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:	***GIARDIA* AND *CRYPTOSPORIDIUM* REMOVAL IN PITTSBURGH, PENNSYLVANIA**	
TECHNOLOGY NAME:	**ZEEWEED® ZW-500 ULTRAFILTRATION 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 Package Drinking Water Treatment Systems (PDWTS) pilot, one of 12 technology areas under ETV. The PDWTS pilot 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

Environmental Inc. ZeeWeed® ZW-500 UF Drinking Water System. Gannett Fleming, Inc., an NSF-qualified field testing organization (FTO), performed the verification testing.

ABSTRACT

Verification testing of the ZENON Environmental Inc. ZeeWeed® ZW-500 UF Drinking Water System was conducted from February 6 to March 7, 1999. The treatment system underwent *Giardia* and *Cryptosporidium* removal challenge testing on March 2, 1999, and demonstrated a 53 $\log_{10}$ removal of *Giardia* cysts and a 6.4 $\log_{10}$ removal of *Cryptosporidium* oocysts. Source water characteristics were: turbidity average 0.09 Nephlometric Turbidity Units (NTU), pH 7.8, and temperature 3.8°C. During the thirty-day verification test, the system was operated at a flux recommended by the manufacturer of 53 gallons per square foot per day (gfd) at 39°F (3.8°C) (91 liters per meter squared per hour [l/m^2/h]) which equates to 94 gfd at 68°F (169 l/m^2/h at 20°C). The average transmembrane pressure was 7.5 pounds per square inch (psi) (0.52 bar [b]). The feed water recovery of the treatment system during the study was 95%. Chemical cleaning of the treatment system was conducted as part of the verification testing.

TECHNOLOGY DESCRIPTION

Ultrafiltration (UF) processes are generally used to remove microbial contaminants such as *Giardia* and *Cryptosporidium* and other particulate contaminants from drinking water. UF is generally capable of removing particle sizes as small as 0.01 μm. The ZeeWeed® OCP ultrafiltration membrane is a hollow fiber made of a proprietary polymeric compound. It has a 0.03 μm nominal pore size and utilizes outside-in flow. A vacuum is applied to the inside of the hollow fiber membrane drawing the feed water into the lumen of the fiber. The membrane is a mechanical barrier, providing removal of particulate contaminants. Filtrate is collected from the inside of the fiber and drawn to the filtrate outlet.

The ZeeWeed® ZW-500 is a stand-alone system. The only required connections are for the water supply, a sewer connection for the discharge of bleed wastewater and chemical cleaning wastes and electrical service. The treatment system consists of one membrane module and reservoir, a filtrate (vacuum) pump, an air blower, chemical cleaning equipment and necessary gauges and controls. The treatment system is capable of operating in an automatic mode with limited operator intervention.

For this test program filtrate was drawn from both the top and bottom of each hollow fiber. The filtrate pump was used to pull feed water through the membrane. Particulate material which is removed from the membrane surface through air agitation and periodic back pulsing is constantly removed from the system using a peristaltic bleed pump.

VERIFICATION TESTING DESCRIPTION

Test Site

The verification testing site was the Pittsburgh Water and Sewer Authority's (PWSA's) open air Highland Reservoir No. 1, Pittsburgh, Pennsylvania. The source water for the verification testing was treated surface water drawn from the Allegheny River. It underwent coagulation, sedimentation, filtration, and disinfection at PWSA's Aspinwall Treatment Plant prior to being pumped to the Highland Reservoir No. 1. The influent to the treatment unit was drawn from the reservoir effluent lines. The verification testing was limited to the performance of the equipment to remove *Cryptosporidium* oocysts and *Giardia* cysts, because the source water was obtained from an open reservoir.

