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 AND PARTICULATE CONTAMINANTS IN ESCONDIDO, CALIFORNIA**	
TECHNOLOGY NAME:	**HYDRACAP™ ULTRAFILTRATION MEMBRANE SYSTEM**	
COMPANY:	**HYDRANAUTICS**	
ADDRESS:	**401 JONES ROAD** **OCEANSIDE, CA 92054**	PHONE: **(760) 901-2500** FAX: **(760) 901-2578**
WEB SITE:	**http://www.membranes.com**	
EMAIL:	**salt@hydranautics.com**	

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 Hydranautics HYDRACap™ Ultrafiltration Membrane System. Montgomery Watson, a NSF-qualified field testing organization (FTO), performed the verification testing.

ABSTRACT

Verification testing of the Hydranautics HYDRACap™ Ultrafiltration Membrane System (Hydranautics UF unit) was conducted over two test periods at the Aqua 2000 Research Center in San Diego, California. The first test period, from August 3,1999 to September 13, 1999 represented summer/fall conditions. The second test period, from February 16, 2000 to March 21, 2000 represented winter/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 69 gfd (115 L/hr-m^2) with feedwater recoveries ranging from 85 to 87 percent. During Test Period 1, membrane fouling due to algae bloom was observed near the beginning of the operating period. The system completed all of Test Period 2 without appreciable loss of specific flux. 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 (described later).

TECHNOLOGY DESCRIPTION

The Hydranautics test unit is comprised of two HYDRACap™ hollow fiber UF membrane modules mounted on a transportable skid constructed of steel. The test unit can be shipped by truck. The Hydranautics UF unit is completely self-contained, including all the components required for operation. The only connections required 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 32 ft^2 (3.0 m^2) of floor space.

The test 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 does not maintain a constant filtrate flow during filtration, instead this is set manually by making adjustments to feed pump speed and filtrate valve setting. The test unit has analog flow, pressure and temperature measurement. It did not include a data logger to acquire operating information digitally.

The Hydranautics UF 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 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. With the flow of water now from the outside of the fiber to the inside of the fiber, the backwash water exits the inside of the fibers at the fiber ends, carrying with it particulate material accumulated during filtration. Chlorine is added to the backwash water and assists in oxidizing organics that have accumulated on the membrane surface. The long-term operation of the 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 citric acid and caustic solutions to restore efficient operation of the membrane.

The Hydranautics UF unit has two HYDRACap™ membrane modules. These 8 inch (20 cm) diameter modules each contain 10,000 fibers. The HYDRACap™ is a hollow fiber configuration, manufactured from polyether sulfone, with nominal molecular weight cut-off of 150,000 to 180,000 Daltons. This

corresponds with a pore diameter of approximately 0.015 to 0.018 micron. At this pore size, the HYDRACap™ 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 ICR Method for Coliphage Analysis (Sobsey, et al. 1990). On-line 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, 5-15 um, and > 15 um. Data from the on-line particle counters and turbidimeters were stored at 1-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 69 gfd (115 L/hr-m^2) with feedwater recoveries ranging from 85 to 87 percent. Filtrate flow rate was set manually by adjusting the feed pump speed and the filtrate valve to achieve the desired flow at a feed pressure of 20 psi (1.4 bar). Backwash frequency was every 19 minutes. Backwash volume averaged 30 gallons (114 liter) for Test Period 1 and 25 gallons (95 liter) for Test Period 2. Backwash chlorine concentration was in the range 10 to 15 mg/L for the first run of Test Period 1 and was increased to 15 to 20 mg/L for the remainder of testing. The system initially ran for 9 days in Test Period 1 with a decrease in specific flux from 16 to 3 gfd/psi (390 to 75 L/hr-m^2). This rapid fouling was likely due to an algae bloom in the source water. Cleaning recovered specific flux to approximately 13 gfd/psi (320 L/hr-m^2). After cleaning, the unit fouled slightly overnight but then gradually recovered specific flux over the remainder of Test Period 1 as the algae bloom subsided. The system ran all of Test Period 2 without requiring a cleaning. The system fouled rapidly over the first eight days of operation at the beginning of Test Period 2. Specific flux decreased from 15 gfd/psi (370 L/hr-m^2) to 5 gfd/psi (120 L/hr-m^2). After this, repairs were made to the backwash chlorine feed pump, and the system recovered over the remainder Test Period 2 to a specific flux of 9 gfd/psi (220 L/hr-m^2).

