super Cel DE. According to the technical data sheet provided by the DE manufacturer, Hyflo Super Cel DE is a flux-calcined filter aid made from plankton marine diatomite and has a median cake pore size of 7.0 µm, pH of 10, dry density of 10 pounds per feet cubed (lbs/ft^3), and is in powder form. Celite® 503 DE was used as the body feed during the test. According to the technical data sheet provided by the DE manufacturer, Celite® 503 DE is a flux-calcined filter aid made from plankton marine diatomite and has a median cake pore size of 10.0 µm , pH of 10, dry density of 12 lbs/ft^3, and is in powder form.

VERIFICATION TESTING DESCRIPTION

Test Site

The verification test site was the UNH WTTAC high bay, room 147 of Gregg Hall located at 35 Colovos Road in Durham, New Hampshire. The source water for the verification test was finished water from the Arthur Rollins Treatment Plant, which serves both the Town of Durham and the University of New Hampshire. The treatment plant obtains its water from a reservoir on the Oyster River. The source water was pretreated with a 15 µm string pre-filter as it entered the UNH WTTAC high bay and prior to collection in the feed and challenge tanks used during verification test. The pre-filter was used to assist in the provision of consistent water for treatment.

Methods and Procedures

Onsite bench-top analyses of temperature, pH, turbidity, and dissolved oxygen (DO) were conducted daily for the feed and effluent water according to *Standard Methods for the Examination of Water and* Wastewater.[1] Weekly analyses for total organic carbon (TOC) and ultraviolet light absorbance at 254 nanometers (UV_{254}) were performed by the UNH WTTAC Laboratory. Analyses for iron and manganese were performed by Analytics Environmental Laboratory, LLC. Laboratory analyses for TOC, UV_{254}, iron, and manganese were also performed according to *Standard Methods* [1]. Online particle counters and turbidimeters continuously monitored both the feed water and effluent water, and these data were recorded every five minutes. Particle counters were configured to enumerate particle counts in the following size ranges: total (>2 µm), 2-3 µm, 3-5 µm, 5-7 µm, 7-10 µm, 10-15 µm, and >15 µm. Six *Cryptosporidium* oocyst challenges and one control challenge were performed during the ETV test. The *Cryptosporidium* oocyst analyses were performed by CH Diagnostic and Consulting Service, Inc. of Loveland, Colorado using EPA Method 1623.

Complete descriptions of the verification test results and quality assurance/quality control (QA/QC) procedures are included in the verification report.

[1] APHA, AWWA, and WEF. *Standard Methods for the Examination of Water and Wastewater*, 20th edition. Washington, DC, 1999.

VERIFICATION OF PERFORMANCE

System Operation

Initial test runs were performed during February 2003 to determine the optimum precoat and body feed rates to be used during the verification test. It was determined during the initial test runs that the system would be operated with a 0.2 lb/ft^2 precoat of Hyflo Super Cel DE and a body feed of 2 mg/L of Celite® 503 DE during the verification test.

The verification test of the pressure DE system was initiated on March 10, 2003, and the system was operated continuously through March 28, 2003. The system was operated again prior to and during the *Cryptosporidium* oocyst challenge testing in May 2003. The system was operated for 22 filter runs totaling 359.9 hours, which exceeded the ETV requirement for 272 hours of verification testing. The filter runs averaged 16.4 hours, with the longest duration filter run at 25.4 hours and the shortest duration filter run at 10.4 hours. Initial differential pressure averaged 7.9 psi while ending differential pressure averaged 24.7 psi. The average flow rate ranged from 1.54 to 1.78 gpm. Over the approximately 360 hours of operation, the unit produced a total of 35,531 gallons of treated water.

Water Quality Results

The feed and effluent water were analyzed daily on site for DO, pH, and temperature. Similar concentrations for DO and pH were consistently recorded for the feed and effluent. The feed water averaged 6.1 mg/L O_2 for DO and the median pH was 8.61 pH units. The effluent water averaged 6.2 mg/L O_2 for DO and the median pH was 8.67 pH units. The temperature of the feed water was consistently lower than the effluent, with average values of 10.4 and 11.6 ^oC, respectively.

The feed and effluent water were periodically tested for total iron, total manganese, TOC, and UV_{254}, and no appreciable differences were detected between the feed and effluent water sample results. The feed water averaged <0.06 mg/L for total iron, <0.05 mg/L for total manganese, 2.47 mg/L for TOC, and 0.039 absorbance units per cm for UV_{254}. The effluent water averaged <0.06 mg/L for total iron, <0.05 mg/L for total manganese, 2.45 mg/L for TOC, and 0.039 absorbance units per cm for UV_{254}.

Particle count and turbidity readings were recorded by online Supervisory Control and Data Acquisition (SCADA) instrumentation every five minutes during the 22 filter runs. At the start of filter runs, effluent particle count and turbidity data often showed elevated particle counts and turbidities relative to the feed water values. After 5 to 10 minutes these elevated readings would quickly decrease to consistently lower readings. The elevated initial readings could be the result of inactivity in the effluent lines or residual particles from the precoat process, or they could be a by-product of the transition from recirculation during precoating to feed water flow through the system or the fine tuning of flow through the particle counters. Separmatic™ recommends that the initial effluent water either be wasted or re-circulated to the feed to maximize effluent water quality. Therefore, the particle count and turbidity SCADA data from the initial 5 to 10 minutes of filter runs were not included in the operational performance evaluation or water production runtime.

The average feed water cumulative (2 to >15 µm) particle counts during the test period were 47 counts per mL, and the average effluent cumulative particle counts were 8 counts per mL. The particle count data showed an 83% removal for cumulative particles. The average feed water online turbidity reading was 0.20 NTU, and the average effluent reading was 0.13 NTU.

Microbial Challenge Results

A *Cryptosporidium* control challenge was performed on March 24, 2003. The control challenge without precoat or body feed indicated 6.2 log_{10} of *Cryptosporidium* oocysts in both the feed and the effluent, demonstrating that oocysts were not removed by the system hardware, plastic filter elements, or septa.

Three sets of two *Cryptosporidium* challenge tests occurred on May 14, May 19-20, and May 28 of 2003. In each, an initial challenge was performed during the first 1.5 hours of operation and a second challenge was performed at the 85% mark of the filter run, commencing when a pressure differential of approximately 21 psi was reached. The removal of oocysts averaged 4.2 ± 0.9 log_{10} for the six challenges with log_{10} removals ranging from 3.1 to 5.2. The data for the three sets of challenges show the 1.5 hour challenges averaged 4.4 ± 0.9 log_{10} removals and the 85% challenges averaged log removals of 3.9 ± 0.9 log_{10}. The results indicate that the removal of *Cryptosporidium* oocysts was not substantially affected by whether the challenge was conducted at the beginning or the end of a filter run. A summary of the *Cryptosporidium* challenge data is provided in Table VS-1.

Table VS-1. *Cryptosporidium* Oocyst Challenge Test Sample Results

Set No.	Date	Time Description	Average Feed Oocysts (#/20L)	Average Effluent Oocysts (#/20L)	Log_{10} Removal Oocysts
1	5/14/03	1.5 hours	2.2 x 10^6	891	3.4
1	5/14/03	85% Headloss	1.5 x 10^6	1270	3.1
2	5/19/03	1.5 hours	1.6 x 10^6	38	4.6
2	5/20/03	85% Headloss	2.0 x 10^6	32	4.8
3	5/28/03	1.5 hours	2.8 x 10^6	19	5.2
3	5/28/03	85% Headloss	2.0 x 10^6	381	3.7

Operation and Maintenance Results

The operation of the system, which included preparing precoat and body feed, monitoring operations, collecting readings, and performing analyses, averaged approximately four hours per day during normal operational runs, not including the time spent performing the *Cryptosporidium* challenges.

During shakedown testing before the start of verification test, modifications were made in the operating procedures following a Separmatic™ representative's visit to the test site in February 2003. The representative brought and installed two new filter elements. The precoating procedure was modified to take place in two steps, with an initial period of precoat flow of 1.5 times target flow followed by a shorter period of target flow to allow the precoat to settle into its intended structure on the DE filter elements. The representative had a pressure differential safety switch sent to UNH for installation, which shut off the system when the pressure differential reached a maximum level. The representative also had a 2.0 gallons per minute flow controller sent to UNH to replace the needle valve shipped with the system.

Separmatic™ provided an operation and maintenance manual (O&M) for the system. The manual included four chapters covering assembly of the system, instructions for pressure filter start-up, precoat filtration, and filtration and backwash procedures. The manual also provided a schematic drawing of the system, a parts list, and equipment O&M manuals for the components of the system. The operating instructions were simple and easy to follow. The O&M manual did not include directions for body feed or the replacement of the septa or the filter bags, which Separmatic™ may wish to perform as a company policy. Separmatic™ provided verbal instructions for these items. UNH requested written body feed instructions from Separmatic™. These were provided and are included in the verification report.

Consumables and Waste Generation

A total of 9.49 lbs of DE was used for precoat and body feed during the 22 filter runs. The unit consumed 9.5 kilowatt-hour (kW-hr) of energy per 1000 gallons of treated water produced.

For the ETV test, the spent DE in the drain box was transferred to a barrel container and allowed to settle. Liquid from the container was decanted and discharged to the Durham sewer system. The spent DE remaining in the container was disposed in an approved landfill.

Quality Assurance/Quality Control

NSF provided technical and quality assurance oversight of the verification test as described in this verification report, including an audit of nearly 100% of the data. NSF personnel also conducted a technical systems audit during testing to ensure the testing was in compliance with the test plan. A complete description of the QA/QC procedures is provided in the verification report.

Original Signed by		*Original Signed by*	
Lawrence W. Reiter	*9/20/04*	*Gordon Bellen*	*9/23/04*
Lawrence W. Reiter	Date	Gordon Bellen	Date
Acting Director		Vice President	
National Risk Management Research Laboratory		Research	
Office of Research and Development		NSF International	
United States Environmental Protection Agency			

Availability of Supporting Documents

Copies of the *ETV Protocol for Equipment Verification Testing for Physical Removal of Microbiological and Particulate Contaminants*, dated April 20, 1998 and revised May 14, 1999, the verification statement, and the verification report (NSF Report #04/01/EPADWCTR) are available from the following sources:
(NOTE: Appendices are not included in the verification report. Appendices are available from NSF upon request.)

1. ETV Drinking Water Systems Center Manager (order hard copy)
   NSF International
   P.O. Box 130140
   Ann Arbor, Michigan 48113-0140
2. NSF web site: http://www.nsf.org/etv (electronic copy)
3. EPA web site: http://www.epa.gov/etv (electronic copy)

September 2004

Environmental Technology Verification Report

Physical Removal of Microbiological and Particulate Contaminants in Drinking Water

Separmatic ™ Fluid Systems
Diatomaceous Earth Pressure Type Filter System, Model 12P-2

Prepared for:

NSF International
Ann Arbor, Michigan 48105

Prepared by:

The University of New Hampshire
Water Treatment Technology Assistance Center
Durham, New Hampshire 03824

Under a cooperative agreement with the U.S. Environmental Protection Agency

Jeffrey Q. Adams, Project Officer
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Notice

The U.S. Environmental Protection Agency (EPA) through its Office of Research and Development has financially supported and collaborated with NSF International (NSF) under Cooperative Agreement No. R-82833301. This verification effort was supported by the Drinking Water Systems (DWS) Center, operating under the Environmental Technology Verification (ETV) Program. This document has been peer reviewed, reviewed by NSF and EPA, and recommended for public release.

Foreword

The U.S. Environmental Protection Agency (EPA) is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, EPA's research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

The National Risk Management Research Laboratory (NRMRL) is the Agency's center for investigation of technological and management approaches for preventing and reducing risks from pollution that threaten human health and the environment. The focus of the Laboratory's research program is on methods and their cost-effectiveness for prevention and control of pollution to air, land, water, and subsurface resources; protection of water quality in public water systems; remediation of contaminated sites, sediments and ground water; prevention and control of indoor air pollution; and restoration of ecosystems. NRMRL collaborates with both public and private sector partners to foster technologies that reduce the cost of compliance and to anticipate emerging problems. NRMRL's research provides solutions to environmental problems by: developing and promoting technologies that protect and improve the environment; advancing scientific and engineering information to support regulatory and policy decisions; and providing the technical support and information transfer to ensure implementation of environmental regulations and strategies at the national, state, and community levels.

This publication has been produced as part of the Laboratory's strategic long-term research plan. It is published and made available by EPA's Office of Research and Development to assist the user community and to link researchers with their clients.

Lawrence W. Reiter, Acting Director
National Risk Management Research Laboratory

Table of Contents

Abbreviations and Acronyms

A/D	Analog-to-digital
^{o}C	Celsius degrees
cm	Centimeter
D.O.	Dissolved oxygen
DE	Diatomaceous earth
DOC	Dissolved organic carbon
DQO	Data quality objectives
DWS	Drinking Water Systems
DWTS	Drinking Water Treatment System
EPA	United States Environmental Protection Agency
ETV	Environmental Technology Verification
FTO	Field Testing Organization
ft^2	Square foot (feet)
ft^3	Cubic foot (feet)
gal	Gallon
gpm	Gallon(s) per minute
HP	Horse power
hr	Hour(s)
kW	Kilowatt
L	Liter(s)
lbs	Pounds
lb/ft^2	Pounds per square foot
lb/ft^3	Pounds per feet cubed
m^2	Square meter(s)
min	Minute(s)
mg/L	milligrams per liter
mL	Milliliter(s)
NHDES	New Hampshire Department of Environmental Services
NIST	National Institute of Standards & Technology
NPT	National pipe thread

NRMRL	National Risk Management Research Laboratory
NSF	NSF International
NTU	Nephelometric turbidity units
O&M	Operation and maintenance
PFW	Particle free water
PM	Preventative maintenance
PSTP	Product Specific Test Plan
psi	Pound(s) per square inch
PVC	Polyvinyl chloride
QA	Quality assurance
QC	Quality control
RPD	Relative percent difference
RSD	Relative standard deviation
rpm	Revolutions per minute
SCADA	Supervisory Control and Data Acquisition
TOC	Total organic carbon
µm	Micron(s)
UNH	University of New Hampshire
UV_{254}	Ultraviolet light absorbance at 254 nanometers
WTTAC	Water Treatment Technology Assistance Center

Acknowledgments

The Field Testing Organization, the University of New Hampshire Water Treatment Technology Assistance Center (UNH WTTAC), was responsible for all elements in the testing sequence, including collection of samples, calibration and verification of instruments, data collection and analysis, data management, data interpretation, and the preparation of this report. Peter L. Dwyer was the Project Coordinator for UNH and the lead author of this report in conjunction with Dr. M. Robin Collins. The University would also like to acknowledge the contributions of Samuel Heffron, Research Technician at the WTTAC.

University of New Hampshire
Water Treatment Technology Assistance Center
Durham, New Hampshire
Contact Person: Dr. M. Robin Collins, Professor of Civil Engineering

The laboratory selected for the microbiological analyses for this study was:

CH Diagnostic and Consulting Service, Inc.
Loveland, Colorado
Contact Person: Ms. Patricia Klonicki, Laboratory Director

The laboratories selected for non-microbiological analytical work were:

Analytics Environmental Laboratory, LLC.
Portsmouth, New Hampshire
Contact Person: Mr. Stephen L. Knollmeyer, Laboratory Director

UNH WTTAC Laboratory
Durham, New Hampshire
Contact Person: Dr. M. Robin Collins, Director

The manufacturer of the Equipment was:

Separmatic™ Fluid Systems
Milwaukee, Wisconsin
Contact Person: Mr. James R. Larsen, Director-Business Development

UNH wishes to thank NSF International, especially Bruce Bartley, Project Manager; Kristie Wilhelm, Environmental Engineer; Angela Beach, Project Coordinator; and Tina Beaugrand, Auditor, for providing guidance and program management.

