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 DRINKING WATER**
TECHNOLOGY NAME:	**ZEEWEED® ZW-500 ULTRAFILTRATION SYSTEM**
TEST LOCATION:	**SANDY, OREGON**
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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) program, one of 12 technology areas under ETV. The DWTS program recently evaluated the performance of a membrane filtration system used in package drinking water treatment system applications. This verification statement provides a summary of the test results for the ZENON

ZeeWeed™ ZW-500 Membrane Filtration System. CH2M HILL, an NSF-qualified field testing organization, performed the verification testing.

ABSTRACT

The ZeeWeed® ZW-500 membrane filtration system was evaluated over the course of three test periods, for a minimum of 30 days each, under a variety of water quality conditions. During the test periods, the feed water turbidity ranged from less than 1 ntu to over 200 ntu.

The ZeeWeed® ZW-500 unit produced water with turbidity of 0.05 ntu or less 95 percent of the time and obtained three to four log removal of particles greater than 2 microns in size. Microbial challenge studies showed that the ZeeWeed® ZW-500 membrane provided better than 4-log removal of *Cryptosporidium*, 3-log removal of viruses, and 3-log removal of *Giardia*. In many cases, the log removals of *Giardia* and *Cryptosporidium* were limited by the number of organisms in the feed.

The permeate flux (normalized to 20°C) exceeded 45 gfd and was typically greater than 65 gfd. Vacuum-based membrane systems are limited in flux based on the inherent water permeability of the membrane and the maximum suction head (vacuum) produced by the permeate pump. Based on the low rate of membrane fouling, increased fluxes would have been possible during the first and second test periods with a larger permeate pump. Permeate recovery was typically 94 to 95 percent.

TECHNOLOGY DESCRIPTION

The ZeeWeed® process uses hollow-fiber ultrafiltration (UF) membranes immersed in a process tank containing source water to be treated. The hollow-fiber membrane is designed to exclude particulate matter exceeding 0.157 microns in size, including *Cryptosporidium* oocysts and *Giardia* cysts, from the treated water stream.

The loose, hollow fiber membranes are assembled into modules by connecting the fibers at both ends (manifolding). During treatment, a vacuum is applied to the inside (lumen side) of the fibers at each manifold. The resulting difference in pressure across the wall of the membrane causes water to flow from the outside of the fiber (feed side) through the membrane pores to the inside, thus becoming filtered (treated) water. The vacuum applied corresponds to the transmembrane pressure for the system.

VERIFICATION TESTING DESCRIPTION

Test Site

The testing was performed at the City of Portland's Bureau of Water Headworks located near Sandy, Oregon. The raw water source was Bull Run Reservoir #2, an impoundment of water from the Bull Run River, on the southwest flank of Mt. Hood.

This source is characterized by low total organic carbon and total dissolved solids, and low to moderate turbidity. During Period 3, turbidity of the source water was augmented with natural clays from the watershed. The pH was typically in the range 6.8-7.2. The temperature ranged from 4.5 to 16°C. Table VS-1 summarizes feed water quality during the test periods.

Table VS-1. Average Feed-Water Quality

Parameter	Units	Period 1	Period 2	Period 3
Alkalinity	mg/L as $CaCO_3$	7.3	6.5	9.6
Total Hardness	mg/L as $CaCO_3$	7.0	5.9	8.2
Calcium Hardness	mg/L as $CaCO_3$	3.9	3.5	4.9
Total Dissolved Solids	mg/L	21 to 22	18	23
Total Suspended Solids	mg/L	8	1	20
Total Coliforms	MPN/100 mL	13	<1	<1
Heterotrophic Plate Count	MPN/100 mL	126	13	74
Total Organic Carbon	mg/L	1.57	0.89	0.93
UV 254	cm^{-1}	0.058	0.037	0.038
SDS TTHM	µg/L	46	28.6	27.2
SDS HAA6	µg/L	73	35.8	27.3
Turbidity (average and range)	ntu	2.14 (0.5 to 10.0)	0.49 (0.4 to 0.7)	18 (0.3 to 250)
Particle Count (>2 µm) (average and range)	#/mL	9,807 (4,000 to 19,500)	4,613 (3,000 to 7,500)	10,094 (1,200 to 27,000)

Methods and Procedures

The package system was operated under the conditions recommended by the manufacturer and monitored 24 hours per day during each test period. During routine operation, the following analyses were performed onsite:

- feed water pH (daily)
- feed water temperature (on-line)
- feed water turbidity (on-line)
- permeate turbidity (on-line)
- concentrate turbidity (on-line)
- particle counts in feed water and concentrate (on-line)

The following samples were collected weekly (unless otherwise indicated) and analyzed at an off-site laboratory:

- alkalinity
- total and calcium hardness
- total dissolved solids
- heterotrophic plate count
- total organic carbon
- UV absorbency at 254 nm
- simulated distribution system total trihalomethanes (monthly)
- simulated distribution system haloaceticacids (monthly)

Total suspended solids and total coliform samples were collected weekly from the feed water, permeate, and concentrate.

