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 PARTICULATE CONTAMINANTS IN DRINKING WATER**	
TECHNOLOGY NAME:	**POLYMEM UF120 S2 ULTRAFILTRATION MEMBRANE MODULE**	
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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 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 under ETV. The DWS Center recently evaluated the performance of an ultrafiltration membrane used in drinking water treatment system applications. This verification statement provides a summary of the test results for the Polymem UF120 S2 Ultrafiltration Membrane Module. Carollo Engineers, P.C., 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.

ABSTRACT

Verification testing of the Polymem UF120 S2 Ultrafiltration Membrane Module was conducted over a 46-day period at the Green Bay Water Utility Filtration Plant, Luxemburg, Wisconsin. The ETV testing described herein was funded in conjunction with a 12-month membrane pilot study funded by the Energy Center of Wisconsin. The Energy Center of Wisconsin chose to participate because the overall scope of the ETV testing fit into the scope of the longer, energy focused study. The testing was performed from March 11, 2002 through April 26, 2002, representing winter/spring conditions when, historically, feed water quality was most difficult to treat. The feed water was Lake Michigan. Verification testing was conducted at optimized conditions based on pilot testing conducted during the 12 months proceeding the verification test period. The testing was performed using a "generic" custom membrane pilot plant (CMPP) capable of operating with a variety of membrane modules that are housed in pressure vessels. Therefore, this ETV testing verified the operation of the membrane module itself, not membrane-specific process equipment. The membrane unit was operated in dead-end mode during two test runs, each at a constant specific flux of 40 and 30 l/h-m^2 (24 and 18 gfd), respectively. Feed water recoveries ranged from 89-96 percent. The two test runs were operated for approximately 12.5 and 32.7 days, respectively. The UF module was chemically cleaned using a "proof of concept" effort based on procedures recommended by the manufacturer. The cleaning procedures were effective in restoring membrane productivity. The membrane module achieved significant removal of particulate contaminants and bacteria, producing an average filtrate turbidity of 0.05 NTU and an average of 4.2 log removal of total particles (>2 ìm in size). Average feed turbidity and total particle counts were 1.3 NTU and 4,281 particles/ml, respectively.

TECHNOLOGY DESCRIPTION

The Polymem UF120 S2 Ultrafiltration Module is comprised of 19 individual polysulfone hollow-fiber membrane bundles housed in a PVC pressure vessel. The bundles are potted on the effluent side of the module, forming a U-shaped configuration and provide a total of 114 m^2 (1227 ft^2) of active membrane surface area. The membrane, classified as an ultrafiltration membrane, has a nominal pore size of 0.01 µm as specified by Polymem and was not verified in this verification test. This pore size should provide a physical barrier to particulate matter, bacteria, protozoans, and viruses when membrane fibers are intact and operated within the recommended operating ranges.

The membrane module is designed for operation in a dead-end mode, reducing power consumption over traditional cross flow membrane products, as recirculation pumps are not required. The flow configuration is outside to inside. This forces the accumulation of particulate matter, pathogens, and suspended solids on the outside of the membrane fiber. The recommended backwash procedure includes simultaneous hydraulic backwash, air scour, and chlorine injection. Backwash is accomplished by pumping filtrate water from the inside to the outside of the fiber. This water is then discharged to waste. An inlet for air scour is provided at the level of the potting resin via air diffusers located inside the module. This design makes minimum chemical cleaning intervals of 30 days possible without exceeding the maximum allowable transmembrane pressure (terminal transmembrane pressure) of 2 bar (29 psi). The membrane system and operating strategy (flux, recovery, and backwash intervals) are typically designed for a 30-day chemical cleaning interval. However, significant changes in water quality will effect membrane performance. Temperature fluctuation, increases in natural organic matter, turbidity, and pH changes may have the potential to increase membrane fouling rates.

Some fraction of the particulate matter and dissolved constituents in the feed water can accumulate on the membrane surface and cannot be removed by hydraulic backwash and air scour. This leads to rise in transmembrane pressure during normal operation. Once the terminal transmembrane pressure has been reached (29 psi), the membrane must be taken off-line to remove this matter from the membrane with a chemical clean. The membrane polymer is designed to be tolerant to a variety of chemicals, including chlorine, acids, bases, and chelating agents commonly used for chemical cleaning.

