THE ENVIRONMENTAL TECHNOLOGY VERIFICATION PROGRAM

U.S. Environmental Protection Agency

NSF International

ETV Joint Verification Statement

TECHNOLOGY TYPE:	**MEMBRANE FILTRATION USED IN DRINKING WATER TREATMENT SYSTEMS**	
APPLICATION:	**PHYSICAL REMOVAL OF MICROBIOLOGICAL & PARTICULATE CONTAMINANTS IN DRINKING WATER**	
TECHNOLOGY NAME:	**US FILTER 3M10C MICROFILTRATION MEMBRANE SYSTEM**	
TEST LOCATION:	**CHULA VISTA, CALIFORNIA**	
COMPANY:	**US FILTER**	
ADDRESS:	**600 ARRASMITH TRAIL** **AMES, IOWA 50010**	PHONE: **(515) 232-4121** FAX: **(515) 232-2571**
WEB SITE: EMAIL:	**http://www.USFilter.com** **GallagherP@usfilter.com**	

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 substantially 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 ETV Centers. The DWS Center recently evaluated the performance of a membrane system used in drinking water treatment system applications. This verification statement provides a summary of the test results for the US Filter 3M10C Microfiltration (MF) Membrane System. MWH, an NSF-qualified field testing organization (FTO), performed the verification testing. NSF provided technical and quality assurance oversight of the verification testing described in this ETV report, including an audit of nearly 100% of the data.

ABSTRACT

Verification testing of the US Filter 3M10C membrane system was conducted over a 44-day test period at the Aqua 2000 Research Center in Chula Vista, California. The test period extended from July 24, 2002 to September 5, 2002. The source water was a blend of Colorado River and State Project Water. Verification testing was conducted at manufacturer-specified operating conditions. The membrane unit was operated in dead-end mode at a constant flux of 24 gfd (41 L/hr-m^2) with feedwater recovery of 91 percent. The membrane showed some fouling at the end of the test period. The manufacturer-recommended cleaning procedure was effective in recovering membrane productivity. Additional data was added to this report from previous California Department of Health Services (CDHS) testing (conducted independently from ETV testing) on the system to supplement particle removal data. Raw water particle counts differed between the ETV testing period and the CDHS testing period; the average for the 3-5 micron size range during the ETV testing was 1,100 particles/mL and the average for the 2-5 micron size range during the CDHS testing was 2,000 particles/mL. The average raw water count for the 5-15 micron size range for the ETV testing was 950 particles/mL whereas during the CDHS testing it was 810 particles/mL. During the ETV testing, the membrane system achieved particle removals in the range 2.3 log to 3.5 log with an average of 3.1 log for the 3-5 micron size range, and particle removal in the range 2.7 log to 3.6 log with an average of 3.1 log for the 5-15 micron size range. For the CDHS testing, particle removals observed were in the range 2.6 log to 4.7 log with an average of 3.8 log for the 2-5 micron size range and particle removal in the range 2.6 log to 4.3 log with an average of 3.9 log for the 5-15 micron size range.

TECHNOLOGY DESCRIPTION

The equipment tested in this ETV is the US Filter 3M10C Microfiltration Membrane System. The 3M10C package plant contains 3 pressure vessels with one membrane module per pressure vessel. Each stainless steel pressure vessel is 4.5 inches (11cm) in diameter and approximately 55 inches (140 cm) long. The top and bottom of the pressure vessels are attached to headers that distribute feed water to the pressure vessels and collect permeate. The skid-mounted unit includes all major equipment elements and controls with the exception of an air compressor that was used to operate pneumatic valves and supply the pressurized air used during backwash. The footprint of the unit is approximately 57 inches (145 cm) long by 39 inches (99 cm) wide. The height of the unit, including the 5 inch (13 cm) base is approximately 87 inches (221 cm). The unit is skid mounted and can be moved with a forklift and transported by truck.