Methods and Procedures

All field analyses (i.e. pH, turbidity, chlorine residual, temperature) were conducted daily using portable field equipment according to Standard Methods for the Examination of Water and Waste Water, 18th Ed., (APHA, et. al., 1992). Likewise, Standard Methods, 18th Ed., (APHA, 1992) and Methods for Chemical Analysis of Water and Wastes (EPA, 1979) were used for analyses conducted in PWSA's laboratory. These analyses included total alkalinity, total hardness, total organic carbon (TOC), dissolved organic carbon (DOC), total dissolved solids (TDS), total suspended solids (TSS), algae (number and species), Ultraviolet Absorbance at 254 nanometers (UVA_{254}), total coliform, and heterotrophic plate counts (HPC). Total alkalinity, total hardness and TDS analyses were conducted monthly. All other laboratory parameters were analyzed weekly.

Microbial challenge was performed using formalin-fixed *Giardia lamblia* cysts and *Cryptosporidium parvum* oocysts. Procedures developed by EPA for use during the Information Collection Rule (ICR) were employed for the identification and enumeration of *Giardia* cysts and *Cryptosporidium* oocysts (EPA, ICR Microbial Laboratory Manual, EPA, April 1996). The protozoans were added to a fifty (50) gallon (190 liter) drum. This drum was filled with the feed water. A total of 8,625,000 *Giardia* cysts and 109,643,000 *Cryptosporidium* oocysts were added to the feed water reservoir. The turbidity of the feed water was 0.12 NTU during the *Giardia* and *Cryptosporidium* removal challenge testing. This stock suspension was constantly mixed using a drum mixer. A diaphragm pump was used to add the protozoans to the membranes on the treatment unit. The pump was operated at about 0.85 gallons per minute (gpm) (3.2 liter per minute [lpm]). Samples of the filtrate were collected using a polypropylene wound filter with a nominal pore size of 1.0 μm. One thousand liters (264 gallons) of filtrate water was filtered through the sampling vessel at one gpm (3.8 liter per minute). In addition, aliquots of the stock suspension were collected and analyzed to calculate concentrations of the microbes in the feed water. Samples of the bleed water were collected and analyzed to verify that the parasites were added to the system and removed by the filters.

VERIFICATION OF PERFORMANCE

System Operation

The treatment system was fully automated and capable of normal operations without manual intervention. All operational data, flows, vacuum, turbidity and particle counts are recorded on data logging software. Manual intervention is required for chemical cleaning. For this test program filtrate was drawn from both the top and bottom of each hollow fiber. The filtrate pump was used to pull feed water through the membrane.

The system was operated at a flux recommended by the manufacturer of 53 gfd at 39 °F (3.8°C) (91 $l/m^2/h$) which equates to 94 gfd at 68 °F (169 $l/m^2/h$ at 20°C). The flow rate was recorded twice per day and the water temperature was recorded once per day. The flow rate of the treatment system averaged 9.4 gpm (36 lpm) and ranged from 7.6 to 14 gpm (29 to 53 lpm).

The average vacuum applied to the system was -7.5 psi (-0.52 b). Since the membranes are immersed in a tank at atmospheric pressure the absolute value of the vacuum applied to the system is equivalent to the transmembrane pressure (TMP) of the unit. The average TMP for the system was 7.5 psi (0.52 b).

In order to minimize the amount of particulate material accumulating on the surface of the fibers, air is constantly introduced into the system to gently agitate the fibers. An airflow of 7.5 standard cubic feet per minute (scfm) was used during the verification testing. This agitation tends to remove particles adhering to the fibers. In order to remove particles not eliminated by the air agitation, flow is periodically reversed through the fibers. This is referred to as back pulsing. The back pulsing was done every 10

minutes for 20 seconds. A backpulse of one and a half to two times the filtrate flux is generally used to ensure the most effective removal particulate material. Chlorine was added to the back pulse water at a level of approximately 4 to 6 mg/l. The particulate material which is removed from the membrane surface through air agitation and periodic back pulsing is constantly removed from the system using a peristaltic bleed pump.

The feed water recovery of the treatment system during the study was 95%. This figure was calculated by comparing the amount of water bled from the system to the total amount of water introduced into the system.