Critical to this testing was the use of a “generic” CMPP. The CMPP was not provided by Polymem. The CMPP used has the capacity to feed, backwash, and clean a variety of pressure vessel-type MF/UF modules. Therefore, this testing verified the operation of the membrane module under a given set of operational parameters, not membrane-specific process equipment.

VERIFICATION TESTING DESCRIPTION

Test Site

The testing site was the Green Bay Water Utility Filtration Plant located at 6183 Finger Road in Luxemberg, Wisconsin. The Green Bay Water Utility Filtration Plant is fed by one or both of two raw water intakes located on the western shore of Lake Michigan in Kewaunee, Wisconsin. The raw water is pumped to the filtration plant in Luxemberg, Wisconsin. A small amount of chlorine (<0.30 mg/L) is added at each intake to prevent growth of zebra mussels during transmission from intake to the treatment facility. The CMPP used for this testing was located approximately 200 feet from the raw water channel at the filtration plant. A submersible pump located 3 feet below the free water surface fed the CMPP via 2-inch schedule 80 PVC pipe, and 1.5-inch PVC tubing.

Methods and Procedures

Onsite bench-top analyses including turbidity, pH, chlorine, and temperature were conducted daily at the test site according to *Standard Methods for the Examination of Water and Wastewater, 20th Edition* (APHA, 1998) and by *Methods for Chemical Analysis of Water and Wastes* (EPA, 1979), where applicable. *Standard Methods for the Examination of Water and Wastewater, 20th Edition* (APHA, 1998) was followed for total coliform analyses conducted at Northern Lake Service, Inc. (NLS), Crandon, Wisconsin and MWH Laboratories, Pasadena, California. Other analyses conducted by NLS were conducted using *Standard Methods for the Examination of Water and Wastewater, 18th Edition* (APHA, 1992) and by *Methods for Chemical Analysis of Water and Wastes* (EPA, Revision 1983), where applicable. Laboratory analyses included alkalinity, total and calcium hardness, total dissolved solids (TDS), total suspended solids (TSS), total organic carbon (TOC), ultraviolet absorbance at 254 nanometers (UVA), total coliform and heterotrophic plate count (HPC). Alkalinity and total and calcium hardness analyses were conducted once per month. TDS analyses were conducted every other week. TOC and UVA analyses were conducted twice per week. TSS, total coliforms, and HPC analyses were conducted five days per week. Online particle counters and turbidimeters continuously monitored both the feed and membrane filtrate waters. The particle counters were set up to enumerate particle counts in the following size ranges: total (>2 µm), 2-3 µm, 3-5 µm, 5-15 µm, and >15 µm. Data from the online particle counters were stored at 5-minute intervals on a dedicated computer. Online turbidity measurements were recorded at 10-minute intervals. Challenge testing, microbial or otherwise, was not performed as part of this study; particle removal was quantified based on turbidity and particle counter data.

VERIFICATION OF PERFORMANCE

System Operation

Verification testing conditions were established based on pilot study optimization results conducted from May 2001 to March 2002. The membrane unit was operated at a constant specific flux of 40 L/h-m^2 (24 gfd) for the first 12.5 days of operation (Run 1) and 30 L/h-m^2 (18 gfd) during the remaining 32.7 days of operation (Run 2). Production backwashes were performed at 50-minute intervals using an average volume of 39 and 30 gallons for Runs 1 and 2, respectively. System recoveries ranged from 89-96 percent throughout the testing. The backwash chlorine concentration was set at 5 mg/L for the duration of the testing.

Test Runs 1 and 2 yielded normalized specific flux decline rates of 7.2 L/h-m^2/bar/day (0.29 gfd/psi/d) and 1.7 L/h-m^2/bar/day (0.069 gfd/psi/d), respectively. The improvement in fouling control during Run 2 is likely due to the lower target normalized flux. It should be noted that the 25 percent decrease in specific flux led to a 260 percent increase in run time before a required chemical cleaning (12.5 vs. 32.7 days).