UNH would also like to thank Separmatic™ Fluid Systems, especially Christopher E. Seter, President, and James R. Larsen, Director-Business Development, for providing the treatment system and their technical and product expertise.

Chapter 1
Introduction

1.1 ETV Purpose and Program Operation

The U.S. Environmental Protection Agency (EPA) has created the Environmental Technology Verification (ETV) Program to facilitate the deployment of innovative or improved environmental technologies through performance verification and dissemination of information. The goal of the ETV Program is to further environmental protection by accelerating the acceptance and use of improved and more cost-effective technologies. ETV seeks to achieve this goal by providing high-quality, peer-reviewed data on technology performance to those involved in the design, distribution, permitting, purchase, and use of environmental technologies.

ETV works in partnership with recognized standards and testing organizations; with stakeholders groups consisting of buyers, vendor organizations, and permitters; and with the full participation of individual technology developers. The program evaluates the performance of innovative technologies by developing test plans responsive to the needs of stakeholders, by conducting field or laboratory tests (as appropriate), collecting and analyzing data, and preparing peer-reviewed reports. All evaluations are conducted in accordance with rigorous quality assurance protocols to ensure that data of known and adequate quality are generated and that the results are defensible.

The EPA has partnered with NSF International (NSF) under the ETV Drinking Water Systems (DWS) Center to verify the performance of small drinking water systems that serve small communities. A goal of verification testing is to enhance and facilitate the acceptance of small drinking water treatment equipment by state drinking water regulatory officials and consulting engineers, while reducing the need for testing of equipment at each location where the equipment's use is contemplated. NSF meets this goal by working with manufacturers and NSF-qualified Field Testing Organizations (FTOs) to conduct verification testing under the approved protocols. It is important to note that verification of the equipment does not mean the equipment is "certified" by NSF or "accepted" by EPA. Rather, it recognizes that the performance of the equipment has been determined and verified by these organizations for those conditions tested by the FTO.

The DWS Center evaluated the performance the Separmatic^{TM} Fluid Systems Diatomaceous Earth Pressure Type Filter System Model 12P-2, which is a portable pressure diatomaceous earth (DE) filter system used in drinking water treatment applications. The test evaluated the filter system's operational performance and its ability to physically remove *Cryptosporidium* oocysts. This document provides the verification test results for the Separmatic^{TM} Diatomaceous Earth Pressure Type Filter System Model 12P-2 System.

1.2 Testing Participants

The FTO was the University of New Hampshire (UNH) Water Treatment Technology Assistance Center (WTTAC), which provided the overall management, operations, data management, and report preparation for the ETV test. The DE pressure system manufacturer for the ETV test was Separmatic™ Fluid Systems. Laboratory analyses were performed by the UNH WTTAC laboratory of Durham New Hampshire, Analytics Environmental Laboratory, LLC, of Portsmouth, New Hampshire, and CH Diagnostic and Consulting Service, Inc., of Loveland, Colorado. NSF provided technical and quality assurance oversight of the verification testing described in this ETV report. The EPA through its Office of Research and Development has financially supported and collaborated with NSF for the operation of the ETV DWS Center.

The following is a brief description of each of the ETV participants and their roles and responsibilities.

1.2.1 NSF International

NSF is an independent, not-for-profit testing and certification organization dedicated to public health and safety and to the protection of the environment. Founded in 1946 and located in Ann Arbor, Michigan, NSF has been instrumental in the development of consensus standards for the protection of public health and the environment. NSF also provides testing and certification services to ensure products bearing the NSF Name, Logo and/or Mark meet those standards. The EPA partnered with NSF to verify the performance of drinking water treatment systems through the EPA's ETV Program.

NSF provided technical oversight of the verification testing. An audit of the field analytical and data gathering and recording procedures was conducted. NSF also provided review of the Product Specific Test Plan (PSTP) as well as this report.

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1.2.2 Field Testing Organization

UNH WTTAC, which is associated with the environmental research group at the university, conducted the verification testing of the Separmatic™ Fluid Systems Diatomaceous Earth Pressure Type Filter System Model 12P-2. UNH WTTAC is an NSF-qualified FTO for the ETV DWS Center. UNH WTTAC provided all needed logistical support, established a communications network, and scheduled and coordinated activities of all participants. UNH WTTAC was responsible for ensuring the testing location and feed water conditions were such

that the verification testing could meet its stated objectives. UNH WTTAC prepared the PSTP; oversaw the pilot testing; managed, evaluated, interpreted and reported on the data generated by the testing; and evaluated and reported on the performance of the technology.

Contact Information:

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Fax: (603) 862-3957
Contact Person: Dr. M. Robin Collins, Director
Email: robin.collins@unh.edu

1.2.3 Manufacturer

The treatment system is manufactured by Separmatic™ Fluid Systems. The manufacturer was responsible for supplying a field-ready DE pressure system equipped with all necessary components, including treatment equipment, instrumentation and controls, and an operations and maintenance (O&M) manual. The manufacturer was responsible for providing logistical and technical support as needed, technical assistance to the FTO during operation, and monitoring of the equipment undergoing field verification testing.

Contact Information:

Separmatic™ Fluid Systems
7628 West Florist Avenue
Milwaukee, Wisconsin 53218
Phone: (414) 466-5200
Fax: (414) 466-5258
Contact Person: Mr. James R. Larsen, Director-Business Development
Email: systems@separmatic.com

1.2.4 Analytical Laboratories

The laboratory selected for microbiological analytical work was CH Diagnostic and Consulting Service, Inc. The microbiological analytical work included *Cryptosporidium* analyses. CH Diagnostic was granted "approval pending" status by the EPA through the EPA's Laboratory Quality Assurance Evaluation Program for analysis of *Cryptosporidium* under the Safe Drinking Water Act (Lab QA Program). The Lab QA Program identifies laboratories that can reliably measure *Cryptosporidium* in surface water using EPA Method 1622 and 1623. The "approval" status is dependent on promulgation of the Long Term 2 Enhanced Surface Water Treatment Rule.

Contact Information:

CH Diagnostic and Consulting Service, Inc.
214 S.E. 19th Street
Loveland, Colorado 80537
Phone: (970) 667-9789
Fax: (970) 667-9719
Contact Person: Ms. Patricia Klonicki, Laboratory Director
Email: customerservice@chdiagnostic.com

The laboratories selected for non-microbiological analytical work were Analytics Environmental Laboratory, LLC and the UNH WTTAC laboratory. Analytics Environmental Laboratory, LLC performed the iron and manganese analyses. UNH WTTAC laboratory performed the total organic carbon (TOC) and ultraviolet light absorbance at 254 nanometer (UV_{254}) analyses.

Contact Information:

Analytics Environmental Laboratory, LLC
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1.2.5 U.S. Environmental Protection Agency

The EPA, through its Office of Research and Development, has financially supported and collaborated with NSF under Cooperative Agreement No. R-82833301. This verification effort was supported by the DWS Center operating under the ETV Program. This document has been peer reviewed, reviewed by NSF and EPA, and recommended for public release.

1.3 Verification Testing Site

The ETV test was conducted at the UNH WTTAC high bay, room 147 of Gregg Hall located at 35 Colovos Road, Durham, New Hampshire.

1.3.1 Source Water

The source water for the verification testing was finished water from the Arthur Rollins Treatment Plant. The treatment plant serves both the Town of Durham and the University of New Hampshire. The treatment plant obtains its water from a reservoir on the Oyster River. The source water was pretreated with a 15 micron (μm) string pre-filter as it entered the high bay and prior to collection in the feed and challenge tanks used during verification and challenge testing. Feed water samples were collected from a sample port in the feed line as water flowed from the feed and challenge tanks to the influent sampling board and on to the Separmatic™ DE Pressure Filter. The pre-filter was used to assist in the provision of consistent water for treatment.

1.3.2 Pilot Effluent Discharge

The ETV test effluent was discharged to the Durham sewer system, which is treated by the Durham Wastewater Treatment Plant. The sewer system provided for the convenient and safe disposal of acceptable effluents and cleaning solutions.

Chapter 2
Equipment Description and Operating Processes

2.1 Equipment Description

The Separmatic™ Fluid Systems Diatomaceous Earth Pressure Type Filter System Model 12P-2 was tested during the ETV test. The serial number of the unit is EXP-5. The system is a small, portable DE pressure filter unit specifically targeted for applications requiring a relatively low flow rate, such as for a small commercial operation or campground. The system is also appropriate for treatment of a common water supply system for several residences. The system's maximum operating pressure is rated at 100 pounds per square inch (psi), but typical maximum differential pressures are 20 to 30 psi.

The system is rated by the manufacturer to have two square feet of effective filter area, and is designed to filter up to 1 gallon per minute (gpm)/ square foot (ft^2) or 2 gpm. Power requirements are 115 volts, at 19.4 amps under full load. There are two tubular, plastic filter elements, each approximately 3.75 inches in diameter and 12 inches long. The septa covering the elements are nylon in a tight linen weave. The filter elements are housed in a steel vessel with two chambers. The lower filter element chamber is 12 inches in diameter and 20 inches deep with a concave bottom. Both inside and outside surfaces are painted. The lower chamber has four glass portals through which the septa may be visually inspected during operation. A 2-inch polyvinyl chloride (PVC) feed and drain line connects to the bottom of the chamber, and a diffuser plate is installed above the pipe connection to force the feed water to the outside of the chamber, thus preventing scour of the septa. A 0.75-inch flushing pipe with a check valve connects through the filter vessel, with a tee and two elbows directed downward for air or clean water flushing of the filter vessel during backwash operations. The filter elements themselves are mounted to a 0.5-inch steel plate, which separates the two chambers. Flat, circular rubber gaskets provide a seal on either side of the steel plate between chambers.

The second (upper) chamber is domed, with a one-inch outlet pipe protruding into the middle of the chamber. This upper chamber is also 12 inches in diameter and 10 inches high. Air is trapped and compressed inside the dome during filter operation. The compressed air provides the bump energy needed to knock the filter cake off the septa during backwashing. The filter vessel is held together with ten 5/8-inch bolts through the vessel flanges. The outlet line is teed outside of the upper chamber, with each branch valved. One branch is for connection to the distribution system, and the other line is directed back into the precoat mixing vessel. A photo of the pressure DE system is provided in Figure 2-1. Photos of the body feed tank and the filter septa are provided in Figure 2-2.

Figure 2-1. Separmatic™ DE Pressure Type Filter System, Model 12P-2.

A.   **B.**

Figure 2-2. Components of Separmatic™ DE Pressure Type Filter System
A. Body Feed Tank B. Filter Septa

The precoat mixing vessel consists of an open-ended steel cauldron 18 inches in diameter and 18 inches deep. The precoat tank is connected to the recirculation pump and finally to the filter vessel by 1.25-inch diameter PVC pipes. Two valves on this line isolate the precoat tank and can allow it to drain. The precoat slurry is mixed by an electric mixer mounted on the precoat tank.

The raw water feed connection to the filter unit is a valved 1.25-inch PVC pipe leading to the recirculation pump. The pump itself is a Sta-Rite Model PLBC-178L, with a 3/8-inch PVC discharge line. A 0.5 horsepower (HP) single-phase motor, operating at 3450 revolutions per minute (rpm), powers the pump. The full service load rating of the motor is 13.4 amps for 115 volts or 6.7 amps for 230 volts. The service factor is 1.9. There are two power cords provided with the unit, both of which are set up for 115 volts. One power cord is dedicated to the recirculation pump, and has a weatherproof switch mounted on the filter frame. The other power cord is connected to an outlet, also mounted on the frame. The body feed pump is plugged into this outlet.

The body feed was pumped from a 100-gallon body feed tank with an outlet and mixer supplied by Separmatic™ Fluid Systems. The body feed was mixed by a Dayton 1/3 HP mixer rated at 276 rpm and pumped using a Masterflex Pump Model 7520-10 with an Easy Load II head.

The components of the system are all bolted or welded onto a steel angle-iron frame. The frame is outfitted with industrial-grade casters, making the unit portable. The overall footprint of the system is 36 inches by 66 inches. The construction is rugged, and the unit has an estimated weight of 500 pounds (lbs). The unit can be loaded into a standard pick-up truck for transport.

Two 0.25-inch national pipe thread (NPT) connections are provided on the feed line and the outlet line of the filter unit for connecting pressure transducers or pressure gages. Certified gauges with a full-scale reading of 100 psi were provided with the unit. The flow rate through the filter unit was measured with an in-line flow meter installed in the effluent discharge line from the pressure vessel. The flow rate through the unit was controlled by a 2 gpm rated flow controller supplied for the testing by Separmatic™ Fluid Systems.

The unit also provides a drain box with a 1-inch valved drain line to catch the spent DE filter cake. The box is 14 inches square by 10 inches deep, and is designed to hold a filter bag, which will retain the spent filter cake while the flushing water is drained off. A 2-inch drain line from the filter vessel empties directly into the drain box. A schematic drawing of the pressure DE system treatment process is provided in Figure 2-3.

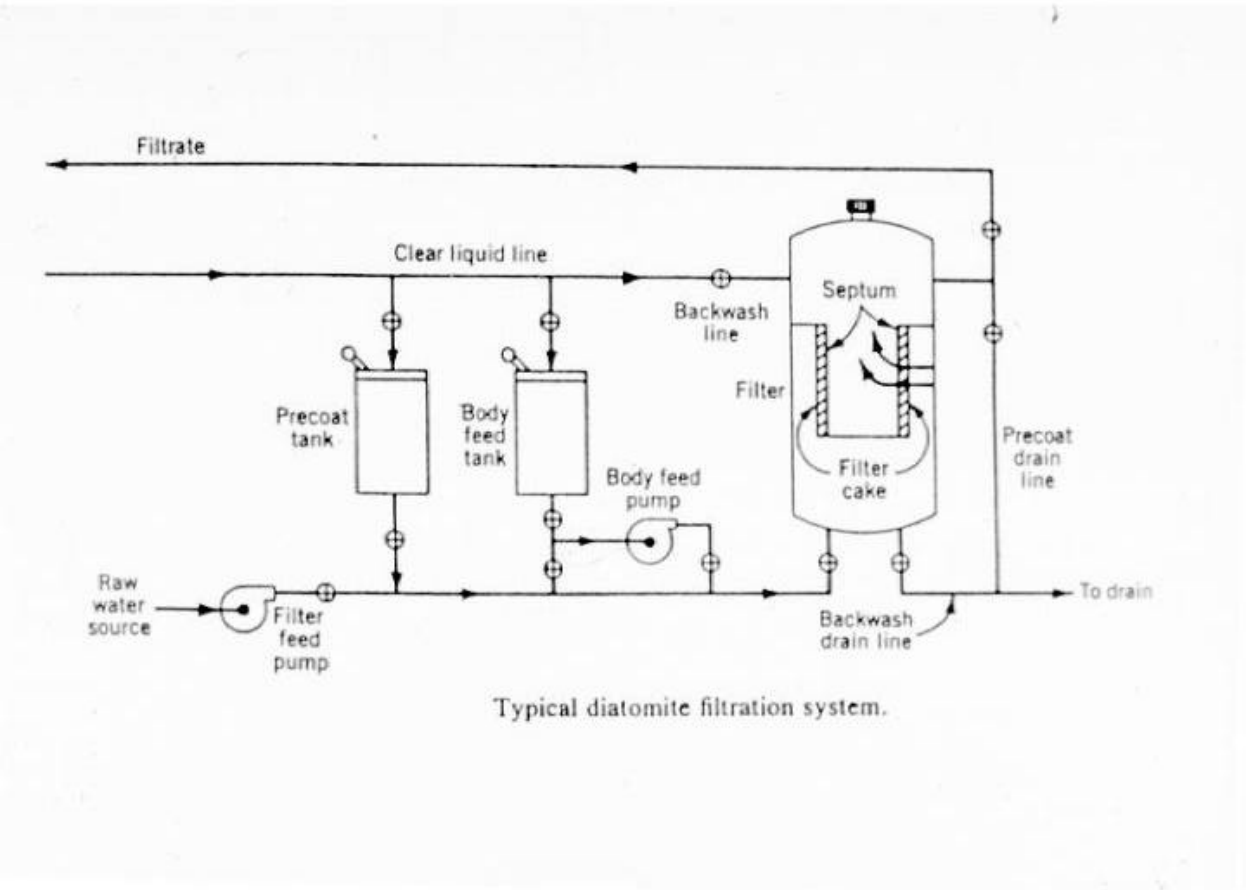

Figure 2-3. Schematic of Separmatic™ DE Pressure Type Filter System treatment process.