The effectiveness of the chemical cleaning process was measured by the recovery of specific flux and loss of original specific flux. Chemical cleaning was conducted at the end of the test period as required by the ETV Protocol for Equipment Verification Testing for Physical Removal of Microbiological and Particulate Contamination (EPA/NSF April, 1998). Data collected before and after the chemical cleaning were used to calculate recovery of specific flux and the loss of original specific flux. The chemical cleaning recovered 57% of the specific flux. Data from when the membranes were placed into service and just after cleaning were used to calculate the loss of original specific flux. The loss of original specific flux was 32%.

System integrity was demonstrated as required by the ETV protocol. Tests were conducted on an intact membrane system and on one that had been intentionally compromised. The air pressure hold test detected a compromised membrane after it was intentionally compromised.

Water Quality Results

During the *Giardia* and *Cryptosporidium* removal challenge testing that occurred on March 2, 1999, the ZeeWeed® ZW-500 system demonstrated a 5.3 $\log_{10}$ removal of *Giardia* cysts and a 6.4 $\log_{10}$ removal of *Cryptosporidium* oocysts. The $\log_{10}$ removals were limited by the amount of the parasites which were present in the stock feed solution, the percentage of the filtrate that could be sampled, and the percent recovery of the analytical methodology. There were no *Giardia* cysts or *Cryptosporidium* oocysts observed in the filtrate. During the challenge testing, the feed water characteristics were: turbidity average 0.12 NTU, pH 7.8, temperature 3.6 ^{o}C.

During the thirty-day ETV operation of the ZeeWeed® ZW-500 system, treatment reductions were seen in heterotrophic plate counts (HPC), algae, turbidity, and particle counts. HPC concentrations averaged 179 cfu/100 ml in the feed water and 6 cfu/100 ml in the filtrate. The presence of HPC in the filtrate may have been due to inadequate disinfection of the Tygon tubing used for water sampling. Algae concentrations averaged 18 cells/ml in the feed water and <8 cells/ml in the filtrate. The turbidity concentration in the feed water was 0.09 NTU and 0.03 NTU in the filtrate. The treatment system reduced feed water particle counts from an average of 64 total counts per ml to an average of 0.70 total counts per ml in the filtrate. Total coliform reduction could not be demonstrated due to the absence of total coliforms in the feed water and filtrate throughout the test. The following table presents the water quality reductions of the feed water and filtrate samples collected during the 30 days of operation:

Feed Water Quality / Filtrate Water Quality
ZENON ZeeWeed® ZW 500 Drinking Water Treatment System

	Total Coliforms (cfu/100 ml)	HPC (cfu/100 ml)	Algae (cells/ml)	Turbidity (NTU)	Particle Counts (particles/ml)
Average[1]	0/0	179/6	18/<8	0.09/0.03	64/0.70
Minimum[1]	0/0	94/2	8/<8	0.06/0.02	----
Maximum[1]	0/0	308/18	24/8	0.13/0.04	----
Standard Deviation [1]	0/0	92/8	8/2	0.02/0.004	----
95% Confidence Interval[1]	N/A/ N/A	(89,268)/ (0, 14)	(10,26)/ (<8, <8)	(0.08, 0.09)/ (0.02, 0.03)	----

1 – Concentration of feed water/concentration of filtrate.
N/A = Not Applicable because standard deviation = 0
---- = Statistical measurements on cumulative data not calculated.
Note: Calculated averages for less than results (<) utilize half of the Level of Detection (Gilbert, 1987).

Temperature of the feed water during the thirty-day ETV study was fairly stable with a high of 40.1°F (4.5°C), a low of 37.9°F (3.3°C), and an average of 38.8°F (3.8°C). The treatment system unit had little or no effect on dissolved constituents such as total alkalinity, total hardness, TOC, TDS, and UVA_{254}.

Operation and Maintenance Results

Maintenance requirements on the treatment system did not appear to be significant but were difficult to quantify due to the short duration of the study. The only interruption of the process occurred due to a power failure at the pumping station. After power was restored to the pumping station the treatment system was restarted and placed back into service.

The Operating and Maintenance (O&M) Manual provided by ZENON Environmental was available for review on-site and was referenced occasionally during the testing. Particularly, the manual was consulted during the cleaning procedure. The manual was well organized and a valuable resource during the testing period.

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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 #00/06/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 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)