A total of three membrane cleanings were performed based on the manufacturer's recommended procedure. A high pH (11-12) chlorine solution (200 mg/L) was injected into the membrane module and was allowed to soak for at least 4 hours. Flux data was collected after each chemical cleaning to evaluate specific flux recovery. The first cleaning was performed prior to membrane operation. Therefore, recovery information was not available for this cleaning. The recovery of specific normalized flux for Chemical Cleaning #'s 2 and 3 was 62 and 73 percent, respectively. Cleaning #2 was performed at ambient water temperature, [14-18.6°C (57-65.5°F)], pH = 12.2, and an average total chlorine concentration of 164 mg/L, for 8 hours. Because recovery of specific flux following Cleaning # 2 was low, Cleaning # 3 was performed with a similar cleaning solution but at elevated solution temperature [22-31°C (72-88°F)], for an extended soaking period. Despite these changes, the specific flux recovery was marginal (73 percent). This may be explained in part by the lack of chemical recirculation. This is because the CMPP was not equipped with heating and recirculation equipment typically used to perform clean-in-place (CIP) procedures on this membrane.

Membrane integrity monitoring was conducted prior-to and after this testing. Air pressure-hold tests were conducted by opening the feed side of the membrane to the atmosphere and applying approximately 10 psi to the filtrate side of the membrane. Once pressurized, the loss of filtrate side pressure was recorded over a two-minute period. The first membrane integrity test yielded a zero pressure loss with time. The test at the end of system operation yielded a pressure loss of 0.35 psi/min, which was within the manufacturers recommended feed side pressure loss (<0.36 psi/min). However, during this test, visual observations showed a steady stream of air bubbles released to the feed side of the membrane. This suggested that a membrane fiber (or fibers) and membrane integrity may have been compromised. Following ETV testing, the membrane module filtrate end cap was removed to further investigate the bubbles noted during the final integrity test. This investigation followed the integrity test/repair procedures outlined in the Polymem UF120 S2 Operations and Maintenance (O&M) Manual. One broken fiber was identified and repaired. One subsequent pressure decay test, performed as described above, yielded a zero loss in pressure and no visual indicators of a loss of membrane integrity (no bubbles were detected).

Water Quality Results

The equipment verification testing described in this report was executed using raw Lake Michigan water obtained from the Green Bay Water Utility Filtration Plant. Water used for CMPP operation was drawn from the process prior to any treatment (other than Cl_2 addition for zebra muscle control) at the water facility and was pumped approximately 200 feet to the skid mounted CMPP located inside a module trailer unit. Table VS-1 below presents the results of the general water quality characterization for both feed and filtrate waters throughout the ETV verification test. The feed water had the following average water quality during this evaluation: Cl_2 residual 0.05 mg/L, alkalinity 110 mg/L as CaCO3, total hardness 130 mg/L as CaCO3, calcium hardness 88 mg/L as CaCO3, TSS 1.3 mg/L, TDS 187 mg/L, TOC 2.3 mg/L, UVA 0.024 cm^{-1}, algae 34 #/ml, temperature 3°C (37°F), and pH 7.8. As expected, there was no notable change in alkalinity, total hardness, calcium hardness, or total dissolved solids across the membrane module. However, there was a small reduction in TOC in the filtrate.

Total suspended solids were measured throughout the testing as an indication of particle removal potential. Filtrate TSS was typically below the detection limit with 32 out of 37 samples reported at or below the level of detection. Like HPC data, some of the filtrate samples were detected at higher than expected levels. These results are likely due to the fact that feed and filtrate samples were so near the detection limit of the analysis. Due to the length of time the equipment was in use prior to the ETV testing, it is also possible that material had built up in the portion of sample piping permanently fixed to the CMPP skid. Although the sample ports were allowed to flush prior to sample collection, accumulated material may have sloughed off during some of the sampling periods.

As presented in Table VS-1, average feed and filtrate bench top turbidities were 1.3 and 0.05 NTU, respectively. Continuously monitored filtrate turbidity was 0.035 NTU or less 90 percent of the time. Average feed and filtrate total particle counts were 4,281 and 4 particles/ml, respectively. Table VS-2 summarizes the particulate log removal data. Average particle log removals of 4.2, 4.1, 4.1, 3.4, 3.3, 2.9, and 2.2 were achieved for particle size ranges of >2 um, 2-3, 3-5, 5-7, 7-10, 10-15, and >15 um, respectively. The 90th percentile for feed and filtrate total particle counts (>2 #/ml) was approximately 9,911 and 2 particles/ml, respectively. The membrane system removed 3.1 logs of total particles 90 percent of the time. A few of the filtrate particle count data were recorded by the data logger as 0.00 particle/ml (below the detection limit of the instrument). Since these data were recorded as zero values, log removal data could not be calculated for these data points and were not included in the statistical analyses. Because the membrane system produced relatively consistent filtrate particle counts, log removals increased during periods when feed water particle counts were higher and decreased during periods when feed water particle counts were lower. Relatively higher particle counts were measured in the filtrate immediately following a backwash due in part to hydraulic and air bubble turbulence. As a result, particle removals were decreased during these events.