2.2 Operating Process

The initial coating of the filter septum is called the precoat. The precoat is applied either as a batch slurry mix from a separate precoat mix tank, or is metered directly into the water feed. The precoat slurry water is then recirculated through the filter septum until the recirculation water in the filter chamber matches the finished filtrate water conditions. The openings of the filter septum are typically larger than the particle size of the DE material, therefore the filter cake is formed as the DE particles bridge across the septum pores. Shocks to the filter at this stage, such as sharp pressure changes or vibrations, can break down the bridging of the filter cake, and re-suspend the precoat. The precoat forms a thin (approximately 1.6 to 3.2 millimeters) coating of DE on the septum. The precoat was prepared with filtrate water to try to prevent clogging or fouling of the septum.

After the precoat is applied, the filter unit is switched over from recirculation (for precoat slurry water) to feed water, taking care to make a smooth transition so as not to dislodge the filter cake. As the filter removes particulate matter from the feed water, the DE pores become clogged, and the filter loses its efficiency. To prolong the working life of the filter and to maintain an effective porosity, a metered amount of DE is applied concurrently with the feed water. This

addition, or body feed, mixes porous media in with the filter-clogging particles contained in the feed water, thus maintaining a certain degree of porosity and preventing rapid clogging of the filter pores. The body feed is prepared in a separate tank, and is pumped under high pressure into the filter feed water at a metered rate. The rate at which body feed is added to the filter affects the operation of the filter. Too little body feed leads to premature clogging of the DE filter and short filter cycles. Too much body feed may result in excessive build-up between septum leaves, with the possibility of bridges forming between the leaves. This condition will result in the reduction of filter area and a subsequent build-up in pressure. The excess pressure created by this condition can warp and damage the filter septum. The feed rate can be optimized experimentally for the feed water conditions to obtain the maximum through-flow.

2.3 Description of Spent DE Removal

When the terminal operating pressure is reached, the filter unit is taken off line, and the filter is backwashed. In this case, the filter cake is dislodged from the septum, and the exhausted DE is removed from the filter chamber through a drain.

The removal of the filter cake from the septum presents some minor difficulties, without requiring it to be cleaned manually. Several techniques can be used, which include backwash, bumping, sluicing, or dry cake discharge. The latter method involves draining the filter chamber using a differential air pressure that also dries the filter cake. The DE filter cake is then removed from the septum by vibration or mechanical scraping. Sluicing involves the removal of the filter cake with high-pressure external sprays directed on the exterior surfaces of the filter leaves. Bumping involves a sudden reversal of flow through the filter leaves making use of trapped air in the vessel. A drain is suddenly opened, which results in a burst of water flowing backward through the filter septa, thus bumping the filter cake from the septa. This is used in conjunction with backwashing (reversing the flow of water through the filter) to make sure all of the filter cake has been removed. At the end of each filter run, the release of pressure should create a significant enough force to remove all visible precoat.

The filter cake is typically removed through the drain in the form of a slurry. In most cases the slurry is dewatered and the solids are disposed in landfills or as soil conditioners. For the ETV test, the spent DE in the drain box was transferred to a barrel container and allowed to settle. Liquid from the container was decanted and discharged to the Durham sewer system. The spent DE remaining in the container was disposed of in an approved landfill.

2.4 Description of DE Used During ETV Test

Hyflo Super Cel DE was used as the precoat during the ETV test. According to the technical data sheet provided by the DE manufacturer, Hyflo Super Cel DE is a flux-calcined filter aid made from plankton marine diatomite and has a median cake pore size of 7.0 microns, pH of 10, dry density of 10 lbs/ cubic foot (ft^3), and is in powder form. Celite® 503 DE was used as the body feed during the ETV test. According to the technical data sheet provided by the DE manufacturer, Celite® 503 DE is a flux-calcined filter aid made from plankton marine diatomite and has a median cake pore size of 10.0 microns, pH of 10, dry density of 12 lbs/ft^3, and is in powder form.

Filter Cel® DE was used during an integrity test performed prior to the ETV test. According to the technical data sheet provided by the DE manufacturer, Filter Cel® DE has a reported median pore size of 2.2 microns.

The technical specifications for the DE are provided for informational purposes only and were not verified during the ETV test. Technical data sheets, which describe the DE products in greater detail, are provided in Appendix A.

2.5 Operator Skill/Licensing Requirements

A typical DE system requires a minimal amount of specialized training. No hazardous chemicals are involved in the operation and maintenance of the equipment. However, respiratory protection is recommended when handling DE. Disposable paper nose and mouth masks were used during the testing. No special licensing is required to operate this equipment.

2.6 Operation Limitations

DE filtration has excellent performance records for the mechanical removal of particulates and turbidity (Spencer 1991). It is capable of treating water with relatively high turbidity levels, although high turbidity levels decrease the run times and shorten the time between backwashing, with corresponding higher operating costs.

In a DE system, the operation of the filter may be limited by short-circuiting and/or scouring of filter media during any of the filter operations. The Separmatic™ Model 12P-2 system has baffling installed in the filter vessel to prevent the feed water from scouring the elements, and to provide a radially upward velocity to keep particles suspended until adsorbed onto filter media. The drain must also be large enough to handle quick discharge of DE slurry during the filter cleaning process. The Separmatic™ Model 12P-2 system has a 2-inch PVC drain line, which should adequately remove the spent DE from the filter chamber.

Another limitation can be the incomplete removal of spent filter cake from the filter vessel during cleaning. The Separmatic™ Model 12P-2 system has two air flush nozzles for flushing the vessel clean of filter cake following the bumping and backwashing of the filter septa. The inspection ports allow the operator to evaluate the backwashing effectiveness and adjust the backwash times accordingly.

Chapter 3
Methods and Procedures

This chapter includes a detailed discussion of the ETV experimental plan, testing conditions, methods, and sampling parameters and frequency. Details on the field operational and maintenance procedures, quality assurance (QA) and quality control (QC), and analytical methods used throughout the ETV testing are provided.

3.1 Task 1: Characterization of the Feed Water

The system was challenged with finished water from the Arthur Rollins Treatment Plant, which serves both the Town of Durham and the University of New Hampshire. UNH gathered information on the historical finished water quality from the plant. The finished water produced by the Arthur Rollins Treatment Plant typically has turbidity ranging from 0.05 to 0.48 nephelometric turbidity units (NTU), a pH of 8.5 to 9.0, TOC/dissolved organic carbon (DOC) ranging from 1.1 to 2.3 milligrams per liter (mg/L), and a total manganese concentration of 0.00 to 0.05 mg/L. A more detailed summary of the historical range of finished water quality from the treatment plant for 2001-2002 is shown below. The feed water quality was evaluated in the context of the manufacturer's performance objectives. This historical data served as the characterization of the feed water and was evaluated prior to the ETV testing to assess that the chemical, biological, and physical characteristics of the feed water were appropriate for the system.

Table 3-1. Historical Finished Water Quality Data for Durham Water Treatment Plant, 2001 - 2002

Parameter	Range of Estimated Results
Turbidity (NTU)	0.05-0.48
Total Coliform (#/100 ml)	0
PH	8.5-9.0
TOC/DOC (mg/L)	1.1-2.3
Total Trihalomethanes (µg/L)	21-67
Alkalinity (mg/L as $CaCO_3$)	20-65
Hardness (mg/L as $CaCO_3$)	25-30
Total Manganese (mg/L)	0.00-0.05

3.2 Task 2: Initial Testing

The system underwent initial test runs to evaluate whether the equipment operation resulted in effective treatment of the feed water. Exploratory tests were performed to evaluate the grade of DE to be used for precoat and body feed and to determine the appropriate concentrations of body feed DE for selection of body feed DE concentration that resulted in filter runs of appropriate duration.

Operational parameters were monitored during initial testing. The pressure drop across the filter elements was monitored on a continuous basis using two pressure transducers, an analog to digital (A/D) converter, and a laptop computer. An in-line, paddle wheel-type flow meter was used to monitor the feed and effluent lines to monitor flow through the filter. The meters were

continuously monitored using the A/D converter and laptop computer. The computer was also used to monitor and record feed and effluent particle counts and turbidity readings.

The operation of the filter unit and all instrumentation was checked during initial testing. The instrumentation was connected to the filter unit, and trial filter runs were made to verify that the filter unit, monitoring instruments, and data collection system were functioning as intended. The flow diagram for the pre-filter, feed and challenge tanks, sampling ports, sampling boards, and Separmatic™ DE Pressure Filter is shown in Figure 3-1. The sampling boards contained the online sampling instrumentation, such as turbidimeters and particle counters.

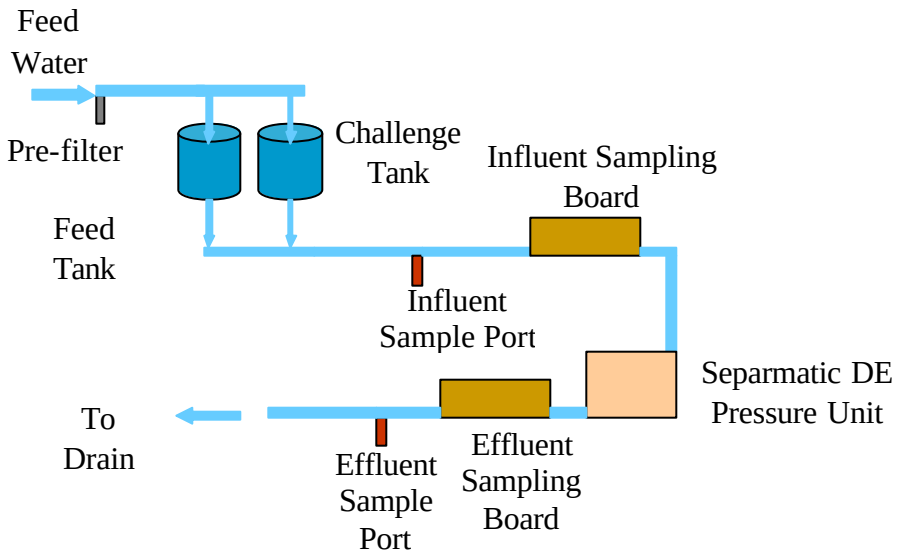

Figure 3-1. Flow diagram for testing and challenge Equipment.

Prior to actual verification testing of the system, an integrity test, or leak check, was performed on the septum and internal components of the pressure system. The integrity test was performed following a 0.4 lb/ft^2 precoat application of Filter-Cel® DE, a very fine grade of DE. The system was then challenged with coliform bacteria while it was operated for one hour at full flow with the effluent valve fully open. The flow was intended to be 2 gpm (1 gpm/ft^2) but actually averaged 1.74 gpm during the integrity test. The system was deemed intact if all of the coliform bacteria in the challenge water were removed. The procedure followed for the integrity test is the method developed by Lange et al. (Lange, 1986).

The manufacturer evaluated the data generated during the initial test runs to verify that the system performed as expected.

3.3 Task 3: Verification Testing

The objective of the verification testing was to perform a 272-hour continuous test and to acquire both quantitative and qualitative evaluations of the performance of the system. Filter operations during a filter run were continued until the system reached terminal headloss (pressure drop) or the filtrate reached a maximum turbidity breakthrough value. The terminal pressure drop goal

was 25 psi. The 272 continuous hours of operation included the time for filter backwashing and precoating.

Operating conditions and operation resources were recorded on a regular and/or continuous basis throughout each filter test run. The operating conditions documented during the ETV test included: flow rate, pressure drop across the filter, number of backwashes, amount of DE used, precoat and body feed rates, flow through the filter, total gallons filtered, power consumption, and operator hours. The DE manufacturer and grade used was recorded as well as the amount of precoat and the percentage of DE used in the body feed for the filter run.

The terminal conditions used to halt a filter run were recorded for each cleaning operation performed during the testing period. Operation parameters during cleaning were recorded in a logbook. These parameters included the duration of the backwashing procedure and the volume of filtered water used during the cleaning. Air pressure to the filter element chamber was also recorded during cleaning.

Water quality parameters were monitored during the filter runs. Both the feed water and the filtered water were tested for parameters shown in Table 3-2. Table 3-2 also shows the sample frequency. Table 3-3 indicates the analytical methods employed on-site and in the laboratory for water quality parameters.

Table 3-2. Water Quality Data Collection Schedule

ONSITE ANALYTES

Parameter	Frequency	Feed	Filtrate
Temperature, ^{o}C	Daily	1	1
pH	Daily	1	1
Turbidity (NTU)	Daily	Continuous	Continuous
Particle Counts	Daily	Continuous	Continuous
Dissolved Oxygen (DO)	Daily	1	1

LABORATORY ANALYTES

Parameter	Frequency	Feed	Filtrate
TOC	1-3 times per week	1	1
UV_{254} Absorbance	1-3 times per week	1	1
Iron	1 per test period if < 0.3 mg/L, otherwise weekly	1	1
Manganese	1 per test period if < 0.5 mg/L, otherwise weekly	1	1

Table 3-3. Analytical Methods for Water Quality Testing

Parameter	Facility	Standard Methods[1]
Temperature	On-site	2550 B
pH	On-site	4500-H^+ B
DO	On-site	4500-O
TOC	UNH Lab	5310C
Turbidity	On-site	2130B
Continuous Turbidity Monitoring	On-site	Manufacturer Specs
Continuous Particle Counting	On-site	Manufacturer Specs
Iron	Analytics Lab	3111D
Manganese	Analytics Lab	3111D
UV_{254} Absorbance	UNH Lab	5910B

1). Standard Methods for the Examination of Water and Wastewater, 20th Edition, 1999. American Water Works Association.

Operational parameters documented during the verification testing included: pressure drop across the filter, flow rate, power consumption, and consumption of DE media for both the precoat and the body feed. The first two parameters were continuously monitored by a laptop computer data-logging system. The flow rate was monitored independently of the in-line flow meter provided with the system using the computer data-logging system. Power consumption was monitored from a separate power meter dedicated to the circuit on which the system was operating. The meter provided a means of monitoring the rate of power consumption as well as the cumulative power used during the filter runs. Daily readings were taken of the power consumption rate and cumulative power consumption.

All filter cleaning operations performed during the ETV test were documented as to the operating conditions at the time of the decision to backwash the filter, the times for backwashing, and the times that the filter unit was brought back on-line. DE usage was computed from the records of DE media mixed in the precoat, and also from the record of body feed consumption. Records were kept on the DE percentage concentration of the body feed, and the body feed rate was measured following each backwash and precoat of the filter. All records were kept in a field book and transcribed to a Microsoft™ Excel spreadsheet, where the data were analyzed and presented in tabular and graphical form. Operator hours and activities were entered in the logbook to evaluate the number of labor-hours required to operate the system, as well as to establish the level of skill required.

Hydrologic and any unusual events regarding the source water were noted in the logbook, although these were not anticipated because the source water was a finished water. . If warranted, the staff of the Arthur Rollins Treatment Plant were contacted to discuss changes in source water quality.