The US Filter 3M10C unit has an Allen Bradley programmable logic controller (PLC). The PLC controls the opening and closing of pneumatic valves and the operation of pumps required for filtration and backwash. The backwash frequency and the length of time the system spends in each backwash phase are set by entering values into the appropriate screen on the PLC. A constant filtrate flow during filtration cannot be maintained by the PLC so the flow had to be manually adjusted by manipulating the filtrate valve. The 3M10C MF unit has digital flow, pressure and temperature measurement, and a data logger to acquire operating information digitally.

The US Filter 3M10C unit has two alternating operating modes known as filtration and backwash. When in the filtration mode, feed water is pumped from the feed tank to both the top and bottom of the modules. The pressurized feed water is directed around a central permeate tube in the module end-caps to the outside surface of the hollow fibers. Permeate passes through the pores of the membrane to the inside of the hollow fibers and is collected from both ends of the module through a central permeate tube in the module end-caps. The package plant operates in dead-end mode only, with no recirculation flow on the feed side of the membrane. During backwash, the feed pump shuts down and valves are repositioned. An air compressor pressurizes both the feed and permeate side of the membrane to approximately 90 psi. The pressure is then released from the feed side of the membrane, dislodging the cake layer from the

membrane surface. Feed water is then pumped from the bottom of the module to flush the dislodged debris. This is followed by a final rewetting phase where both sides of the membrane are again pressurized to approximately 90 psi to force water into the membrane pores before resuming the next filtration cycle. The backwash phase lasts approximately two minutes. The long-term operation of the US Filter MF unit frequently results in the accumulation of materials on the membrane surface, which are not effectively removed by backwash. This is called membrane fouling and is observed as a gradual increase in the pressure required to force water through the membrane pores. Once a critical upper pressure has been reached, normal operation is discontinued and the membrane undergoes chemical cleaning. Chemical cleaning typically involves the use of acid solutions to restore efficient operation of the membrane.

The pressure vessel of the US Filter 3M10C unit contains three model M10C polypropylene membrane modules. The manufacturer estimates that these 4.7 inch (12 cm) diameter by 45.5 inch (1.157 m) length modules each contain approximately 20,000 fibers. The 3M10C module is a hollow fiber configuration, manufactured from polypropylene, with a nominal pore size of 0.20 microns. At this pore size, the membrane is expected to remove particulates, including protozoa and bacteria.

VERIFICATION TESTING DESCRIPTION

Test Site

The verification test site was the City of San Diego's Aqua 2000 Research Center at 1500 Wueste Road in Chula Vista, California. The Research Center includes office and lab trailers, a covered concrete test pad and a dedicated operations staff with substantial membrane experience. The source water for testing was the San Diego Aqueduct pipeline. This water consists of Colorado River water and State Project water, which are two of the major raw drinking water supplies in Southern California.

Methods and Procedures

Turbidity, pH, chlorine and temperature analyses were conducted daily at the test site according to Standard Methods for the Examination of Water and Wastewater, 20th Ed. (APHA, et. al., 1998). Standard Methods, 20th Ed. (APHA, 1998) and Methods for Chemical Analysis of Water and Wastes (EPA, 1979) were used for analyses conducted at The City of San Diego Laboratory. These included alkalinity, total and calcium hardness, total dissolved solids (TDS), total suspended solids (TSS), total organic carbon (TOC), ultraviolet absorbance at 254 nanometers (UV254), total coliform, and heterotrophic plate count (HPC). Total and calcium hardness analyses were conducted every other week. All other analyses were conducted weekly. Online Hach 1900 WPC particle counters and 1720D turbidimeters continuously monitored these parameters in both the raw water and membrane system filtrate. The particle counters were set up to enumerate particle counts in the following size ranges: 2-3 um, 3-5 um, 5-7 um, 7-10 um, 10-15 um and > 15 um. Data from the online particle counters and turbidimeters were stored at one-minute intervals on a computer.

