THE ENVIRONMENTAL TECHNOLOGY VERIFICATION PROGRAM

U.S. Environmental Protection Agency

NSF International

ETV Joint Verification Statement

TECHNOLOGY TYPE:	**ENHANCED COAGULATION MEMBRANE FILTRATION USED IN PACKAGED DRINKING WATER TREATMENT**
APPLICATION:	**PHYSICAL REMOVAL OF MICROBIOLOGICAL, PARTICULATE AND ORGANIC CONTAMINANTS IN DRINKING WATER IN ESCONDIDO, CALIFORNIA**
TECHNOLOGY NAME:	**ENHANCED COAGULATION ZEEWEED® ZW-500 ULTRAFILTRATION SYSTEM**
COMPANY:	**ZENON ENVIRONMENTAL, INCORPORATED**
ADDRESS:	**3239 DUNDAS STREET WEST OAKVILLE, ONTARIO L6M 4B2 CANADA** PHONE: **(905) 465 3030** FAX: **(905) 465 3050**
WEB SITE:	**http:\\www.zenonenv.com**
EMAIL:	**gbest@zenonenv.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 Package Drinking Water Treatment Systems (PDWTS) pilot, one of 12 technology areas under ETV. The PDWTS pilot recently evaluated the performance of an enhanced coagulation membrane filtration system used in package drinking water treatment system applications. This verification statement provides a summary of the test results for the

ZENON Enhanced Coagulation ZeeWeed® ZW-500 Ultrafiltration (UF) System. Montgomery Watson, an NSF-qualified field testing organization (FTO), performed the verification testing.

ABSTRACT

Verification testing of the ZENON Enhanced Coagulation ZeeWeed® UF System was conducted over two test periods. The first test period, from March 22, 1999 to April 19, 1999 represented winter/spring conditions. The second test period, from September 22, 1999 to October 29, 1999 represented summer/fall conditions. The test system consists of an enhanced coagulation unit followed by a submerged ultrafiltration membrane unit. Verification testing was conducted at manufacturer specified operating conditions. Alum was added to the enhanced coagulation unit at a dose of 30 mg/L along with acid to produce a coagulation pH of 6.2. The membrane unit was operated at a constant flux of 37 gfd (62 L/hr-m^2), with air flow of 15 scfm (420 lpm) and an overall feedwater recovery of 95 percent. The combined enhanced coagulation and membrane unit achieved significant removal of organic material, in addition to microbial and particulate contaminants (presented later). Chemical cleaning of the treatment equipment was conducted as part of the verification testing.

TECHNOLOGY DESCRIPTION

The ZENON Enhanced Coagulation ZeeWeed® UF System combines enhanced coagulation, for removal of organic material, with ultrafiltration, for removal of microbial and particulate contaminants. Enhanced coagulation relies on addition of coagulant and acid to natural waters along with mixing to promote destabilization, charge neutralization and agglomeration of particles and organic colloidal material. This results in the adsorption of organic material to floc particles. These particles are then removed by membrane filtration. The ability of the ZeeWeed® OCP UF membrane to operate in a high-solids environment further enhances the removal of organic material by combining the effects of coagulation, coprecipitation and adsorption. The ZeeWeed® UF membrane removes particles by physical sieving. Particulate material larger than the pore size of the membrane (0.03 um nominal, 0.1 um absolute) are removed.

The ZENON Enhanced Coagulation unit consists of chemical feed systems for coagulant and acid, a static mixer, and a serpentine flocculation tank using air diffusers to provide mixing energy. The effluent from the enhanced coagulation unit serves as the feed water to the membrane unit. The ZeeWeed® OCP UF membrane is a submerged hollow-fiber membrane that utilizes a vacuum of 1 to 12 psi (0.07 to 0.83 bar) to draw product water through the membrane. The approximately 4,700 fibers have a combined surface area of 463 ft^2 (43 m^2). The 5.4 ft (2.7 m) long fibers are connected to top and bottom headers and submerged in a 200 gallon process tank. The top and bottom headers are connected to the filtrate vacuum pump. A blower supplies air to a diffuser at the base of the process tank to continuously agitate the fibers and remove accumulated solids. A bleed pump continuously wastes process tank contents to drain, limiting the buildup of solids in the process tank. The bleed flow rate and net permeate flow rate determine overall system feedwater recovery. The system includes a clean-in-place (CIP) tank where filtrate is stored for backpulsing the membrane. During backpulsing, at regular intervals of from 10 to 20 minutes, the flow through the membrane is reversed for 10 to 15 seconds to remove solids accumulated on the membrane surface. The system included a diaphragm pump for adding chlorine, in the form of sodium hypochlorite, to the backpulse water. Both the enhanced coagulation and membrane units are skid mounted and can be moved by forklift and transported by truck.

