THE ENVIRONMENTAL TECHNOLOGY VERIFICATION PROGRAM

U.S. Environmental Protection Agency

NSF International

ETV Joint Verification Statement

TECHNOLOGY TYPE:	**MEMBRANE FILTRATION USED IN PACKAGED DRINKING WATER TREATMENT SYSTEMS**	
APPLICATION:	**PHYSICAL REMOVAL OF MICROBIOLOGICAL & PARTICULATE CONTAMINANTS IN DRINKING WATER IN ESCONDIDO, CALIFORNIA**	
TECHNOLOGY NAME:	**UF-1-7T ULTRAFILTRATION MEMBRANE SYSTEM**	
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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 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; stakeholders groups which consist 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 Treatment Systems (DWTS) Pilot, one of 12 technology areas under ETV. The DWTS Pilot recently evaluated the performance of an ultrafiltration membrane system used in package drinking water treatment system applications. This verification statement provides a summary of the test results for the Ionics UF-1-7T Ultrafiltration (UF) Membrane System. Montgomery Watson, an NSF-qualified field testing organization (FTO), performed the verification testing.

ABSTRACT

Verification testing of the Ionics UF-1-7T Ultrafiltration membrane system was conducted over two test periods at the Aqua 2000 Research Center in Escondido, California. The first test period, from December 7, 1999 to January 11, 2000 represented winter conditions. The second test period, from March 6, 2000 to April 6, 2000 represented spring conditions. 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 33 gfd (57 L/hr-m^2) with feedwater recovery of 92-93 percent. Test Period 1 consisted of one filtration run. The membrane was completely fouled at the end of Test Period 1. Between test periods, modifications were made to the backwash protocol. As a result, the system completed Test Period 2 without appreciable loss of specific flux. The system experienced one incident of fiber breakage during Test Period 1 and three incidents of fiber breakage in Test Period 2. The manufacturer recommended cleaning procedure was effective in recovering membrane productivity. The membrane system achieved significant removal of particulate contaminants and bacteria and seeded MS2 bacteriophage as described later.

TECHNOLOGY DESCRIPTION

The Ionics UF-1-7T unit is comprised of seven hollow fiber UF membrane modules inside an aluminum pressure vessel and mounted on a transportable skid. The skid is constructed of steel, and can be shipped by truck. The Ionics UF unit is completely self-contained, including all the components required for operation. The only connections are a raw water connection to the feed pump, drain lines for filtrate tank overflow and backwash waste, and electrical power. The unit requires approximately 35 ft^2 (3.2 m^2) of floor space.

The UF-1-7T 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. The PLC maintains a constant filtrate flow during filtration by automatically adjusting feed pump speed. The Ionics UF unit has digital flow, pressure and temperature measurement and a data logger to acquire operating information digitally.

The Ionics UF-1-7T unit has two alternating operating modes. These are filtration and backwash. During filtration, raw water is driven under pressure through pores in the UF membrane. Treated water is collected from the filtrate side (inside) of the membrane. At the end of the filtration cycle, the system initiates a backwash. During backwash, the feed pump shuts down, valves are repositioned, and the backwash pump starts. The backwash pump draws treated water from the filtrate storage tank, chlorinates it, and forces the water under pressure in the reverse direction through the fibers. This reverse flow removes solids and organics, which have accumulated on the membrane surface. Chlorine is added to the backwash water to assist in oxidizing organics that have accumulated on the membrane surface. Air is also added during backwashing to scour the membrane for more effective cleaning. The long-term operation of the Ionics UF 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 quantified by a gradual increase in the pressure required to maintain the desired flux. Once a critical upper pressure has been reached, normal operation is discontinued and the membrane undergoes chemical cleaning. Chemical cleaning involves the use of a citric acid solution, followed by a high pH solution and pH 2 backwash to restore membrane productivity.

The pressure vessel of the Ionics UF unit contains seven Toray Model TP-TE07-S membrane modules. These 3.5 inch (8.8 cm) diameter modules each contain approximately 3,600 fibers. The Toray module is a hollow fiber configuration, manufactured from polyacrylonitrile, with nominal molecular weight cut-off

of 100,000 Daltons. This corresponds with a pore diameter of approximately 0.01 micron. At this pore size, the membrane is expected to remove particulates, including protozoa, bacteria and virus.