Membrane cleaning was performed according to manufacturer recommended procedure. Citric acid and caustic cleaning solutions were prepared in the filtrate storage tank and recirculated through the feed side of the membrane at approximately 4 gpm (15 L/min) for 60 minutes. 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 10 percent after the first cleaning in Test Period 1 and decreased to 8 percent after the second cleaning in Test Period 1. Specific flux was recovered to new membrane conditions on cleaning at the end of Test Period 2.

Air pressure-hold tests were conducted near the beginning and end of each test period to assess membrane integrity. Air pressure-hold tests were conducted by opening the filtrate side of the membrane to atmosphere and pressurizing the feed side of the membrane. Once pressurized, the loss of held pressure on the filtrate side was monitored over 10 minutes. All air pressure-hold tests had minimal loss (< 1 psi every 5 minutes) of held pressure, indicating the membranes were intact during both test periods.

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 500/480 mg/L, hardness 250/220 mg/L as $CaCO_3$, alkalinity 120/120 mg/L as $CaCO_3$, TOC 3.3/3.3 mg/L, pH 8.2/8.2, temperature 30/17 and turbidity 1.4/1.3 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 2 logs of both Cryptosporidium-sized (3-5 um) particles and Giardia-sized (5-15 um) particles, 95 percent of the time. 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:

Hydranautics HYDRACap™ 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	2500/1700	4.0/0.35	3.0/3.7	1400/870	4.2/0.30	2.7/3.5
Standard Deviation	690/300	9.4/0.70	0.35/0.30	410/240	9.2/0.60	0.40/0.30
95% Confidence Interval	2400-2600/ 1700-1700	2.8-5.2/ 025-0.45	2.9-3.1/ 3.6-3.8	1300-1500/ 840-900	3.0-5.4/ 0.21-0.39	2.6-2.8/ 3.4-3.6
Minimum	890/1200	0.60/0.15	1.6/2.5	410/520	0.65/0.10	1.4/2.3
Maximum	4000/2700	110/9.3	3.4/4.0	2300/2500	100/7.9	3.2/3.8

Microbial Removal

Total Coliforms and HPC were analyzed on a weekly basis during both ETV test periods. Raw water total coliforms averaged 7 MPN/100mL during both Test Periods 1 and 2. No total coliform were detected in the filtrate. HPC were significantly reduced. HPC averaged 443 and 82 cfu/mL in the raw water for Test Periods 1 and 2 while filtrate levels of HPC averaged 2 and 1 cfu/mL, respectively. Seedings with MS2 bacteriophage were conducted at the beginning of each Test Period, 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 beginning of Test Period 1 was 15 gfd/psi (360 L/hr-m^2-bar), while specific flux for the seeding conducted at the beginning of Test Period 2 was 16 gfd/psi (400 L/hr-m^2-bar). Feed virus concentration ranged from 2.8 x 10^7 to 1.7 x 10^8 plaque forming units/100mL (pfu/100mL) for the first virus seeding and from 4.5 x 10^7 to 1.1 x 10^8 pfu/100mL for the second virus seeding. Log removal of virus ranged from 3.9 to 4.7 for Test Period 1 and from 3.4 to 4.3 for Test Period 2.

Operation and Maintenance Results

Operation was initiated by entering backwash frequency in the appropriate PLC screen. Backwash times were entered on the appropriate PLC screen. Backwash flow rate was adjusted manually using a valve. Filtrate flow rate was adjusted by manually setting feed pump speed and throttling the filtrate valve. As the membrane system fouled, the feed pump speed required manual readjustment 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 15 to 20 mg/L. Chlorine concentration in the backwash feedwater was checked twice daily.

Operation of the membrane unit consumed 0.36 gal (1.4 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, 4.0 pounds (1.8 kg) of citric acid, 0.29 gallon (1.1 liter) of caustic soda and 200 milliliters of muriatic acid (40% hydrochloric acid) 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	
E. Timothy Oppelt	*9/28/00*
E. Timothy Oppelt	Date
Director	
National Risk Management Research Laboratory	
Office of Research and Development	
United States Environmental Protection Agency	

Original Signed by	
Tom Bruursema	*10/17/00*
Tom Bruursema	Date
General Manager	
Environmental and Research Services	
NSF International	

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 #00/04/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 Treatment Systems ETV Pilot 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)