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 onsite daily using desk top units. All other water quality samples were sent to the City of San Diego Laboratory for analysis. These included alkalinity, total and calcium hardness, total dissolved solids (TDS), total suspended solids (TSS), total organic carbon (TOC), dissolved organic carbon (DOC), ultraviolet absorbance at 254 nanometers (UV254), aluminum, color, total coliform and heterotrophic plate count (HPC). All samples were analyzed according to the Standard Methods for the Examination of Water and Wastewater, 18th Ed. (APHA, et. al., 1992) and/or Methods for Chemical Analysis of Water and Wastes (EPA, 1979). 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, 5-15 um, and > 15 um. SDS DBP formation tests were conducted during each test period. For this testing, the uniform formation conditions of the EPA Information Collection Rule were followed. DBP analyses were conducted according to EPA Method 502.2 for trihalomethanes and EPA Method 552.2 for haloacetic acids.

Virus seedings, using MS2 virus, were conducted after membrane cleaning, at system startup with enhanced coagulation. The first seeding was conducted approximately three hours after system startup and the second was conducted less than one hour after system startup. During each seeding, approximately 2×10^{13} virus were added directly to the process tank after the completion of a backpulse. The system was then allowed to operate for one 10-minute filtration cycle to allow for mixing and equilibration. Sampling was initiated after completion of the next backpulse, with three process tank and three filtrate samples being collected in each of the next two filtration cycles. Samples were analyzed within 24 hours according to EPA ICR Method for Coliphage Assay (Sobsey, et al. 1990).

VERIFICATION OF PERFORMANCE

System Operation

The flow rate of raw water to the enhanced coagulation unit was controlled manually using a valve and rotameter. Coagulant feed to the system was manually set using a diaphragm pump. The coagulation pH was automatically maintained with a Prominent pH controller. A stand-pipe within the flocculation tank maintained water level in the tank. The flow to the flocculation tank was automatically switched on and off by process tank level control signals received from the membrane unit to maintain adequate water levels in the process tank. Feed-on and feed-off signals generated by the control logic of the process tank level controlled the influent valve to the enhanced coagulation unit. Water entering the flocculation tank flowed through four serpentine chambers, then overflowed the standpipe in the last chamber and flowed under gravity into the top of the process tank. Air from the membrane unit blower was diverted to diffusers in the base of each of the four serpentine chambers to accomplish mixing. The air flow rate to each chamber was individually adjustable using a valve and rotameter.

The enhanced coagulation unit was operated with a raw water flow of 14 gpm (52 lpm) in the first test period and 16 gpm (61 lpm) in the second. The coagulant, coagulant dose and coagulation pH were established by the manufacturer. Alum was used as a coagulant at 30 mg/L with acid added to produce a coagulation pH of 6.2. Enhanced coagulation chemical tanks had to be refilled approximately every two days.

The ZeeWeed® UF membrane system required manual adjustments to the filtrate flow control valve to maintain a constant flux as the membrane fouled. The bleed waste pump required manual adjustment to maintain a constant bleed waste flow from the process tank. In addition, the chlorine dosing pump required initial manual adjustment to achieve the proper backpulse chlorine dose. Beyond this, the system was automated. Programmable logic controllers automatically opened the appropriate valves to

initiate filtration and backpulse based on the settings of two timers mounted on the front panel of the membrane unit. Control signals were automatically sent to a feed valve to maintain the proper water level in the process tank. The manufacturer established membrane system operating conditions. The unit was operated at a constant flux of 37 gfd (62 l/hr-m^2) with a bleed waste flow of 0.62 gpm (2.4 lpm). A backpulse volume of 4.2 gallon (16 liter), backpulse duration of 15 seconds and backpulse frequency of every 10 minutes, resulted in overall system recovery of 95 percent. Air flow to the process tank was maintained at 15 scfm (420 lpm). Flows, pressures and temperatures were recorded twice daily.

At the above operating conditions, the enhanced coagulation UF system was able to operate for approximately 25 days during Test Period 1 before chemical cleaning was required. During Test Period 2, however, shorter filtration cycles of 9 to 12 days were observed. A total of four chemical cleanings were conducted over the course of ETV testing. To determine the effectiveness of the chemical cleanings in restoring membrane productivity, recovery of specific flux and loss of original specific flux were calculated for each cleaning. Recovery of specific flux ranged from 54 to 69 percent, while loss of original specific flux ranged from 11 to 17 percent.

Air pressure-hold tests were conducted by pressurizing the permeate side of the membrane and observing pressure decay over a 10 minute period. These tests were conducted at the beginning and end of each test period. The results showed minimal pressure decay (<0.5 psi every 5 minutes), indicating no loss of membrane integrity during the course of testing.