3.4 Task 4: *Cryptosporidium* oocyst Challenges

This task was designed to address the primary objective of this ETV test, which was to evaluate the filter system's capability to remove *Cryptosporidium* oocysts. The filter system accomplishes its removal task by direct filtration through the DE filter cake. *Cryptosporidium* samplings for the feed and effluent were performed for each of the microbiological challenges. Inactivated formalin fixed *Cryptosporidium* oocysts were used for the challenges.

Seven *Cryptosporidium* oocyst challenges were performed during the testing. The challenges included an initial control test of the filter system without the addition of either precoat or body feed and three sets of two challenges performed during the same filter run. The sets of challenges included a challenge performed within the first 1.5 hours of the start of a filter run and the second challenge performed near 85% terminal headloss when the differential pressure reached approximately 21.25 psi.

Once the filter unit was cleaned, precoated, and operated to ensure proper performance, a challenge test commenced with the feed of a continuously mixed feedwater dosed with the desired concentration of target microorganisms. Time zero for the sampling was marked after at least three filter volumes (30 gallons) of feedwater had passed through the filter unit. For example, at 2 gpm the effluent would be collected after 15 minutes. Duplicate samples were collected for both the influent and effluent to obtain a data set that was analyzed statistically. The removals were computed by the difference in concentrations in the analytical samples taken from the collected influent and effluent. Particle counts were also monitored during the *Cryptosporidium* oocyst challenges. The analytical removals were compared with the difference in particle concentrations measured by particle counters on the influent and effluent sides of the filter unit.

The *Cryptosporidium* oocyst challenges were performed as follows: a vial containing approximately 1×10^8 inactivated formalin fixed *Cryptosporidium* oocysts was seeded into a feed tank containing 170 gallons of Arthur Rollins Treatment Plant finished water to create a feedwater concentration of approximately 155,000 oocysts/liter. This seeding produced approximately 3.1×10^6 oocysts in the 20 liters that were filtered through an Envirochek^{TM} filter making a 6-$\log_{10}$ reduction possible. The analysis of the feed samples found that there were 6-$\log_{10}$ concentrations in the feed to the treatment system during each challenge. The tank was constantly mixed with a mixer attached to a frame above the opening of the tank. The feed and effluent samples were collected continuously during the challenges, and Envirochek^{TM} filter samples were taken from that sample water. Collection of the effluent sample water did not begin until three times the volume of the initial water in the filter unit, approximately thirty gallons in all, had passed through the effluent lines, which took approximately 15 minutes. The total length of each challenge was approximately 75 minutes or until the majority of the volume of the challenge tank had been used. Care was taken to not introduce air into the feed line, which might affect filter condition. Therefore, the challenge tank was not drained to the very bottom.

A total of at least four Envirochek^{TM} filter samples were collected during each challenge. Duplicate samples were taken from both the effluent water and the seeded feed water. In addition, at the start of each challenge set one background effluent sample was collected from a clean effluent sample container. QA triplicate samples were collected where appropriate. The sampling frequency and challenge conditions, including target *Cryptosporidium* oocyst concentrations, average initial flow, and target precoat and body feed concentrations, are listed in Table 3-4. Operational data during the challenges was collected as outlined under Task 3.

The sample filters from the first challenge in the set were held in refrigerated storage until the second challenge had been successfully completed. When both challenges were finished for the

same filter run, the samples were sent to the laboratory by overnight delivery for the fastest possible analysis.

The *Cryptosporidium* oocyst analyses were performed by CH Diagnostic and Consulting Service, Inc. of Loveland, Colorado, using EPA Method 1623 for the analysis of Envirochek™ filters. CH Diagnostic was granted "approval pending" status by the EPA through the EPA's Laboratory Quality Assurance Evaluation Program for analysis of *Cryptosporidium* under the Safe Drinking Water Act (Lab QA Program). The Lab QA Program identifies laboratories that can reliably measure *Cryptosporidium* in surface water using EPA Method 1622 and 1623. The "approval" status is dependent on promulgation of the Long Term 2 Enhanced Surface Water Treatment Rule.

Table 3-4. Summary of *Cryptosporidium* oocyst Challenges and Sample Frequency

Challenge	Target Feed Concentration (oocysts/20L)	Initial Effluent Flow (gpm)	Precoat (lbs/ft^2)	Body Feed (mg/L)	Samples
Control Run	3.1×10^6	2.0	None	None	1- Effluent Blank 2- Effluent 3- Effluent Duplicate 4- Feed 5- Feed Duplicate
Set 1 First 1.5 hours of filter run	3.1×10^6	1.9	0.2	2 .0	6- Effluent Blank 7- Effluent 8- Effluent Duplicate 9- Feed 10- Feed Duplicate
85% of filter run					11- Effluent 12- Effluent Duplicate 13- Effluent Triplicate 14- Feed 15- Feed Duplicate
Set 2 First 1.5 hours of filter run	3.1×10^6	2.0	0.2	2.0	16- Effluent Blank 17- Effluent 18- Effluent Duplicate 19- Feed 20- Feed Duplicate
85% of filter run					21- Effluent 22- Effluent Duplicate 23- Feed 24- Feed Duplicate 25- Feed Triplicate
Set 3 First 1.5 hours of filter run	3.1×10^6	1.9	0.2	2.0	26- Effluent Blank 27- Effluent 28- Effluent Duplicate 29- Feed 30- Feed Duplicate
85% of filter run					31- Effluent 32- Effluent Duplicate 33- Feed 34- Feed Duplicate

3.5 Task 5: Data Collection and Reporting Protocols

Data collection for most of the operating parameters was performed using a laptop computer in conjunction with an A/D converter. Data were collected and organized into text files using a custom Visual Basic program. The text files were formatted to be readily imported into an Excel spreadsheets or Microsoft™ Access data files.

The operational data collected in this manner included the pressure head in the feedwater line, pressure head in the filtered water line, and the pressure drop across the filter, flow rate, and time of operation. In addition, water quality data were also collected on a continuous basis using the same laptop data-logging system. Turbidity was recorded at regular intervals throughout the test using flow through cells with appropriate probes and meters coupled to the data logger. Particle counts from the in-line particle counters were also monitored on a continual basis throughout the tests. The logging program wrote data to external files on the hard drive, and wrote a copy of the data files directly to a floppy disk for backup.

All other real-time operational measurements were made manually and logged in a dedicated logbook containing water resistant rag-content paper. Photocopies were made daily of each day's data entry in the logbook, signed, dated, and placed in the equipment testing files. The logbook remained at the test site in a secure location during the testing period. Data entry logs included the name of the technician, date and time of entries, and notations on hydrologic conditions for that day. Parameters logged manually included power consumption rate, cumulative power consumed, body feed rate and concentration, precoat amounts, times for filter cleaning, operator's hours and tasks, and sampling data.

Sampling data included the date and time of grab sample collection, samplers, number and size of sample containers filled, preservatives used, and analyses to be performed. Any unusual events or problems that occurred during the sampling or operation of the filter system were noted in the logbook.

The data collected in the logbook were entered daily into an Excel spreadsheet or an Access database file, thus providing for real-time analyses of the operational data. A hard copy of the data entry was generated following each data entry. An independent party checked the hard copy against the originals for errors. Data errors were noted on the hard copy, and corrected in the data base. Hard copies were made of the corrected spreadsheet or data base file, and rechecked.

Water quality samples collected during the testing period were logged into the logbook and onto a Chain-of-Custody Form, which accompanied the samples to their final destination, typically the laboratory. All possession changes were documented on this form. Following the analysis of each sample, a copy of the Chain-of-Custody Form was maintained in the project files. Each filter run was designated with a unique identification number, which was written on each sample container. The identification number was used in the laboratory to maintain continuity and to keep track of the analysis results.

Daily logbook sheets and operational and QA/QC summary sheets were written and assembled for the initial testing and verification testing and were sent to NSF on a weekly basis to maintain ongoing communication regarding progress.

3.5.1 Statistical Analyses

For data sets of eight or more, statistical analyses were performed to establish 95% confidence intervals. Results were analyzed as a separate data set for each filter run. Additional analyses were performed that treated all samples taken for the same operating conditions (i.e., precoat and body feed concentration and feed rate) as a single data set. The confidence intervals were computed according to the following relationship:

For 95% confidence interval:

$$CI = \overline{X} \pm t_{n-1,0.975} \frac{[S]}{[\sqrt{n}]}$$

where:

CI = confidence interval,

$\bar{X}$ = data set mean,

S = data set standard deviation,

n = number of samples in data set,

$t_{n-1, 0.975}$ = Student's t distribution statistic with n-1 degrees of freedom.

The mean value of each data set was reported along with the confidence intervals. Additional statistical analyses were performed, such as analysis of variance to examine the correlations between the filter effectiveness and feedwater quality parameters.

The results of the verification testing were evaluated to determine if the filter performance objective had been achieved.

3.6 Task 6: QA/QC Plan

The objective of this task was to maintain strict QA/QC methods and procedures during the ETV test to ensure data quality and integrity. Careful adherence to these procedures ensured that data generated from the verification testing provided sound analytical results to serve as the basis for this performance evaluation. The QA/QC methods and procedures for this ETV included the following:

- Use of chain-of-custody documents;
- Sampling QA/QC procedures including duplicate and triplicate sample methods, method blanks, sample spikes, and performance evaluation samples;
- Identification of samples;
- Sample handling procedures;
- Sample transport procedures;
- Calibration of field instruments;

- General field equipment verifications;
- Specific equipment QA verifications;
- Maintenance procedures;
- Laboratory QA/QC procedures;
- Project Quality Assessment; and
- UNH Laboratory Audits.

3.6.1 Chain-of-Custody

The primary objective of the chain-of-custody procedure is to create an accurate written record that can be used to trace the possession and handling of all samples. The chain-of-custody starts in the laboratory with the bottles the laboratory provides for sampling. It follows those containers through sample collection and analysis to their final disposition. The samplers, who are responsible for documenting each sample transfer and maintaining custody of the samples until they are relinquished to the laboratory personnel, maintained sample custody during the sampling phase of this project.

3.6.2 Sampling QA/QC

The generalized procedures used for sample collection are presented above. Details for each parameter sampled are provided in Section 3.6.8. QA in the field was monitored throughout the process in a two-fold manner. Documentation tracked the specifics of the sampling effort, and sampling performance measured QA of samples.

3.6.2.1 Documentation

During the sampling process information was recorded on the Chain-of-Custody Form, sampling data sheet, and in the field notebook. The chain-of-custody tracked the samples through all phases of handling. The logbook was used to record all operational, maintenance, and hydrologic data. Entries were made documenting each sampling event, the conditions at the time of sampling, and the personnel making the measurements as well as any necessary or appropriate deviations from standard sampling methodology.

3.6.2.2 QC Samples

To obtain a quantitative measure of the reproducibility of the sampling and analysis results, QC samples were collected or supplied. QC samples included trip blanks, field blanks, duplicates, triplicates, and matrix spikes.

Duplicate Sample - A duplicate sample was collected in a manner that produced two samples with a high degree of homogeneity. Samples were collected from the same collection container. If a large quantity of water was needed for a number of analyses, then each collection was among a pair of sample bottles. Duplicate samples were taken for most samples collected during the verification testing, given a number so that the laboratory did not know they were duplicates, and sent to the laboratory as a "blind" samples.

Sample Spikes and Performance Evaluation Samples - The CH Diagnostic and Consulting Service, Inc. performs internal QC for *Cryptosporidium* analysis. CH Diagnostics has been granted "Approval Pending" status by the EPA through the EPA's Laboratory Quality Assurance Evaluation Program for analysis of *Cryptosporidium* under the Safe Drinking Water Act (Lab QA Program). The laboratory used spikes to evaluate the accuracy of the analytical instruments. A performance evaluation sample for turbidity was analyzed during the ETV test, as part of an on-site QA evaluation of turbidity measurement techniques.

Triplicate Sample - For every 10 samples collected or as appropriate, one sample was collected in triplicate and used for the laboratory's QC testing. Triplicates were collected in the same manner as the duplicate samples.

Method Blanks - Laboratory-grade water was used for method blanks to evaluate the baseline of the analytical instrument and provide the means to evaluate interferences from the sample bottle and sample preparation methodology. If measurable quantities were reported in the method blank, all containers were cleaned again, or the laboratory methods were modified until subsequent method blanks contained no significant concentrations. This did not apply to Envirochek™ filter analysis.

3.6.3 Identification of Samples

A unique identification number was assigned to each sample as soon as it was obtained. The number was written on the sample label and recorded on the Chain-of-Custody Form. If the sample was subdivided, each sub-sample was assigned its own identification number, which retained each sub-sample's association with the original sample. Additional information written on the label, included time and date of sample, sampler's initials, preservatives used, test site identification, and parameters to be analyzed.

3.6.4 Handling

Samples were handled in a way that did not adversely affect their future use. Containers were free of foreign substances, particularly any substance that changed the sample or interfered with required analyses and tests. The laboratory provided containers of appropriate size and material for each type of analysis. The samples were fixed with the appropriate preservative. All samples analyzed were stored in a manner that prevented changes in temperature and protected the sample from breakage. In the field, samples were kept in iced coolers with an internal temperature sufficient to maintain the integrity of the sample. Each sample container was placed in a plastic bag and sealed to prevent cross contamination with other samples.

Samples not sent to the laboratory on the day of collection were placed in a controlled refrigerated storage facility on the site, which provided protection against damage or loss until samples were sent to the laboratory. The temperature of the refrigerated storage facility was checked daily with a National Institute of Standards and Technology (NIST) traceable thermometer.

3.6.5 Sample Transport

Samples were packed to prevent breakage, and ice packs were used to maintain an internal temperature sufficient to protect the integrity of the samples. The Chain-of-Custody Form accompanied the samples from the time of collection until they were received by the laboratory. Each party handling the samples was required to sign the Chain-of-Custody Form signifying receipt. The laboratory was asked to provide a copy of the completed form along with its report of results.

3.6.6 Calibration of Field Instruments

Field instruments were used to measure parameters of temperature, pH, DO, particle counts, and turbidity. Several of these parameters were measured on a continuous basis using flow-through cells and in-line probes. Separate probes were calibrated and used to spot-check the in-line instrument calibration. For example, a bench-top turbidimeter was used to check the calibration of the in-line turbidimeters.

The field personnel documented the calibration check activities in the field logbook. The documentation included the date of the calibration check, concentration of the check standard, the reading obtained, whether it was reset, the reading after resetting, and the initials of the person doing the calibration check.

3.6.7 General Field Equipment Verification

QA verifications were performed on the measurement devices on the filter system itself, and also on the instrumentation used to characterize the feed water and filtered water. The flow meter and the body feed pump on the filter system required calibration. .

The flow through the filter was monitored by a paddle-wheel in-line flow meter coupled to a data logger. In addition, daily spot-check readings were taken from the in-line flow meter supplied with the filter unit. These devices were calibrated using a bucket-and-stop-watch technique with the filtered water discharge. The flow meter reading was verified at the beginning of testing and every two weeks using the bucket-and-stop-watch method.

The body feed rate was calibrated using a graduated cylinder and stopwatch while the unit was in operation. The amount used during each filter run was measured on a daily basis during each filter run to confirm that filter aid was fed to the filter element at the expected rate. The results were recorded in the logbook. The body feed pump was readjusted if significant discrepancies were found.

Calibrated pressure gauges supplied by the manufacturer were used to measure the pressure head differential.. The calibration certificates supplied by the manufacturer are included in Appendix G. Pressure differential was measured on a continuous basis using pressure transducers. The calibration curve of the transducers was established prior to testing. Daily readings were made of pressure gauges, recorded in the logbook, and compared to the data logger readout as a check on the performance of the transducers. If a significant discrepancy was noted, the manual

reading frequency of the gauges was increased, and the data validity of each was evaluated by the end-of-run re-calibrations; pressure gauges should not vary and were checked for consistent readings.

Tubing and piping were inspected on both the filter unit and the flow-through cells used for continuous field parameter measurement. The tubing was inspected prior to the ETV test for excess sediment build-up and cracking, and any leaks were fixed.