VERIFICATION TESTING DESCRIPTION

Test Site

The verification test site was the City of San Diego's Aqua 2000 Research Center at 14103 Highland Valley Road in Escondido, 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 Lake Skinner water via the San Diego Aqueduct. Lake Skinner 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, 19th Ed. (APHA, et. al., 1995). Standard Methods, 19th Ed. (APHA, 1995) 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. MS2 bacteriophage analysis was conducted by EPA Information Collection Rule (ICR) Method for Coliphage Analysis (Sobsey, et al. 1990). 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 manufacturer specified operating conditions. The membrane unit was operated at a constant flux of 33 gfd (57 L/hr-m^2) with feedwater recovery of 92 percent. Filtrate flow rate was set by entering the target flow in a screen on the PLC. Backwash frequency was every 60 minutes. Backwash volume averaged 55 gallons (208 liters) for Test Period 1 and 75 gallons (283 liters) for Test Period 2. Backwash chlorine concentration was in the range 5 to 10 mg/L. The reverse flow backwash volume was increased from 15 gallon (57 liters) in Test Period 1 to 30 gallon (113 liters) in Test Period 2. The system was operated during Test Period 1 with moderate fouling until it reached the maximum recommended operating pressure towards the end of the testing period. During this period specific flux decreased from 6.0 to 1.2 gfd/psi at 20°C (148 to 39 L/hr-m^2 at 20°C). The system, however, ran all of Test Period 2 without appreciable fouling. During Test Period 2 the specific flux decreased from 5.9 gfd/psi at 20°C (145 L/hr-m^2 at 20°C) over three days before stabilizing at 4.0 gfd/psi at 20°C (98 L/hr-m^2 at 20°C) for remainder of testing.

Membrane cleaning was performed according to manufacturer recommended procedure. A citric acid solution followed by a high pH cleaning solution was prepared in the feed storage tank and recirculated through the feed side of the membrane at approximately 330 gpm (1250 L/min) for 60 minutes. A pH 2 acid rinse was used after the high-pH cleaning step to remove potential precipiates. Flux-pressure profiles were performed after each cleaning step to evaluate recovery of specific flux. The manufacturer recommended cleaning procedure was effective in recovering specific flux. Loss of original flux was 4.8

percent after the cleaning at the end of Test Period 1 and 17 percent after the cleaning at the end of Test Period 2.

One incident of broken fibers occurred during Test Period 1 and three incidents of broken fibers occurred during Test Period 2. Air pressure-hold tests were conducted near the beginning and end of each test period as well as before and after fiber repairs to assess membrane integrity. Air pressure-hold tests were conducted by selecting the integrity test from the appropriate PLC screen. During the air pressure-hold test the pressure vessel is first drained, then the feed side of the membrane is pressurized with air and the filtrate side of the membrane is opened to atmosphere. Once pressurized, the loss of held pressure on the feed side was monitored over 10 minutes. A loss of > 1 psi every five minutes of held pressure typically would indicate the membranes were not intact. The air pressure-hold test was inconsistent in identifying fiber breaks based on this performance criterion. The pressure decay before repair was less than 2 psi for two fiber breakages and just over 2 psi for the other two fiber breakage incidents. Particle counting was a reliable indicator of broken fibers, and all incidents of broken fibers were identified by visual observation of filtrate particle counts. Typically, one or two broken fibers produced a increase in permate particle counts (> 2 um) of from one-half to one log.

Source Water

The source water for the ETV testing consisted of a blend of Colorado River water 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 two test periods: TDS 500/470 mg/L, total hardness 240/220 mg/L as $CaCO_3$, alkalinity 120/120 mg/L as $CaCO_3$, TOC 3.2/3.6 mg/L, pH 8.3/8.2, temperature 15/19 °C and turbidity 1.2/1.4 NTU.