VERIFICATION OF PERFORMANCE

System Operation

Verification testing was conducted at the manufacturer-specified operating conditions. The membrane unit was operated at a constant flux of 24 gfd (41 L/hr-m^2) with feedwater recovery of 91 percent. Permeate flow rate was set by entering the target flow in a screen on the PLC. Backwash frequency was every 22 minutes. Backwash volume averaged 41 gallons (155 liters). The system was operated during the test period with moderate fouling throughout the testing period until it reached the end of the testing period. The temperature adjusted specific flux decreased from 3 to 1.6 gfd/psi at 20°C (75 to 38 L/hr-m^2-bar at 20°C) over the 44 days of the test period.

Membrane cleaning was performed according to the manufacturer-recommended procedure. A citric acid solution (2 percent) followed by a high pH cleaning solution was prepared in the feed storage tank and recirculated through the feed side of the membrane. The 2 percent citric acid cleaning solution was prepared by dissolving 8 pounds (17 kg) of citric acid in the feed tank. The pH of this solution was in the range 2 to 2.5. The citric acid solution was recirculated through the feed side of the membrane for 120 minutes at a flow of 32 gpm (121 L/min) with a feed pressure of approximately 9 psi. After discarding the cleaning solution and rinsing the system with feed water, the same cleaning procedure was followed using a high pH cleaning solution. The high pH cleaning solution was made by adding 1 gallon (3.7 liters) of Memclean EAX2 to the feed tank. The pH of this solution was in the range of 12-13. The manufacturer-recommended cleaning procedure was effective in recovering specific flux. The recovery of specific flux for the cleanings at the end of the test period was 100 percent indicating no irreversible fouling.

No incident of broken fibers occurred during the test period. Air pressure-hold tests were manually conducted two times during the test period. These tests indicate that the fibers were intact during the testing period with a pressure loss of less than 1.5 psi per minute. In addition, automatic air pressure hold tests were performed by the system every 24 hours during the testing. Automatic air pressure-hold tests were conducted by selecting the integrity test from the appropriate PLC screen. The air pressure-hold test on the US Filter system was conducted by pressurizing the feed side of the membrane. If any of the membrane fibers were compromised, one would expect significant loss of held pressure (>1.5 psi every minute) across the membrane element. The air pressure-hold test results show that there were no compromises in membrane integrity during the test period. The automated pressure-hold test performed every 24 hours was set to shut the system down when pressure decays were greater than 1.5 psi/min. There was no shut down of the system because of unacceptable automated pressure-hold results during the test period.

Source Water

The source water for the ETV testing consisted of a blend of Colorado River and State Project Water delivered to the test site via the San Diego Aqueduct. The source water had the following average water quality during the test period: TDS 521 mg/L, total hardness 253 mg/L, alkalinity 125 mg/L, TOC 2.6 mg/L, pH 8.3, temperature 27 °C and turbidity 0.75 NTU.

Particle Removal

Total suspended solids in the filtrate were removed to below the detection limit for the analysis for all samples analyzed (<1 mg/L to <10 mg/L). Filtrate turbidity was 0.1 NTU or less 95 percent of the time. The system achieved particle removals of up to 3.5 logs for *Cryptosporidium*-sized (3-5 um) particles and particle removals of up to 3.6 logs for *Giardia*-sized (5-15 um) particles. The range of log removals was 2.3 log to 3.5 log and the average was 3.1 log for the 3-5 micron particles, while the range was 2.7 log to 3.6 log and the average 3.1 log for the 5-15 micron particles. Four hour average raw water and filtrate particle levels and daily average particle removal in these size ranges for the test period are presented in the following table:

US Filter 3M10C MF System Particle Counts and Particle Removals for ETV Test Period						
	3-5 um Particles			5-15 um Particles		
	Raw Water (#/mL)	Filtrate (#/mL)	Log Removal	Raw Water (#/mL)	Filtrate (#/mL)	Log Removal
Average	1100	1.2	3.1	950	0.86	3.1
Standard Deviation	450	1.7	0.29	630	0.97	0.27
95% Confidence Interval	1000-1200	0.98-1.4	3.0-3.2	870-1000	0.73-0.99	3.0-3.2
Minimum	290	0.23	2.3	190	0.23	2.7
Maximum	2300	13	3.5	3800	6.1	3.6