A control run was performed with low-turbidity water and without the precoat or body feed to evaluate the organism recovery of the filter unit equipment.

3.6.8 Specific Equipment QA Verification

A routine daily walk-through during testing was performed to verify that each piece of equipment or instrumentation was operating properly. Particular care was taken to confirm that filter aid was being fed at the defined flow rate into a flow stream that was operating at the expected flow rate. Daily readings of the in-line flow meter, and the pressure gages were collected, along with daily calibration checks of the in-line turbidimeters, particle counters, and field parameter instruments. The individual calibration requirements for each instrument used in the testing are described below.

3.6.8.1 pH

Analyses for pH was performed according to *Standard Methods* 4500-H+ (APHA et al. 1999). A 3-point calibration of the pH meter used in this study was performed once per day when the instrument was in use. Certified pH buffers in the expected range were used (4, 7 and 10). The pH probe was stored in the appropriate solution defined in the instrument manual. Transport of carbon dioxide across the air-water interface can confound pH measurement in poorly buffered waters.

3.6.8.2 Temperature

Readings for temperature were conducted in accordance with *Standard Methods* 2550. Raw water temperatures were measured manually. The thermometer was certified by NIST and had a precision of 0.1°C.

3.6.8.3 Dissolved Oxygen

Analysis for DO was performed according to *Standard Method* 4500-O using the membrane electrode method. The techniques described for sample collection were followed very carefully to avoid causing changes in DO during the sampling event. Samples taken for DO were analyzed immediately using the DO membrane-electrode probe.

3.6.8.4 Bench-top Turbidimeters

Turbidity analysis was performed according to *Standard Methods* 2130 with either a bench-top or in-line turbidimeter. In-line turbidimeters were used for measurement of turbidity in the filtrate water and the feedwater.

During each verification testing period, the bench-top turbidimeters were left on continuously. Once each turbidity measurement was complete, the bench-top unit was switched back to its lowest setting. All glassware for turbidity measurements was cleaned and handled using lint-free tissues to prevent scratching. Sample vials were stored inverted to prevent deposits from forming on the bottom surface of the cells.

Grab samples were taken daily for analysis using a bench-top turbidimeter. Readings from this instrument served as reference measurements throughout the study. The bench-top turbidimeter was calibrated at the beginning of pilot plant operation and on a weekly basis using primary turbidity standards of 18 NTU and 180 NTU as per the manufacturer's recommendation for that model turbidimeter. Gelex secondary turbidity standards of 0 to 2 NTU, 0 to 20 NTU and 0 to 200 NTU were checked against the primary standards after calibration to assign them a specific value. The secondary standards were used on a daily basis to verify the calibration of the turbidimeter. The calibration of the turbidimeter was checked against a 0.091 ± 0.003 NTU turbidity proficiency standard on a weekly basis, or each time the turbidimeter was calibrated. If the proficiency standard did not meet an allowable difference of approximately 10%, a primary calibration was performed.

The method for collecting grab samples consisted of running a slow, steady stream from the sample tap, triple-rinsing a dedicated sample beaker in this stream, and allowing the sample to flow down the side of the beaker to minimize bubble entrainment. The sample vial was double rinsed with the sample, carefully pouring from the beaker down the side of the sample vial, wiping the sample vial clean, inserting the sample vial into the turbidimeter, and recording the measured turbidity. For cold-water samples, which caused the vial to fog preventing accurate readings, the vial was allowed to warm up by partially submersing it into a warm water bath for approximately 30 seconds.

3.6.8.5 In-line Turbidimeters

In-line turbidimeters used for feed water and filter water monitoring during verification testing were calibrated and maintained as specified in the manufacturer's operation and maintenance manual. In-line readings were verified daily using a bench-top turbidimeter. Although the mechanism of analysis is not identical between the two instruments, the readings are comparable. When these readings suggested inaccurate readings, all in-line turbidimeters were recalibrated. Periodic cleaning of the lens was conducted using lint-free paper to prevent any particle or microbiological build-up that could produce inaccurate readings. Daily verification of the sample flow rate was performed using a volumetric measurement. Instrument bulbs were replaced as needed. It was also verified that the LED readout matched the data recorded on the data acquisition system.

3.6.8.6 In-line Particle Counters

In-line particle counters were employed to measure particle concentrations in both feed waters and filtrate waters. The Hach 2200 PCX Particle Counters with a size range of 2 to 750 µm were manufactured in December 1999, serial numbers #991200240 and #991200244. A Hach service representative calibrated the particle counters in the high bay at the test site on March 7, 2002. The calibration reports are included in the Appendix G.

The following particle size ranges (as recommended by the AWWARF Task Force) were monitored during the verification testing:

- 2-3 µm
- 3-5 µm
- 5-7 µm
- 7-10 µm
- 10-15 µm
- >15 µm

Any problems experienced with the particle counting equipment were documented in the daily logbook, as were modifications or remedial actions. The flow through the particle counters was calibrated volumetrically on a daily basis and recorded in the logbook.

The use of particle counting to characterize feedwater and filtered water quality was planned as one surrogate method for evaluation of microbiological contaminant removal. The particle sensors selected for this project were capable of measuring particles as small as 2 µm. Performance criteria included a less than 10% coincidence error for any one measurement.

The particle counters had an updated calibration by the manufacturer. The performance of the particle counters was also verified at the beginning of verification testing using calibrated mono-sized polymer microspheres in sizes of 3, 10 and 15 microns. The results of this verification are provided in Chapter 4. The procedure for the verification of the calibration of the particle counters is provided below.

- Analyze the particle concentration of the dilution water;
- Add an aliquot of the microsphere suspension to the dilution water to provide a final particle concentration of approximately 50,000 particles per 25 mL (2,000 particles per mL), and then gently swirl the suspension;
- Promptly analyze a suspension of each particle size separately to determine that the peak of particle concentration coincides with the diameter of particles added to the dilution water;
- Prepare a cocktail of all three microsphere solutions to obtain a final particle concentration of approximately 1,000 particles per mL of each particle size; and
- Promptly analyze this cocktail to determine that the particle counter output contains peaks for all of the particle sizes.

Analysis for the in-line particle counters was achieved by feeding the solution through the in-line counter using a chemical feed pump.

The need for routine cleaning of the sensor cell is typically indicated by illumination of the sensor's "cell" or "laser" lamps, an increase in sampling time from measurement to measurement, or an increase in particle counts from measurement to measurement. During the testing, the sensor's "cell" and "laser" lamps and the sampling time were checked periodically.

Particle-free water (PFW) was used for final glassware rinsing, dilution water, and blank water. This water consisted of de-ionized water that had passed through a cartridge filtration system. This water was expected to contain fewer than 10 total particles per mL, as quantified by the on-site particle counter.

All beakers used for particle counting calibration were designed specifically for the instrument being used. Glassware was cleaned after every use by hand washing using hot water and laboratory glassware detergent solution followed by a triple PFW rinse. Sample beakers were stored inverted. Dedicated beakers were used at all times for unfiltered water (feed water before addition of body feed), diluted unfiltered water, filtered water, and PFW. Other materials in contact with the calibration samples, including volumetric pipettes, volumetric flasks, and other glassware used for dilution, were triple-rinsed with both PFW and sample between each measurement.

3.6.9 Maintenance

Routine preventive maintenance (PM) was conducted on all instruments used in the field. Maintenance was based on the recommendations of the instrument manufacturer and experience gained through use of the instrument in the field. A log of these activities was kept that detailed the PM performed, when it was performed, and the name of the person doing the work.

3.6.10 Laboratory QA/QC

The laboratory was responsible for timely analysis of the samples according to approved methods. The analysis report included the following:

- Method of analysis
- Detection limits
- Copy of the Chain-of-Custody Form
- Analysis results of all samples listed on the Chain-of-Custody Form
- Analysis results of all QA/QC samples
- Documentation of analytical problems encountered and the corrective procedures taken to solve those problems

3.6.11 Project Quality Assessment

Overall data quality was assessed by a thorough understanding of the Data Quality Objectives (DQOs) developed for the ETV test. The project data were closely monitored for accuracy, precision and completeness by:

1) maintaining thorough documentation of all decisions made during each phase of sampling;
2) performing field and laboratory audits;
3) thoroughly reviewing (validating) the analytical data as they are generated by the laboratory; and
4) providing appropriate feedback as problems arise in the field or at the laboratory.

3.6.11.1 Field Data Quality Assessment

To assure that all field data were collected accurately and correctly, specific instructions were written for each type of sampling effort. The Project Director issued this sampling and analysis plan to all personnel involved in field data acquisition. The QA personnel performed field audit(s) during the investigation to document that the appropriate sampling procedures were being followed. These audits included a thorough review of the field books used by the project personnel to ensure that all tasks are performed as specified in the instructions. Field audits enabled data quality to be assessed with regard to the field operations. Evaluation of field blanks and other field QC samples provided indications of data quality.

3.6.11.2 Data Quality Assessment

A preliminary review was performed to verify all necessary paperwork (Chain-of-Custody Form, analytical reports, laboratory personnel signatures) and deliverables. The QA personnel verified the qualitative and quantitative reliability of the data presented, and performed a detailed QA review that included a detailed review and interpretation of all data generated. The primary tools used included guidance documents, established (contractual) criteria, and professional judgment. Once the laboratory analytical data were validated, the data were assessed by comparison with analytical results obtained from previous samplings.

For each testing event, a QA report was prepared that stated the qualitative and quantitative reliability of the analytical data. The report consisted of a general introduction section, followed by qualifying statements that were taken into consideration for the analytical results to best be utilized. During the data review, a documentation package was prepared which provided the backup information that accompanied all qualifying statements presented in the QA review.

Once the review was completed, the QA personnel submitted the data to the Project Director. These approved data tables and QA reviews were signed and dated by the QA personnel.

3.6.11.3 On-Site Audit

During field activities, an on-site audit was conducted by QA personnel to review all field-related QA activities. This audit consisted of a checklist that assisted the QA personnel in covering all of the necessary QA details.

Specific elements of the on-site audit included the verification of the following:

- Completeness and accuracy of sample Chain-of-Custody Forms, including documentation of times, dates, transaction descriptions, and signatures.
- Completeness and accuracy of sample identification labels, including notation of time, date, location, type of sample, person collecting sample, preservation method used, and type of testing required.
- Completeness and accuracy of field notebooks, including documentation of times, dates, sampling method used, sample locations, number of samples taken, name of person collecting samples, types of samples, results of field measurements, and any problems encountered during sampling.
- Adherence to sample collection, preparation, preservation, and storage procedures.

3.6.11.4 Corrective Procedures

Field QA activities were reported to the Project Director. The appropriate sampler was responsible for initiating any corrective procedures and for ensuring that action was taken in a timely manner with the desired results. All corrective procedures implemented were reported to the Project Director.

3.6.12 UNH Laboratory Audits

The UNH WTTAC Laboratory performed the TOC and UV_{254} analyses. The UNH WTTAC Laboratory is not state- or EPA-certified because of the nature of the educational mission of the University. However, the UNH WTTAC Laboratory underwent internal and NSF QA audits as part of the ETV testing protocol.

3.7 Task 7: Operation and Maintenance Manual Evaluation

The O&M manual supplied by Separmatic™ for their Model 12P-2 filter unit was evaluated both quantitatively and qualitatively throughout the course of the initial test runs and the verification testing. The quantitative analysis compared references to specific components of the system, and verified that the references are accurate and referred to the components of the unit shipped. Recommendations for operation settings were checked against the settings determined to be optimal for the verification testing. These included precoat amount and body feed pump settings, power requirements, and backwashing requirements for water and air.

The qualitative analyses of the O&M manual addressed its ease of use, organization, and completeness. The manual was examined for a description of the procedures for hook-up, setup, operation, and maintenance; instructions for troubleshooting common problems; and a phone number contact for technical support. The setup and operational sections of the manual were checked for recommended safety procedures.

The operations section of the manual was evaluated for completeness of the description of the precoat process to mix the DE media and feed it into the filter element. Operation and calibration recommendations for determining the end of the effective filter run were also evaluated. The filter cleaning procedure description was evaluated regarding inspection of the filter elements to determine cleaning effectiveness, and the manual was also examined for a discussion of the proper disposal of the filter cake.

The usefulness and applicability of the manual's trouble shooting suggestions were evaluated during testing as problems arose. Typical suggestions are what to do if the filter septa are not fully coated during the precoat, if the pump fails, or if filter cake remains on the septa after backwashing.

3.8 Safety Measures

The following health and safety procedures were employed during the ETV test to ensure the safety of the operator and health of the public being served by the testing facilities at the UNH WTTAC high bay.

- Proper connections, material handling procedures, and personal protection equipment safeguarded the operator.
- The filter system was isolated within the facility to protect the public.
- During the testing, a tank of water separated the filter system and the raw water to provide constant pressure to the system. This disconnect ensured that the filter media and microbial challenge water were not drawn back into the raw water feed piping.
- The unit has two electrical plugs that fit a standard 120-volt outlet. To minimize electrical hazards, the unit was plugged into a receptacle on a circuit protected by a 20-amp ground-fault interrupter circuit breaker.
- This filter unit does not utilize chemicals in the operation of the equipment.
- Operators were required to wear protective gloves and particulate respiratory filters when handling the DE filter aid media for the preparation of the precoat and the body feed.
- Operators were required to wear particulate respiratory filters, protective gloves, coveralls or lab coats, and safety glasses when working with microbiological seed materials to prevent personal contact with the organisms.

3.9 Testing Schedule

The system integrity test was performed on January 9, 2003. Task 2 initial test runs began on January 31, 2003, to determine that the filter system was operating as expected. The verification testing occurred during March, April, and May 2003.

Chapter 4
Results and Discussion

4.1 Prior Test

The Separmatic™ Model 12P-2 System's first ETV test occurred between April 22 and July 7, 2000, in Manchester, New Hampshire. The source water used during the first verification test came from a canal on Lake Massabesic. Unfortunately, the canal water became stagnant during the first ETV test due to lack of use of the canal water by a local power facility, and the water contained high amounts of algae as a result. The algae shortened run times by approximately 75% of the manufacturer's estimated duration. As a result, the first ETV test fell short of the required ETV test duration of 11.3 days and lacked the required number of ETV *Cryptosporidium* challenges for DE filter units. The data collected from this first ETV test were deemed incomplete, and UNH WTTAC performed a retest of the system. The retest (the second ETV test) is described in this report. A description of the first ETV test (April 22 – July 7, 2000) is provided in Appendix I.

4.2 ETV Retest

The ETV retest was conducted at the UNH WTTAC high bay, room 147 of Gregg Hall located at 35 Colovos Road, Durham, New Hampshire. The retest was conducted between March 10 and May 28, 2003.

4.2.1 Task 1: Characterization of the Feed Water

The source water for the ETV retest was finished water from the Arthur Rollins Treatment Plant. The treatment plant, which serves both the Town of Durham and the University of New Hampshire, obtains its water from a reservoir on the Oyster River. Water quality characterization details can be found in Chapter 3. The source water was pretreated with a 15 µm string pre-filter prior to use to assist in the provision of consistent water for treatment. The pre-filtration occurred before the Durham finished water was collected in the feed and the challenge tanks used during the testing. The feed water sampling port and sampling board, which contained the online sampling instrumentation such as turbidimeters and particle counters, were located between the feed and challenge tanks and the Separmatic™ Pressure DE unit.

4.2.2 Task 2: Initial Testing

Prior to the actual retest of the pressure filter, an integrity test, or leak check, was performed on the septum and the internal components of the pressure system on January 9, 2003, using the method developed by Lange et al. (Lange, 1986). The integrity test was performed following a 0.4 lb/ft^2 precoat application of Filter Cel® DE, a very fine grade of DE. The system was then challenged with *E. Coli* F-amp for 1 hour. The target flow rate was 1 gpm/ft^2 or 2 gpm, but the unit averaged 1.74 gpm with the 0.4 lb/ft^2 precoat of Filter Cel®. The effluent samples collected at 30 minutes and after 60 minutes of operation indicated that no *E. Coli* were detected in the effluent produced during the integrity challenge. The system was therefore deemed to be functioning properly and operating reliably.