Particle Removal

Total suspended solids in the filtrate were removed to below the detection limit for the analysis (1 mg/L), for all samples analyzed. Filtrate turbidity was 0.05 NTU or less 95 percent of the time. The test system removed greater than 3 logs of both Cryptospordium-sized (3-5 um) particles and Giardia-sized (5-15 um) particles, 95 percent of the time. Filtrate levels of particles in these size ranges were elevated and particle removal was decreased during periods of operation with compromised fibers that occurred during Test Period 2. Four hour average raw water and filtrate particle levels and daily average particle removal in these size ranges for Test Periods 1 and 2 are presented in the following table:

Ionics UF-1-7T UF System Particle Counts and Particle Removals for Test Periods 1/2

	3-5 um Particles			5-15 um Particles		
	Raw Water (#/mL)	Filtrate (#/mL)	Log Removal	Raw Water (#/mL)	Filtrate (#/mL)	Log Removal
Average	1700/1400	0.19/0.63	4.2/3.4	900/680	0.16/0.37	3.9/3.3
Standard Deviation	230/310	0.35/0.46	0.40/0.30	170/200	0.26/0.24	0.40/0.24
95% Confidence Interval	1700-1700/ 1400-1400	0.14-0.24/ 0.56-0.70	4.1-4.3/ 3.3-3.5	880-920/ 650-710	0.12-0.20/ 0.34-0.40	3.8-4.0/ 3.2-3.4
Minimum	1200/690	0.04/0.15	3.0/2.9	530/270	0.04/0.11	3.0/2.8
Maximum	2300/2400	1.7/3.4	4.6/3.9	1400/1500	1.9/2.3	4.4/3.7

Microbial Removal

Total Coliforms and HPC were analyzed on a weekly basis during both ETV test periods. Raw water total coliforms averaged 25 and 8 MPN/100mL during Test Periods 1 and 2, respectively. No total coliforms were detected in the filtrate. HPC averaged 83 and 310 cfu/mL in the raw water for Test Periods 1 and 2 while filtrate levels of HPC averaged 100 and 200 cfu/mL, respectively. The relatively high levels of HPC in the filtrate are possibly due to contamination of the filtrate side with HPC during periods of operation with compromised fibers. Challenge experiments with MS2 bacteriophage were

conducted at the end of Test Period 1 and beginning of Test Period 2, immediately after membrane cleaning (worst case for virus removal). Virus were continuously added to the membrane feed water. The membrane was allowed to operate for 1 filtration cycle to come to equilibrium and then paired samples were taken from the feed and filtrate within 1-minute of completion of backwash, at the middle and at the end of the filtration cycle, over the next two filtration cycles. Specific flux during the seeding conducted at the end of Test Period 1 was 4.9 gfd/psi (119 L/hr-m^2-bar), while specific flux for the seeding conducted at the beginning of Test Period 2 was 6.2 gfd/psi (152 L/hr-m^2-bar). Feed virus concentration ranged from 7.4 x 10^6 to 2.8 x 10^7 plaque forming units (pfu)/100mL for the first virus seeding and from 3.5 x 10^7 to 6.0 x 10^7 pfu/100mL for the second virus seeding. Log removal of virus ranged from 4.0 to 5.7 for Test Period 1 and from 2.9 to 4.3 for Test Period 2.

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 feed pump speed was automatically readjusted to maintain a constant filtrate flow rate. The sodium hypochlorite dosing pump required initial manual adjustment to achieve a target chlorine dose in the backwash water of 5 to 10 mg/L. Chlorine concentration in the backwash feedwater was checked twice daily.

Operation of the membrane unit consumed 0.12 gal (0.46 L) of 10% sodium hypochlorite per day to chlorinate backwash water. No other chemicals were consumed during routine operation of the system. During a typical chemical cleaning, 17.0 pounds (7.7 kg) of citric acid, 1.8 gallon (7.0 liter) of high pH cleaning solution and 200 milliliters of muriatic acid (40% hydrochloric acid) were consumed. The manufacturer supplied an Operations and Maintenance manual that was extremely helpful in explaining the setup, operation and maintenance of the ETV test system.

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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 #00/13/EPADW395) are available from the following sources:
(NOTE: Appendices are not included in the Verification Report. Appendices are available from NSF upon request.)

1. Drinking Water Systems ETV 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)