A sensitivity analysis was performed on the data collected from one 24-hour period to determine the potential effects of backwash events on calculated log removals. Data from March 14, 2002 were chosen for this analysis due to the clusters of relatively lower log removal data during that time period, thereby representing a worse case scenario. Log removals calculated for the raw data set (data including backwash events) were 3.2 logs or greater, 90 percent of the time. Log removals calculated for the data set excluding data obviously collected during backwash events, increased to 3.6 logs or greater, 90 percent of the time.

Table VS-3 summarizes total coliform and HPC data. Total coliform enumeration results showed feed concentration ranging from <1.1-23 MPN/100 ml. Filtrate results for total coliform enumeration were reported below the detection limit of <1 MPN/100ml. HPC were significantly reduced. Feed water HPC ranged up to 330 CFU/ml. 33 of 38 filtrate HPC samples were at or below the method detection limit of 2 CFU/ml.

Table VS-1 General Water Quality for Both Feed and Filtrate Waters

Parameter	Units	Feed Water	Filtrate
Cl_2 –Residual[(1)]	mg/L	0.05	--
Alkalinity	mg/L as $CaCO_3$	110	110
Total Hardness	mg/L as $CaCO_3$	130	130
Calcium Hardness	mg/L as $CaCO_3$	88	87
TSS[(2)]	mg/L	1.3	1.2
TDS	mg/L	187	203
TOC	mg/L	2.3	2.0
UVA	cm^{-1}	0.024	0.019
Algae	#/ml	34.4	--
pH	Units	7.80	--
Temperature	°C (°F)	3.4 (38)	--
Bench Top Turbidity	NTU	1.3	0.05
Particles >2 µm	#/ml	4281	4

(1) Measured as part of the daily sampling activities of the Green Bay Water Utility Filtration Plant (GBWUFP).
(2) Limit of detection = 1 mg/L

Table VS-2 Particulate Log Removal

Particle Size	Average Feed Count, #/ml	Average Filtrate Count #/ml	Average Log Removal
>2 um	4,281	4	4.2
2-3 um	1,602	1	4.1
3-5 um	1,880	1	4.1
5-7 um	325	0	3.4
7-10um	305	0	3.3
10-15 um	127	1	2.9
>15 um	41	2	2.2

Table VS-3 Average Microbial Water Quality

Parameter	Units	Feed Water	Filtrate	Backwash Water
Total Coliforms [(1)]	MPN/100 ml	6.2	<1.1	<1.1
HPC [(2)]	CFU/ml	17	2	24

(1) Limit of detection = 1.1 MPN/100 ml
(2) Limit of detection = 2 CFU/ml

Operation and Maintenance Results

Operating conditions were established in a Programmable Logic Controller (PLC) prior to beginning the test. These conditions included flux rate, production dwell time, backwash procedures (interval and duration), alarm condition settings, chemical feed doses, and data logging intervals. A notable exception to the logged parameters is air scour flow rate. With the exception of backwash duration, these parameters were not adjusted during operation. Backwash duration was adjusted as needed to maintain a recovery of at least 90 percent and ranged from 60-120 seconds. Backwash chlorine was set to a dose of 5 mg/L and was checked daily through onsite analyses.

Operation of the membrane consumed approximately 0.05 and 0.03 lbs/day of sodium hypochlorite during test Runs 1 and 2, respectively. Chemical cleanings each consumed 0.06 lbs of sodium hypochlorite and approximately 1.5-2 lbs of sodium hydroxide.

Original Signed by Clyde R. Dempsey
for Hugh W. McKinnon *06/10/03*

Hugh W. McKinnon Date
Director
National Risk Management Research Laboratory
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Gordon Bellen Date
Vice President
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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 May 14, 1999, the Verification Statement, and the Verification Report (NSF Report # NSF 02/05/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 and from http://www.nsf.org/etv/dws/dws_project_documents.html (electronic copy)

3. EPA web site: http://www.epa.gov/etv (electronic copy)