Initial test runs performed during February 2003 to determine the optimum precoat and body feed rates to be used during the verification and challenge testing determined that the system would be operated with a 0.2 lb/ft^2 precoat of Hyflo Super Cel DE and that a body feed of 2 mg/L of 503 DE would be used during the ETV test. Hyflo Super Cel is a flux-calcined filter aid made from plankton marine diatomite and has a median pore size of 7.0 microns, pH of 10, dry density of 10 lbs/ft^3, and is in powder form. Celite® 503 is a flux-calcined filter aid made from plankton marine diatomite with a median cake pore size of 10.0 microns, a pH of 10, a dry density of 12 lbs/ft^3, and is in powder form. The technical data sheets describing the DE in more detail are provided in Appendix A.

Separmatic™ representatives visited the test site and inspected the system in February 2003, and replaced the filter septa and bags. One of the septa was slightly loose, which may have caused slightly elevated particle counts in the effluent produced by the system during the initial test runs. Separmatic™ representatives also arranged for a pressure differential cutoff switch and a 2.0 gpm flow controller to be sent to UNH to be installed on the system for the verification test.

4.2.3 Task 3: Verification Testing

The verification testing of the pressure DE System was initiated on March 10, 2003, and the system was operated continuously each day through March 28, 2003, and again prior to and during the *Cryptosporidium* oocyst testing. The total of 359.9 hours of operation exceeded the ETV requirement for 272 hours of verification testing. The *Cryptosporidium* control challenge was performed on March 24, 2003, and the *Cryptosporidium* challenge testing occurred on May 14, May 19, May 20, and May 28. The data for the continuous operational period and the *Cryptosporidium* challenge testing are treated as the entire data set for the verification test. Copies of the logbook that documented field activities are provided in Appendix B.

4.2.3.1 Water Quality Results

The feed and effluent water were tested on site daily for DO, pH, and temperature. Similar values for DO and pH were consistently recorded for the feed and effluent with average values of 6.1 and 6.2 mg/L O_2 for DO and median values of 8.61 and 8.67 pH units for pH, respectively. The temperature of the feed water was consistently lower than the effluent with average values of 10.4 and 11.6 ^oC, respectively. The DO content and the pH of the feed water were not affected during the treatment process. The feed water warmed slightly during treatment. The feed and effluent water summaries are provided in Tables 4-1 and 4-2.

Table 4-1. Feed Water Quality Results for DO, pH and Temperature

	DO (mg/L O_2)	pH (pH units)	Temperature (^oC)
Count	44	47	46
Average DO/Temp., Median pH	6.1	8.61	10.4
Maximum	9.2	9.00	15.1
Minimum	3.9	8.44	7.5
Standard Deviation	1.5	NA	2.1
95% Confidence Interval	(5.6, 6.5)	NA	(9.8, 11.0)

NA – Not calculated for pH.

Table 4-2. Effluent Water Quality Results for DO, pH and Temperature

	DO (mg/L O_2)	pH (pH units)	Temperature (^oC)
Count	44	47	44
Average DO/Temp, Median pH	6.2	8.67	11.6
Maximum	8.9	8.98	16.4
Minimum	4.2	8.45	9.2
Standard Deviation	1.4	NA	2.2
95% Confidence Interval	(5.8, 6.6)	NA	(10.9, 12.2)

NA – Not calculated for pH.

During the testing, both the feed water and the effluent water were periodically tested for total iron, total manganese, TOC, and UV_{254}. . There was no appreciable difference detected between the feed water and the effluent water for the iron, manganese, TOC, and UV_{254} samples. The feed water averaged <0.06 mg/L for total iron, <0.05 mg/L for total manganese, 2.47 mg/L for TOC, and 0.039 absorbance units per cm for UV_{254}. Table 4-3 summarizes these results during verification testing. Analytical reports can be found in Appendix D.

Table 4-3. Feed Water Quality Results for Iron, Managanese, TOC , and UV_{254}

Date	Total Iron (mg/L)	Total Manganese (mg/L)	TOC (mg/L)	UV_{254} (cm^{-1})
3/13/03	---	---	2.63	0.047
3/13/03 Duplicate			2.63	0.046
3/17/03	<0.06[1]	<0.05[2]	---	---
3/17/03 Duplicate	<0.06[1]	<0.05[2]		
3/20/03	---	---	2.55	0.035
3/20/03 Duplicate			2.56	0.037
3/26/03	<0.06[1]	<0.05[2]	---	---
3/26/03 Duplicate	<0.06[1]	<0.05[2]		
3/27/03	---	---	1.86	0.032
3/27/03 Duplicate			1.86	0.032
5/20/03	---	---	2.50	0.038
5/20/03 Duplicate			2.54	0.038
5/28/03	---	---	2.77	0.043
5/28/03 Duplicate			2.76	0.042
Count	4	4	10	10
Average	<0.06[1]	<0.05[2]	**2.47**	**0.039**
Maximum	<0.06[1]	<0.05[2]	**2.77**	**0.047**
Minimum	<0.06[1]	<0.05[2]	**1.86**	**0.032**

Note:--- = no sample collected on this date.

[1] – 0.06 mg/L is the reporting detection limit for total iron.

[2] – 0.05 mg/L is the reporting detection limit for total manganese.

Table 4-4 summarizes the results of the effluent water samples analyzed for total iron, total manganese, TOC, and UV_{254} during verification testing. The effluent water averaged <0.06 mg/L for total iron, <0.05 mg/L for total manganese, 2.45 mg/L for TOC, and 0.039 absorbance units per cm for UV_{254}. Analytical reports are provided in Appendix D.

Table 4-4. Effluent Water Quality Results for Iron, Manganese, TOC, and UV_{254}

Date	Total Iron (mg/L)	Total Manganese (mg/L)	TOC (mg/L)	UV_{254} (cm^{-1})
3/13/03	---	---	2.67	0.047
3/13/03 Duplicate			2.62	0.047
3/17/03	<0.06[1]	<0.05[2]	---	---
3/17/03 Duplicate	<0.06[1]	<0.05[2]		
3/20/03	---	---	2.57	0.034
3/20/03 Duplicate			2.55	0.036
3/26/03	<0.06[1]	<0.05[2]	---	---
3/26/03 Duplicate	<0.06[1]	<0.05[2]		
3/27/03	---	---	1.87	0.032
3/27/03 Duplicate			1.87	0.032
5/20/03	---	---	2.50	0.037
5/20/03 Duplicate			2.49	0.037
5/28/03	---	---	2.77	0.042
5/28/03 Duplicate			2.63	0.043
Count	4	4	10	10
Average	**<0.06[1]**	**<0.05[2]**	**2.45**	**0.039**
Maximum	**<0.06[1]**	**<0.05[2]**	**2.77**	**0.047**
Minimum	**<0.06[1]**	**<0.05[2]**	**1.87**	**0.032**

Note:
--- = No sample collected on this date.
[1] – 0.06 mg/L is the reporting detection limit for total iron.
[2] – 0.05 mg/L is the reporting detection limit for total manganese.

4.2.3.2 Operational Results

The Separmatic™ Pressure DE filter was operated for 22 runs during verification and challenge testing with a total operational time of approximately 360 hours. The runs averaged 16.4 hours, with the longest duration filter run of 25.4 hours and the shortest duration filter run of 10.4 hours. The precoat was added at a rate of 0.2 lb/ft^2, and the body feed was added to attain a concentration of 2.0 mg/L in the feed. The variation in the length of filter runs may indicate that the body feed was not always optimized for the feed water conditions. Even though the feed water was filtered through a 15 micron filter, the quality of the feed water during the runs may have been influenced by water use within the system and/or treatment plant performance, which may have resulted in shorter than anticipated filter runs.

The total amount of DE used was, therefore, a function of the precoat, the length of each filter run, and the amount of body feed added. A total of 9.49 lbs of DE was used for precoat and body feed during the 22 filter runs. The summary data in the following tables include information on precoat and body feed loading rate, total DE used, power consumption, and total water filtered. Summary spreadsheets with the calculations are included in Appendix E.

Table 4-5. Operational Results

Filter Run	Dates (2003)	Run Start	Run Stop	Run Time (hours)	Precoat (lbs/ft^2)	Body feed (grams)	Total DE (lbs)
1	3/11-3/12	14:30	9:40	19.2	0.2	18.1	0.44
2	3/12- 3/13	14:49	7:04	16.3	0.2	14.5	0.43
3	3/13-3/14	11:55	4:10	16.3	0.2	13.7	0.43
4	3/14- 3/15	12:30	9:15	20.8	0.2	18.6	0.44
5	3/15-3/16	10:15	9:30	23.3	0.2	20.8	0.45
6	3/16-3/17	10:25	6:25	20.0	0.2	15.7	0.43
7	3/17-3/18	10:51	5:16	18.4	0.2	16.6	0.44
8	3/18-3/19	13:10	8:00	18.8	0.2	18.7	0.44
9	3/19-3/20	10:37	5:37	19.0	0.2	14.0	0.43
10	3/20-3/21	11:13	1:49	14.6	0.2	12.4	0.43
11	3/21-3/22	11:27	1:22	13.9	0.2	12.1	0.43
12	3/22-3/22	7:04	19:44	12.7	0.2	10.6	0.42
13	3/23-3/24	10:24	1:44	15.3	0.2	13.6	0.43
14	3/24-3/25	17:57	4:27	10.5	0.2	9.9	0.42
15	3/25-3/26	15:45	4:55	13.2	0.2	11.7	0.43
16	3/26-3/27	10:00	1:50	15.8	0.2	12.9	0.43
17	3/27-3/28	10:55	1:39	14.7	0.2	11.8	0.43
18	3/28-3/28	11:32	21:57	10.4	0.2	9.5	0.42
19	4/30-5/1	13:46	1:31	11.8	0.2	10.0	0.42
20	5/14-5/14	7:10	21:45	14.6	0.2	12.3	0.43
21	5/19-5/20	6:46	8:10	25.4	0.2	24.6	0.45
22	5/28-5/28	6:54	21:59	15.1	0.2	12.3	0.43
	Total For Verification Testing			359.9	4.4	314	9.49
			Average	16.4	0.2	14.3	0.43
			Maximum	25.4	0.2	24.6	0.45
			Minimum	10.4	0.2	9.5	0.42
			Standard Deviation	3.9	0.0	3.88	0.01
			95% Confidence Interval	(14.7, 18.0)	(0.2, 0.2)	(12.7, 15.9)	(0.43, 0.44)

1. Note: The Separmatic™ Pressure DE unit Model 12P-2 is rated for two square feet of effective filter area.

Over the approximately 360 hours of operation, the unit produced a total of 35,531 gallons of treated water. The unit consumed 9.5 kW-hr of energy per 1000 gallons of treated water produced. Table 4-6 summarizes the average flow rate, the approximate amount of water treated, the power consumed, and the amount of water used to clean the filter for each filter run.

Table 4-6. Flow Rate and Amount of Water Treated

Filter Run	Dates	Run Start	Run Stop	Run Time (hours)	Average Flow Rate[1] (gpm)	Water Treated[2] (gal)	Power (kW-h)[3]	Water Used[4] (gals)
1	3/11-3/12	14:30	9:40	19.2	1.78	2047	19	30
2	3/12- 3/13	14:49	7:04	16.3	1.67	1628	14	30
3	3/13-3/14	11:55	4:10	16.3	1.62	1580	16	30
4	3/14- 3/15	12:30	9:15	20.8	1.64	2042	21	30
5	3/15-3/16	10:15	9:30	23.3	1.74	2427	23	30
6	3/16-3/17	10:25	6:25	20.0	1.69	2028	18	30
7	3/17-3/18	10:51	5:16	18.4	1.60	1768	17	30
8	3/18-3/19	13:10	8:00	18.8	1.70	1921	18	30
9	3/19-3/20	10:37	5:37	19.0	1.63	1858	18	30
10	3/20-3/21	11:13	1:49	14.6	1.63	1428	14	30
11	3/21-3/22	11:27	1:22	13.9	1.60	1336	14	30
12	3/22-3/22	7:04	19:44	12.7	1.64	1247	13	30
13	3/23-3/24	10:24	1:44	15.3	1.64	1509	15	30
14	3/24-3/25	17:57	4:27	10.5	1.56	983	10	30
15	3/25-3/26	15:45	4:55	13.2	1.59	1256	13	30
16	3/26-3/27	10:00	1:50	15.8	1.57	1491	15	30
17	3/27-3/28	10:55	1:39	14.7	1.57	1388	14	30
18	3/28-3/28	11:32	21:57	10.4	1.54	963	11	30
19	4/30-5/1	13:46	1:31	11.8	1.62	1142	11	30
20	5/14-5/14	7:10	21:45	14.6	1.68	1470	12	30
21	5/19-5/20	6:46	8:10	25.4	1.64	2499	20	30
22	5/28-5/28	6:54	21:59	15.1	1.68	1520	14	30
Totals				**359.9**		**35,531**	**340**	**660**

1. Average flow rate was calculated from SCADA flow rate data recorded at five-minute intervals.
2. Water treated was calculated by multiplying the average flow rate from the SCADA data recorded at five-minute intervals and the filter run time.
3. The power meter was read at the start and following a run and the power (kW-h) used is pro-rated for the runtime listed in the tables.
4. Water used is total water used for cleaning. A portion of this water might be recycled to reduce water use.

4.2.3.3 Particle Count and Turbidity Results

Particle count and turbidity readings were recorded by a Supervisory Control and Data Acquisition (SCADA) system every five minutes during the 22 filter runs. Elevated particle counts and turbidities relative to the feed water values were often measured at the start of filter runs. After 5 to 10 minutes, these elevated readings would quickly decrease to consistently lower readings. These elevated initial readings could be the result of inactivity in the effluent lines or residual particles from the precoat process, or they could be a by-product of the transition from recirculation during precoating to feed water flow through the system or the fine tuning of flow through the particle counters. Therefore, the initial 5 to 10 minutes of data were not included in the operational performance evaluation or water production runtime when this occurred. An example of the initial elevated effluent particle counts and turbidities is shown in Table 4-7. The manufacturer recommends that the initial effluent water either be wasted or recirculated to the feed to maximize effluent water quality.