Microbial challenge tests were performed to evaluate removal of pathogens of concern in drinking water. The challenge tests were performed just after the membranes were cleaned to be sure that there was no screening effect from particles that had built up on the membrane surface. MS-2 phage and formalin-fixed *Giardia cysts* and *Cryptosporidium oocysts* were added to a large tank, mixed well with the feed water and treated with the ZeeWeed® ZW-500 membrane filtration system. Samples were then collected from the feed, concentrate, and permeate. *Giardia* and *Cryptosporidium* analyses were performed in the permeate using USEPA Method 1623 and 1622, respectively. The MS-2 phage concentrations were measured using SM18 9211D.

During the third and final test period, the turbidity of the feed water was augmented with sediment from the watershed, which had been previously observed to increase the turbidity of the reservoir during severe rain events. The turbidity was increased to as high as 250 ntu and averaged 18 ntu during this test period.

VERIFICATION OF PERFORMANCE

System Operation

Table VS-2 summarizes the membrane flux and recovery, two of the critical performance criteria. During test periods one and two, the membrane flux was limited only by the vacuum pump supplied with the unit. Increased fluxes would have been possible. During the third test period the turbidity was great enough that increased flux would not have been possible. The ZW-500 membrane filtration system was capable of handling a wide variety of turbidities, up to 250 ntu, without sacrificing flux or recovery.

Table VS-2. Summary of Membrane Operational Parameters

Test Period	Mean Temperature	Flux (95 percent confidence interval)	Recovery (95 percent confidence interval)
1	5.8°C	49.7 ± 0.3 gfd	94.5 ±0.1%
2	6.2° C	48.6 ± 0.1 gfd	94.7 ±0.03%
3	15° C	46.2 ± 0.3 gfd	94.4 ±0.1%

The membranes operated for an interval of 30 days between cleanings even when treating water with high turbidity. Cleaning with chlorine typically restored the specific flux.

Water Quality Results

Table VS-3 summarizes the turbidity and particle removal observed during the test. The ZW-500 membrane system provided excellent turbidity and particle removal. The turbidity was equal to or less than 0.05 ntu in 95% of all samples during all three test periods. The particle counts were less than 30 particles per mL and particle removal exceeded 3.5 log 95 percent of the time. The results indicate that this membrane system is able to effectively remove particles and provide drinking water under a variety of conditions. These removals were also exhibited during the microbial challenge studies. Table VS-4 summarizes the observed performance. *Cryptosporidium* was always below detection in the permeate and the log removal results were limited by the detection limit in the permeate and the amount measured in the feed. Although some *Giardia* were detected in the permeate, the concentrations detected were typically less than 1 organism per liter of water. The virus removal goals were exceeded on a consistent basis. In summary, the ZeeWeed® ZW-500 membrane system provided 3.2 to 3.6-log removal of viruses, >4.3 log removal of *Cryptosporidium*, and >3.3 log removal of *Giardia*. The ZeeWeed® ZW-500 membrane filtration process provided excellent removal of pathogens.

Table VS-3. Summary of Particle Removal

Test Period	Turbidity (ntu) at 95 percent confidence[1]	Particle Counts (particles per mL >2 microns) at 95 percent confidence
1	0.04	1.0
2	0.05	5.0
3	0.05	28

[1]95 percent of the values in permeate are less than the value shown

Table VS-4. Summary of Microbe Removal

Test Period	*Giardia*	*Cryptosporidium*	MS-2 Phage
1	>3.3 log	>5.4 log	3.6 log
2	4.7 log	>4.3 log	3.6 log
3	5.0 log	>5.0 log	3.3 log

Operation and Maintenance Results

The ZeeWeed® membrane system was easy to operate. Very few adjustments were needed to maintain operation. The automated operations system worked very well. Operation did require a dependable source of electrical power. On several occasions, power surges caused the unit to shut down and required an operator to start it back up.

The manufacturer's pressure hold test demonstrated the ability to confirm if a fiber was severed or if the membrane surface was damaged (pin-pricked). Additionally, integrity testing indicated an apparent restoration of integrity over time due to plugging of the defect by solids within the process tank.

Membrane integrity monitoring using a particle counter confirmed the sensitivity of a particle counter in detecting particles in the permeate. However, particle counting may be an inadequate integrity monitoring technique if particles are being formed downstream of the membrane due to oxidation or other precipitate forming process.

Cleaning did require some informed judgement on the part of the operator. A working knowledge of the control panel and ability to prepare a 200-mg/L chlorine solution were needed to adequately clean the membranes. The operations manual provided the instructions needed to operate the control panel and provided guidance for cleaning.

Original Signed by Frank Princiotta for E. Timothy Oppelt	*07/25/01*	*Original Signed by Gordon Bellen*	*07/26/01*
E. Timothy Oppelt	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			

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Availability of Supporting Documents

Copies of the *ETV Protocol for Equipment Verification Testing for Removal of Microbiological and Particulate Contaminants in Drinking Water*, dated February 1999, the Verification Statement, and the Verification Report (NSF Report #01/05/EPADW395) are available from the following sources:
(NOTE: Appendices are not included in the Verification Report. Appendices are available from NSF upon request.)

Drinking Water Systems ETV Pilot Manager (order hard copy)
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Ann Arbor, Michigan 48113-0140

NSF web site: http://www.nsf.org/etv (electronic copy)

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