ETV-Reviewed Supplemental Particle Count Data

Additional particle removal data has been included in the testing report from previous California Department of Health Services (CDHS) testing. This particle removal data was collected during CDHS testing at the A. H. Bridge Plant, in Rancho Cucamonga, CA, owned by Cucamonga County Water District (CCWD) on two days (5/17/2001 and 5/18/2001) (Adham, 2001). This testing was done to obtain CDHS approval process for the same US Filter 3M10C system that was tested during this ETV. Hence, this data is directly applicable even though this data was collected independently from the ETV testing. The system was operated at a flux of 50 gfd and transmembrane pressures ranging from 20 to 23 psi during the period of CDHS particle data collection. The 3M10C MF system achieved log removals of 2.6 log to 4.7 log with an average of 3.8 log for the 2-5 micron particles and a range of 2.6 log to 4.3 log and an average of 3.9 log for the 5-15 micron particles during the CDHS testing. Summary statistics for particles in the raw water, particles in the membrane filtrate and log removal of particles, based on data collected at the one-minute sampling interval over the 24-hour collection period, are presented in the following table:

US Filter 3M10C MF System Particle Counts and Particle Removals for CDHS Testing						
	2-5 um Particles			5-15 um Particles		
	Raw Water (#/mL)	Permeate (#/mL)	Log Removal	Raw Water (#/mL)	Permeate (#/mL)	Log Removal
Average	2000	0.68	3.8	810	0.19	3.9
Standard Deviation	90	0.84	0.55	56	0.24	0.43
95% Confidence Interval	2000 - 2000	0.64 - 0.72	3.8 - 3.8	810 - 810	0.18 - 0.20	3.9 - 3.9
Minimum	1700	0.046	2.6	650	0.046	2.6
Maximum	2200	1.8	4.7	950	1.8	4.3

All CDHS testing data was reviewed according to the ETV Drinking Water Systems Quality Management Plan and ETV Program Policies. Although the calibration of the particle counters and the verification of calibration for the CDHS testing were outside of the time frame recommended in the ETV Technology-Specific Test Plan (11 months vs. within two months and five months vs. immediately before testing, respectively), both the raw and permeate particle counters gave comparable responses to the same microsphere solution (Figure 3-5); therefore, log removals should be comparable. Also, the particle counters were made by the same manufacturer and were the same model. The calibration did occur within the one-year time frame recommended by the particle counter manufacturer.

Microbial Removal

Total Coliforms and HPC were analyzed on a weekly basis during both ETV test periods. Raw water total coliforms averaged 560 MPN/100 mL during the test periods. Total coliforms were not detected in

the filtrate. HPC averaged 2000 cfu/mL in the raw water while filtrate levels of HPC averaged 140 cfu/mL.

Operation and Maintenance Results

Operation was initiated by entering target filtrate flow rate, backwash frequency and time of each backwash phase in the appropriate PLC screen. Backwash flow rate was adjusted manually using a valve. As the membrane system fouled, the permeate valve was manually readjusted to maintain a constant permeate flow rate.

No chemicals were consumed during routine operation of the system. During a typical chemical cleaning, 8 pounds (17 kg) of citric acid and 1.0 gallon (3.7 liter) of high pH cleaning solution (Memclean EAX2) were consumed. The manufacturer supplied an Operations and Maintenance Manual that was helpful in explaining the setup, operation and maintenance of the ETV test system.

Original Signed by	*Original Signed by*
Hugh W. McKinnon *06/12/03*	*Gordon Bellen* *06/17/03*
Hugh W. McKinnon Date	Gordon Bellen Date
Director	Vice President
National Risk Management Research Laboratory	Federal Programs
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 #03/07/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/dws/dws_reports.html (electronic copy)
3. EPA web site: http://www.epa.gov/etv (electronic copy)