Table 4-7. Example of Elevated Initial Effluent Particle Counts and Turbidities

Date	Time	Influent Total Count (particles/mL)	Effluent Total Count (particles/mL)	Influent Turbidity (NTU)	Effluent Turbidity (NTU)
March 14	12:25	82.2	485.4	0.16	0.15
	12:30	80.6	28.4	0.17	0.19
	12:35	80.2	37.7	0.16	0.16
	12:40	79.4	23.0	0.16	0.15
March 15	10:10	65.8	503.3	0.16	0.15
	10:15	63.9	17.8	0.16	0.22
	10:20	63.7	15:5	0.16	0.17
	10:25	63.0	11.2	0.16	0.15
March 16	10:20	33.1	97.7	0.09	0.29
	10:25	33.6	36.3	0.09	0.20
	10:30	32.5	28.5	0.09	0.13
	10:35	34.0	17.1	0.09	0.10

The average influent cumulative (2 to >15 microns) particle counts during the test period was 47 counts/mL and the average effluent cumulative particle counts was 8 counts/mL. The particle count data showed an 83% removal for cumulative particles. The Durham, New Hampshire, drinking water was pre-filtered with a 15 micron string filter prior to collection in the storage tanks used to feed the system for operation and challenges. Feed water samples were collected from a sample port, and continuous on-line analysis occurred after the water had been pre-filtered and collected in the feed and challenge tanks. The pre-filtration created a feed water with low particle counts in the 10-15 micron and the >15 micron size ranges. The feed averaged 0.2 counts/mL in the 10-15 micron size range and 0.0 counts/mL in the >15 micron size range. The addition of body feed to the system just before the pressure filter but following the feed particle counter resulted in a negative removal of particles in the 10-15 micron and the >15 micron size ranges. A printout of the SCADA recordings is provided in Appendix E. Tables 4-8 to 4-10 summarize the particle count data:

Table 4-8. Feed Water Particle Counts (counts/mL)

	2-3 µm	3-5 µm	5-7 µm	7-10 µm	10-15µm	> 15 µm	Cumulative
Count	4323	4323	4323	4323	4323	4323	4323
Average	24.2	18.8	2.4	1.4	0.2	0.0	47.1
Maximum	418.3	332.7	41.7	22.8	3.1	0.3	818.6
Minimum	3.2	1.6	0.0	0.0	0.0	0.0	6.0
Standard Deviation	29.9	23.0	2.9	1.6	0.3	0.0	57.3
95% Confidence Interval	(23.3, 25.1)	(18.1, 19.5)	(2.3, 2.5)	(1.3, 1.4)	(0.2, 0.2)	(0.0, 0.0)	(45.4, 48.8)

Table 4-9. Effluent Water Particle Counts (counts/mL)

	2-3 µm	3-5 µm	5-7 µm	7-10 µm	10-15µm	> 15 µm	Cumulative
Count	4319	4319	4319	4319	4319	4319	4319
Average	3.1	3.1	0.7	0.7	0.3	0.1	7.9
Maximum	28.2	28.2	7.5	8.9	4.6	7.4	72.9
Minimum	0.3	0.2	0.0	0.0	0.0	0.0	0.8
Standard Deviation	2.1	2.1	0.5	0.6	0.2	0.3	5.4
95% Confidence Interval	(3.0, 3.1)	(3.0, 3.2)	(0.6, 0.7)	(0.7, 0.7)	(0.2, 0.3)	(0.1, 0.1)	(7.7, 8.1)

Table 4-10. Particle Count Percent Removal

	2-3 µm	3-5 µm	5-7 µm	7-10 µm	10-15µm	> 15 µm	Cumulative
Average	87%	84%	73%	48%	-10%	-480%	83%

Note: Based on feed water and effluent average particle counts/mL.

The influent particle counts, while low on average, showed a decreasing trend over the period of each run. This may have been a function of water use and demand for the water within the water system. The particle counts for the effluent produced by the pressure DE system generally mirrored the influent particle counts, with the highest particle counts occurring at the beginning of a filter run and diminishing counts occurring during the first hour of operation. The effluent particle counts were then fairly steady during the remainder of the filter run with periodic increases in counts/mL followed by a subsequent decrease.

The influent and effluent particle count data are shown in the following two graphs. Figures 4-1 and 4-2 present identical data with two different scales for particle counts. The larger scale graph shows the data trends for the influent and the effluent and the tighter scale helps to show the differences between the influent and the effluent data.

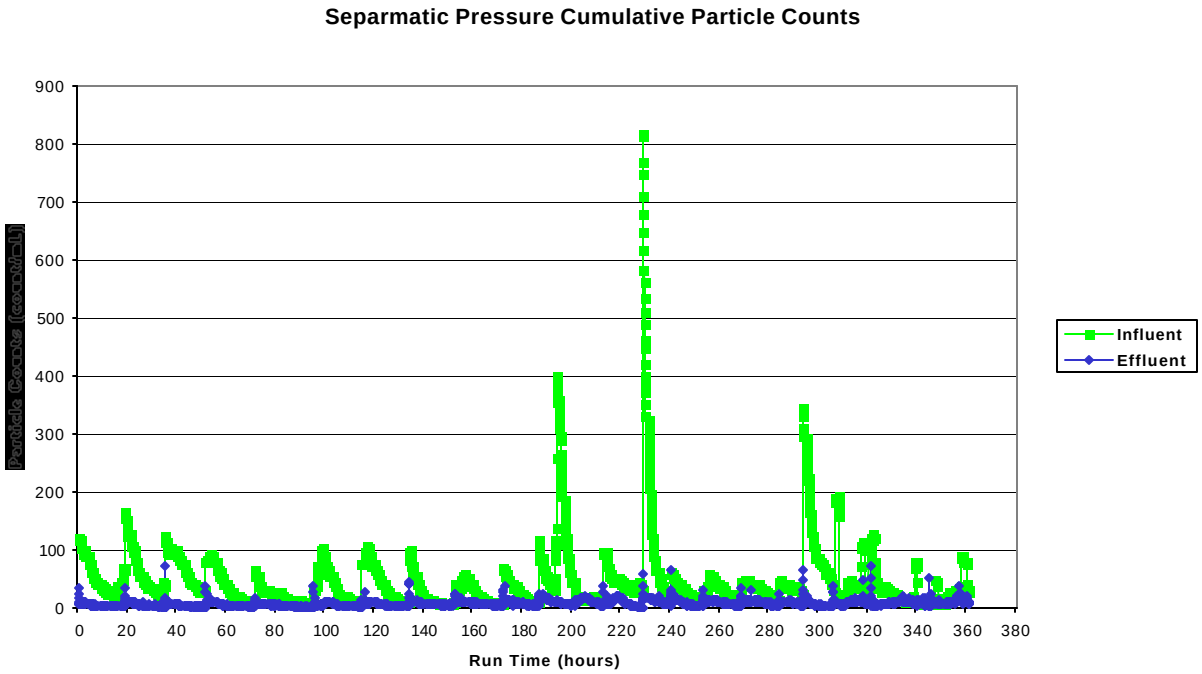

Figure 4-1. Separmatic™ Pressure DE System cumulative particle counts.

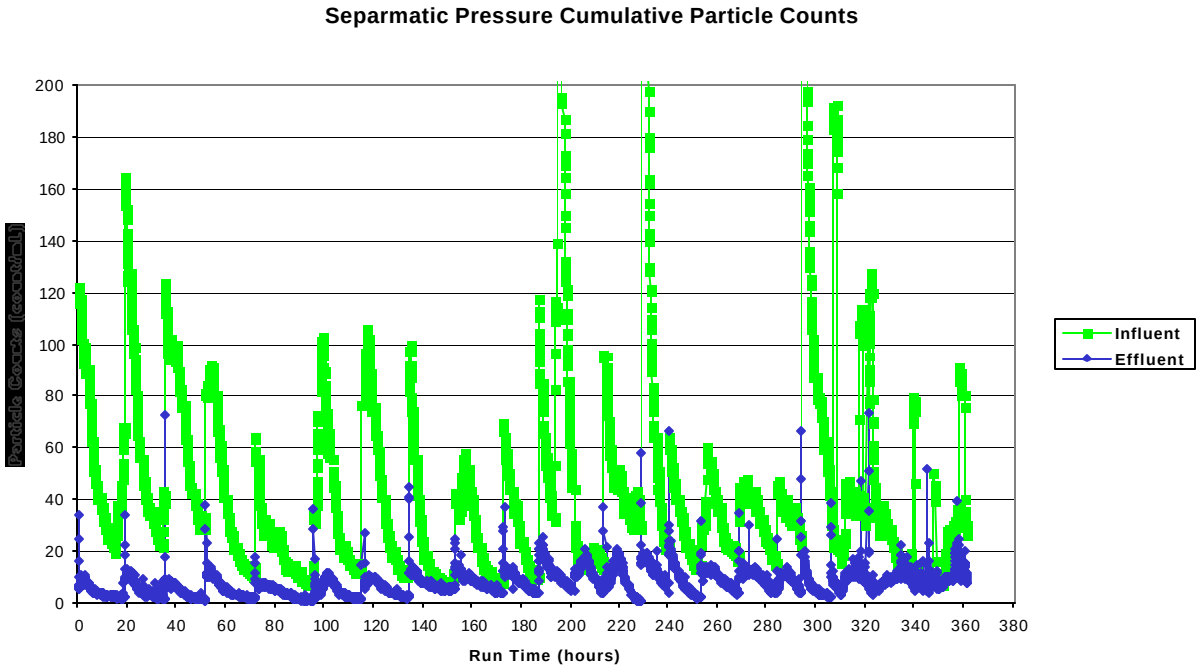

Figure 4-2. Separmatic™ Pressure DE System cumulative particle counts 0 to 200 counts/mL scale.

The development of the differential pressure between the pressure entering the filter and the pressure exiting the filter during the filtration runs is shown in Figure 4-3. It was quite consistent and repeatable during the 22 filter runs. Initial differential pressure averaged 7.9 ± 1.3 psi, while ending differential pressure averaged 24.7 ± 1.5 psi during the 22 runs.

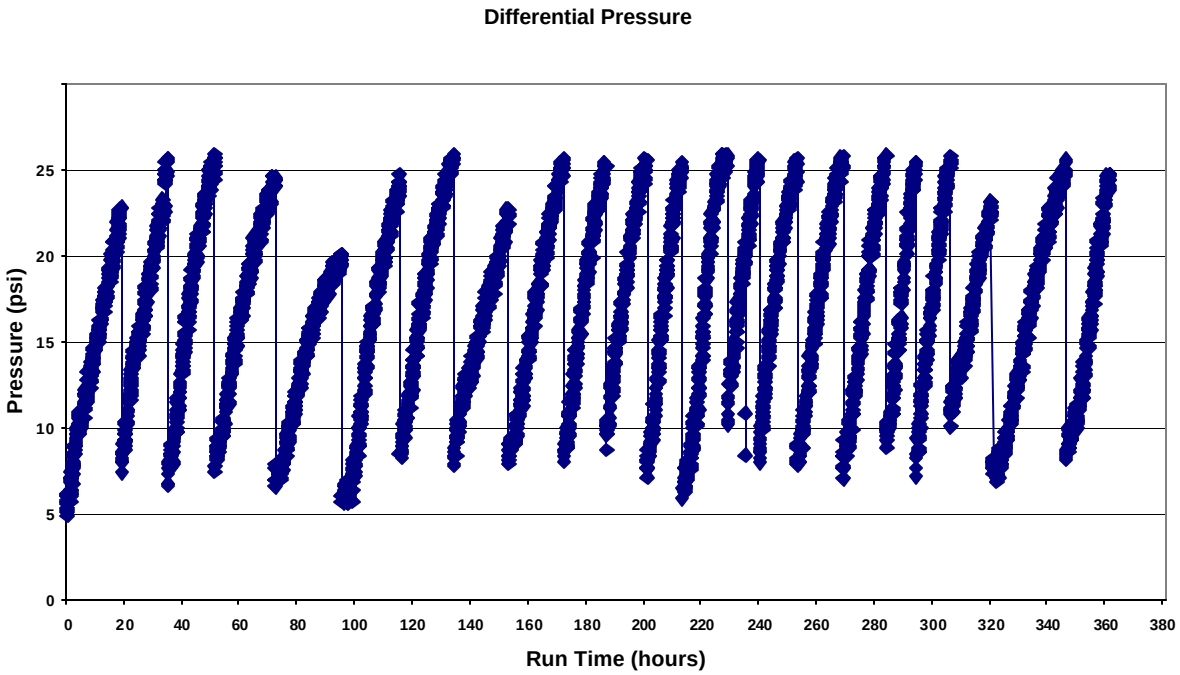

Figure 4-3. Separmatic™ Pressure DE System differential pressure.

The in-line turbidity results, summarized in Table 4-11, showed the effluent following the trend of the influent turbidity. While the effluent turbidity was often slightly elevated at the beginning of a filtration run, the levels quickly returned to lower readings, usually within 5 to 10 minutes. After an initial break-in or ripening, the effluent DE turbidity consistently mirrored the influent, only at a lower turbidity. The elevated initial effluent turbidity readings may reflect inactivity during the precoat process or the passage of remnants in the system of the DE used for the precoating or the ripening of the filter cake. These data were not included in the graphs. There were no periods of breakthrough indicated by prolonged elevated effluent turbidity, although during several runs the influent and effluent turbidity both increased, which may indicate that the body feed was not optimized for the change in influent water conditions. This was most noticeable during the last filter run, where effluent turbidity levels rose to higher than usual levels following the increase in influent turbidity during the course of the filter run. ETV reporting requirements for turbidity include determining the percentage of turbidity data in the range of 0.50 NTU or lower, the percentage between 0.51 NTU and 1.0 NTU, and the percentage that exceed 1.0 NTU. One hundred percent of the reported effluent turbidity results fell within the 0.50 NTU or lower range. The influent and effluent turbidity data for the entire verification period are shown in Figure 4-4.

Table 4-11. Summary of In-Line Turbidity Results

	Influent (NTU)	Effluent (NTU)
Count	4323	4290
Average	0.20	0.13
Standard Deviation	0.08	0.04
Maximum	0.65	0.38
Minimum	0.08	0.07
95% Confidence Intervals	(0.20, 0.21)	(0.13, 0.14)

Note: Readings recorded by SCADA every 5 minutes.

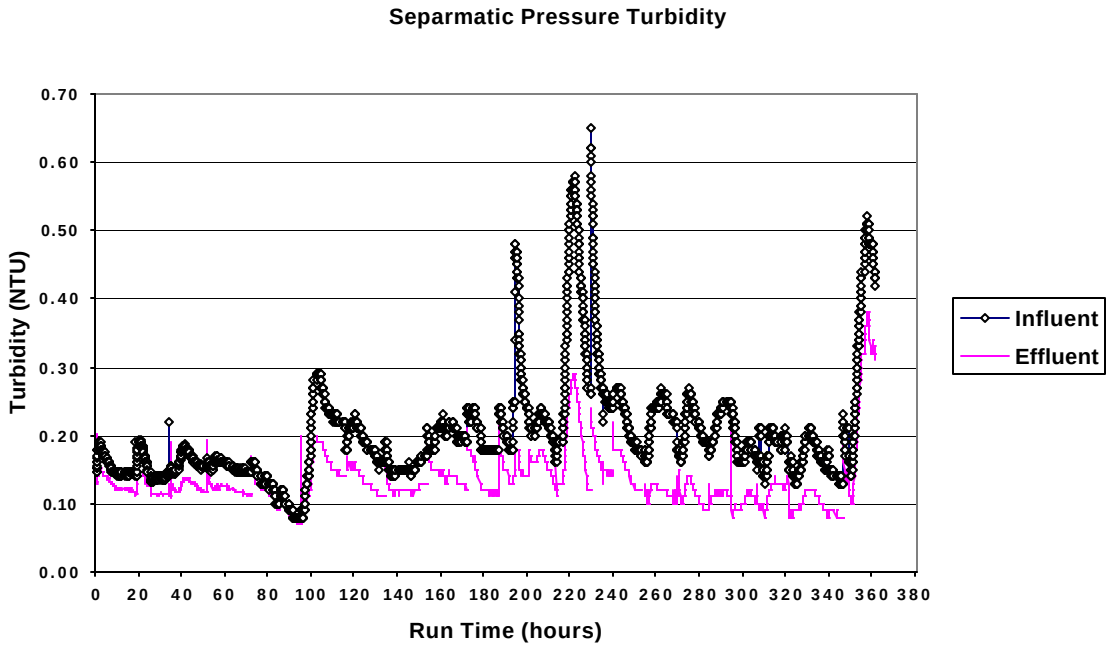

Figure 4-4. Separmatic™ Pressure DE turbidity profile.

4.2.4 Task 4: Cryptosporidium oocyst Challenges

Seven *Cryptosporidium* oocyst challenges were conducted during the challenge testing. The challenges included one control to determine if oocysts would be removed by just the Separmatic™ Pressure DE System with the septa and filter bags but without DE precoat or body feed, and three sets of two challenges each, which were conducted during the same filter run with DE precoat and body feed. In the sets, an initial challenge was performed during the first 1.5 hours of operation and a second challenge was performed at 85% of terminal headloss during the filter run, commencing when a pressure differential of approximately 21 psi was reached.

The control challenge performed on March 24, 2003, without precoat or body feed indicated 6.2 log_{10} of *Cryptosporidium* oocysts in both the feed and the effluent, demonstrating that oocysts were not removed by the system hardware, plastic filter elements, or septa.

Three sets of two challenges were performed. A set was performed on each of the following dates: May 14, May 19 and 20, and May 28. The results of the three sets of challenges are summarized in Table 4-12. The removal of oocysts averaged 4.2 ± 0.9 log_{10} for the six challenges with log_{10} removals ranging from 3.1 to 5.2. In two of the three sets of challenges, the challenge at the start of the run (1.5 hour point) and the challenge at the 85% point showed very similar log_{10} removals. In the third set of challenges, there was a difference between the log_{10} removal of oocysts at 1.5 hours and at the 85% mark, largely the result of the 5.2 log_{10} removal recorded for the 1.5 hour challenge, which was the highest achieved during the three challenges. The 3.7 log_{10} at 85% point was within the range of the 3.1 log_{10} removal recorded for challenge set #1 and the 4.8 log_{10} removal for challenge set #2 at the 85% point in each filter run.

A summary of the data for the three sets of challenges shows the 1.5 hour challenges averaging 4.4 ± 0.9 log_{10} and the 85% challenges averaging log removals of 3.9 ± 0.9 log_{10}. The results indicate that the removal of *Cryptosporidium* oocysts was not substantially affected by whether the challenge was conducted at the beginning or the end of a filter run.

The particle count removals provided in Table 4-12 are based on the sum of the particles in the 2-5 micron size range that were recorded by the SCADA system during each challenge period. The log_{10} removal of *Cryptosporidium* oocysts, as shown by the laboratory analysis of the Envirochek^{TM} filters for the influent and effluent water collected during each challenge, was higher than the removal of 2-5 micron size particles during each challenge. The particle count results were a function of lower than expected particle counts in the feed water and did not reflect high counts in the effluent water.

Table 4-12. *Cryptosporidium* Oocyst Sample Results

		Cryptosporidium oocysts (#/20L)			Particles (2-5 μm)
Challenge Set # (Date)	Time/Description	Feed Water	Effluent	Log_{10} Removal Oocysts	Log_{10} Removal Particles
1					
(5/14/03)	**1.5 hrs**	2.1 x 10^6	1044	---	---
	1.5 hrs Duplicate	2.3 x 10^6	737	---	---
	1.5 hrs Average	**2.2 x 10^6**	**891**	**3.4**	**1.4**
(5/14/03)	**85%**	1.3 x 10^6	1177	---	---
	85% Duplicate	1.6 x 10^6	1215	---	---
	85% Triplicate	---	1419	---	---
	85% Average	**1.5 x 10^6**	**1270**	**3.1**	**1.0**
2					
(5/19/03)	**1.5 hrs**	1.6 x 10^6	36	---	---
	1.5 hrs Duplicate	1.5 x 10^6	39	---	---
	1.5 hrs Average	**1.6 x 10^6**	**38**	**4.6**	**1.4**
(5/20/03)	**85%**	2.5 x 10^6	43	---	---
	85% Duplicate	1.7 x 10^6	20	---	---
	85% Triplicate	1.7 x 10^6	---	---	---
	85 % Average	**2.0 x 10^6**	**32**	**4.8**	**1.1**
3					
(5/28/03)	**1.5 hrs**	2.9 x 10^6	19	---	---
	1.5 hrs Duplicate	2.7 x 10^6	NA[1]	---	---
	1.5 hrs Average	**2.8 x 10^6**	**19**	**5.2**	**0.8**
(5/28/03)	**85%**	2.3 x 10^6	404	---	---
	85% Duplicate	1.7 x 10^6	357	---	---
	85% Average	**2.0 x 10^6**	**381**	**3.7**	**0.9**

1 – The results for the duplicate were lost during processing at the diagnostic laboratory and are not available.

4.2.5 Task 5: Data Collection

Data were recorded using the methods specified in Chapter 3. During the verification process, data were downloaded onto a laptop computer and backed up using 100 MB "Zip" disks. Data on particle counts were processed using VISTA™ software, which accompanied the Hach particle counters. This system was set up to download data every five minutes. The VISTA data were then copied to an Excel spreadsheet for analysis. Other water quality data were compiled from reports and field logbooks and transferred to an Excel spreadsheet for statistical analysis.

4.2.6 Task 6: Quality Assurance/Quality Control (QA/QC)

A QA/QC program was conducted throughout the testing to assure the quality and integrity of the measurements for operational and water quality parameters.

4.2.6.1 Data Correctness

There are five indicators of data correctness:

- Representativeness
- Statistical Uncertainty
- Completeness
- Accuracy
- Precision

The methods used for data analysis are outlined in Chapter 3. EPA/NSF ETV protocols were followed during testing to ensure the representativeness of the samples.

4.2.6.2 Statistical Uncertainty

Ninety-five percent confidence intervals were calculated for operational runtimes, DE precoat, body feed and total DE, and for water quality parameters including particle counts and turbidity. The results are summarized in tables in Chapter 4 and included in the appropriate appendices.

4.2.6.3 Completeness

Data completeness refers to the amount of data collected during the ETV testing compared to the amount of data proposed in the PSTP. Nearly 100 % of the required readings and calibrations were performed during the verification and challenge testing. A summary of the calculation of completeness is included in Appendix F.

4.2.6.4 Accuracy

Accuracy was quantified as the percent recovery of a parameter in a sample to which a known quantity of that parameter was added. Accuracy determination in this ETV testing was performed by the analysis of a turbidity proficiency sample and on-site bench-top turbidimeter standards. The analysis of the bench-top turbidity proficiency samples during the verification testing averaged 98 percent, with a range of 89 to 100 percent.

The performance of the particle counters was also verified at the beginning of verification testing using Duke Scientific NIST traceable mono-sized polymer microspheres in sizes of 3, 10 and 15 microns. Individual verification challenges were performed for 3, 10 and 15 micron microspheres. The target particle concentrations were 2,000 particles/mL. A verification challenge was also performed with a cocktail of all three different sized monospheres, each with an anticipated concentration of 1,000 particles/mL.

The influent and effluent particle counters were analyzed at flow rates of 100 mL/ minute treating the same particle stream, which was split to feed the two particle counters. The 3 µm monospheres were detected in the 2-3 and the 3-5 µm bins by the particle counters, the 10 µm monospheres were detected in the 7–10 and 10-15 µm bins, and the 15 µm monospheres were detected in the 10 - >15 µm bins. The particle counters produced similar responses to the microspheres in the combined 2-5 µm, 7-15 µm and 10 - >15 µm bins, respectively. Figure 4-5 summarizes the responses for the three individual challenges for the 3 µm, 10 µm and 15 µm monospheres. The data for all four verification challenges are included in Appendix F.

4.2.6.5 Precision and Relative Percent Deviation

Duplicate water quality samples were analyzed to determine the consistency of sampling and analysis using relative percent deviation (RPD). The calculations for RPD for duplicate samples are included in Appendix F. The RPDs calculated for samples were generally excellent and averaged below the ideal maximum of 10%. A few RPDs calculated for the effluent turbidimeter did exceed 10%, but these were primarily due to the sensitivity of the instrument, the low numbers involved, and a small difference resulting in a larger RPD.

4.2.6.6 Daily Checks

Daily checks included the verification of the rate of body feed addition, in-line turbidimeter and particle counter flow rates, system flow rate, and a comparison of in-line turbidity readings to bench top turbidity values. The body feed solution was mixed to provide a 2 mg/L body feed concentration when added to the feed line at approximately 47 mL/ minute. The body feed addition rate averaged 45.0 ± 3.4 mL/minute during the 22 filter runs.

Daily verification of flow through the in-line influent and effluent turbidimeters was within the 250-750 mL/minute range for 100% of the samples. The flow through the influent and effluent particle counters averaged 100 ± 0.6 mL/minute and 101 ± 0.7 mL/minute, respectively, during daily flow checks which was very close to the target flow of 100 mL/ minute. All flows were within a 98 to 102 mL/minute flow range for 100% of the verification samples.

System flow meter verification was performed daily, and the in-line flow meter and the system flow check averaged 0.76 ± 0.71 % RPD. A comparison of in-line turbidity and bench-top turbidity showed a 2.71 ± 2.14 % RPD for influent turbidity and 5.51 ± 4.36 % RPD for effluent turbidity. The higher effluent % RPD is attributable to the lower effluent turbidity readings and small differences resulting in higher % RPDs.

The data and summary tables for the QA/QC tests can be found in Appendix F.

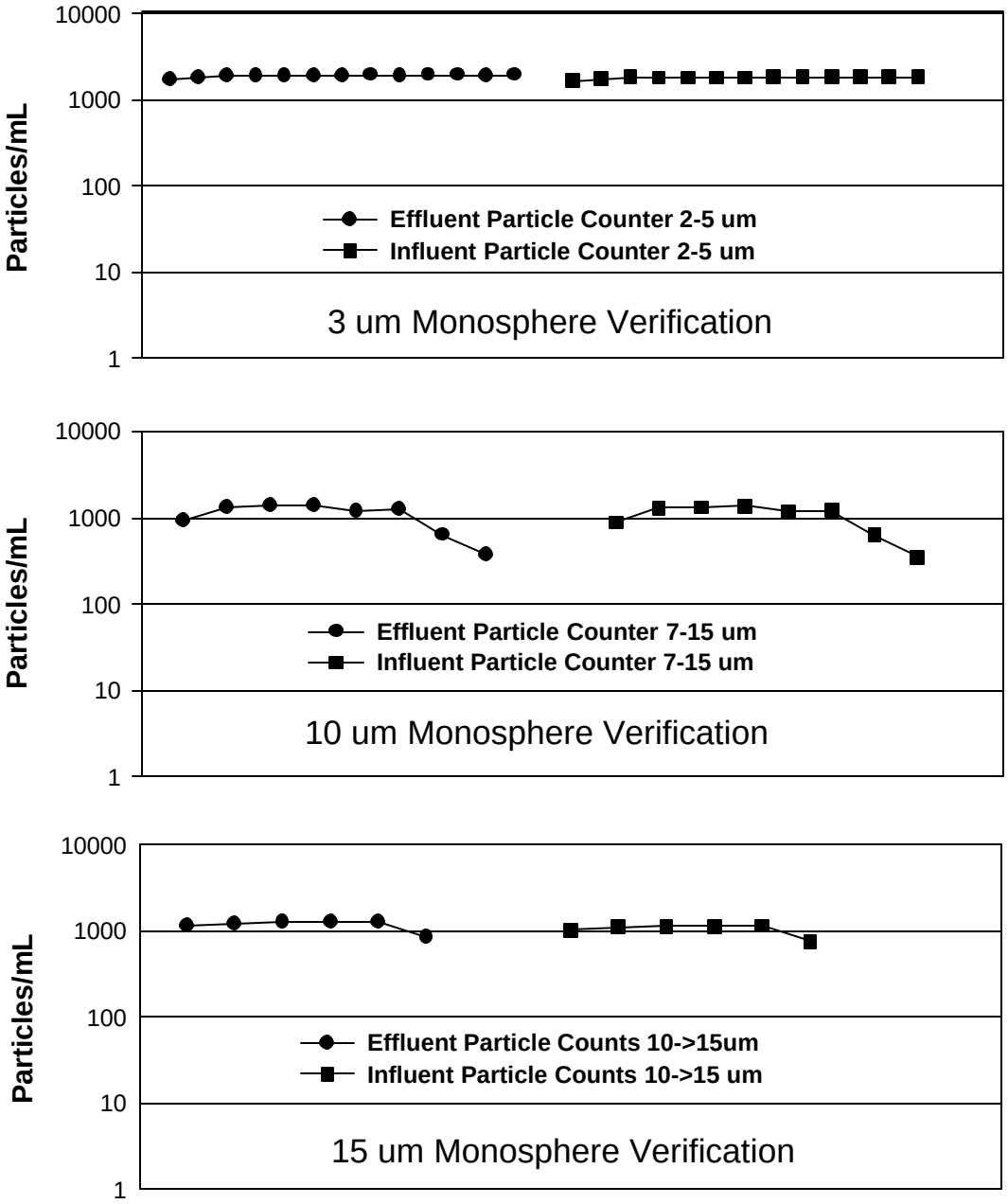

Figure 4-5. Response of In-Line Particle Counters to 3 um, 10 um and 15 um Monospheres

4.2.6.7 QA/QC Checks Performed During the Test Period

The flow meter, turbidimeters, and other equipment were routinely checked for performance, and when a discrepancy was found corrective measures were performed to avoid erroneous readings. The turbidimeters, particle counters, pressure transducers, flow meter and, tubing were all checked prior to and during the verification period.

4.2.6.8 Other QA/QC Checks

Background effluent line control samples were collected and filtered before each *Cryptosporidium* oocyst challenge set. Three of the control samples showed either no oocysts/20L or 1 oocyst/20L of effluent that was filtered for each background sample. The background sample for the second set of challenges, which were performed on May 19 and May 20, 2003, registered 169 oocysts/20L. This control sample preceded a challenge set with average effluent concentrations of 38 oocysts/20L for the 1.5 hour challenge and 32 oocysts/20L for the 85% challenge. This was the most consistent challenge with the highest average $\log_{10}$ removal. The 1.5 hour and the 85% challenges showed removals of 4.6 and 4.8 $\log_{10}$, respectively, and averaged a 4.7 $\log_{10}$ removal. The oocysts in the background sample did not appear to affect the challenge results. The analytical laboratory could not explain the results based on its analytical procedures. Aside from error or cross contamination, one possible explanation is that *Cryptosporidium* oocysts had become lodged within the system, possibly in a valve. Even though the lines and system were flushed before background sampling, it is possible that when an effluent sampling line valve was adjusted the oocysts were released to the background sample collection container sometime during the approximately 20 minutes when the sample was collected. Subsequently, even more particular attention was paid to the cleaning regimen, and the effluent sampling board, lines and valves were flushed with clean Durham finished water for one hour prior to the next and last challenge.

4.2.7 Task 7: Evaluation of the Operation and Maintenance Manual

Separmatic™ provided an O&M manual for the Model 12P-2 Pressure Filter. The manual included four chapters covering assembly of the Model 12P-2, instructions for pressure filter start-up precoat filtration, filtration and backwash procedure, a schematic drawing of the system and a parts list, and equipment operation and maintenance manuals for the components of the system. The operating instructions were simple and easy to follow. A copy of the O&M manual is provided in Appendix H.

Body feed instructions for the system were provided verbally at the test site by Separmatic™ personnel before the commencement of the verification test. Written information on body feed that is not included in the O&M manual was provided by Separmatic™; these written instructions are provided in Appendix H. The O&M manual does not include directions for the replacement of either the septa or the filter bags, which Separmatic™ may wish to perform as a company policy. Separmatic™ was helpful in providing verbal instructions for these items.

4.2.8 Other Operations and Maintenance Items

Changes were made in the procedures following the Separmatic™ representative's visit to the testing site at the WTTAC high bay during shakedown testing prior to verification testing. The representative brought and installed two new filter elements in the system. The precoating procedure was modified to take place in two steps, with an initial period of precoat flow at 1.5 times target flow followed by a shorter period of target flow to allow the precoat to settle into its intended structure on the DE filter elements. The representative also ordered a pressure differential safety switch to shut off the system when the pressure differential reached a maximum level and a 2.0 gallons per minute flow controller to replace the needle valve shipped with the system.

The operation of the system, which included preparing precoat and body feed, monitoring operations, collecting readings, and performing analyses, averaged approximately four hours per day during the normal operational runs. The time spent performing the *Cryptosporidium* challenges was not included in that average figure. The operator time during the testing is summarized in Appendix E.

Chapter 5

References

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