Particle Removal Results

Filtrate turbidity of the enhanced coagulation UF system was 0.05 NTU or less 95 percent of the time during both test periods. 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. 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:

ZENON Enhanced Coagulation ZeeWeed® UF System Particle Concentrations 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	2400/2400	0.16/0.28	4.3/4.0	1500/1300	0.13/0.29	4.2/4.0
Standard Deviation	750/540	0.25/0.48	0.31/0.43	730/370	0.13/0.29	0.30/0.41
95% Confidence Interval	2300-2500/ 2300-2500	0.12-0.20/ 0.20-0.36	4.2-4.2/ 3.9-4.1	1400-1600/ 1200/1400	0.80-0.12/ 0.13-0.23	4.1-4.3/ 3.9-4.1
Minimum	640/450	0.049/0.06	3.6/3.2	290/390	0.05/0.05	3.5/3.1
Maximum	5200/3800	2.1/4.9	4.7/4.6	3900/2400	1.1/3.0	4.6/4.6

Microbial Removal Results

Total Coliforms were analyzed on a weekly basis during both ETV test periods. Raw water total coliforms averaged 15 and 5 MPN/100mL during Test Periods 1 and 2, respectively. No total coliform were detected in the filtrate of the UF system during both Test Periods. HPC averaged 120 and 600 cfu/mL in the raw water for Test Periods 1 and 2. Filtrate levels of HPC averaged 1 and 4 cfu/mL. Two microbial seedings with MS2 virus were conducted on the ZENON Enhanced Coagulation ZeeWeed® UF system. Both seedings were conducted after a membrane cleaning and shortly after system startup with enhanced coagulation. The first seeding was conducted three hours after system startup. Feed concentrations of MS2 ranged from $3.5x10^8$ to $5.9x10^8$ pfu/mL, filtrate concentrations ranged from $<1x10^3$ to $1x10^3$ pfu/mL. Log removals of MS2 virus for the first seeding ranged from >5.5 to 5.8. The second seeding with MS2 virus was conducted less than one hour after system startup with enhanced coagulation. For this seeding, feed concentrations ranged from $2.4x10^8$ to $4.6x10^8$ pfu/mL, filtrate concentrations ranged from $3.1x10^6$ to $4.7x10^6$ pfu/mL. Log removals of MS2 virus for the second seeding ranged from 1.7 to 2.1.

Organics Removal Results

The enhanced coagulation membrane system achieved significant removal of naturally occurring organics. Dissolved organic carbon was reduced on average during Test Periods 1 and 2 from 2.2 and 2.7 mg/L in the raw water to 1.7 and 2.2 mg/L in the filtrate, respectively. This represents a 23 percent DOC reduction in each test period. UV254 was reduced on average during Test Periods 1 and 2 from 0.070 and 0.078 /cm in the raw water to 0.048 and 0.043 /cm in the filtrate, respectively. This represents reductions in UV254 of 31 and 44 percent in Test Periods 1 and 2, respectively. SDS DBP formation tests were conducted during each test period. Total trihalomethane concentration was reduced during Test Periods 1 and 2 from 73 and 69 ug/L in raw water to 43 and 46 ug/L in the filtrate, respectively. This represents a 41 and 34 percent TTHM reduction in Test Periods 1 and 2, respectively. HAA5 concentration was reduced during Test Periods 1 and 2 from 23 and 26 ug/L in raw water to 10 and 14 ug/L in the filtrate. This represents a 56 and 48 percent HAA5 reduction in Test Periods 1 and 2, respectively. The system also removed 76 percent of color from the source water during Test Period 2.

Operation and Maintenance Results

After system startup, routine operation of the system involved occasional adjustment of filtrate flow rate to maintain constant flux, and daily verification and adjustment of bleed waste flow and chemical feed flows. The system experienced one failure of the pH controller, which caused it to run without acid addition for three days during Test Period 1. The system experienced three high level alarms in the process tank during the first period which caused the system to shut down overnight. During the first test period, the membrane unit spent approximately 10 percent of filtration time in permeate-recycle mode because of problems with the process tank level-control logic. This was resolved in Test Period 2 by reprogramming the level control logic. Operation of the membrane unit consumed 0.05 gal (0.20 L) of 10% sodium hypochlorite per day to chlorinate backpulse water. Operation of the enhanced coagulation unit consumed 0.89 gal (3.4 L) of 48% alum stock per day on average and 0.6 gal (2.4 L) of 40% Sulfuric Acid. During the average cleaning, 2 gal (7.8 L) of household bleach (5.25% NaOCl) were used and 8.8 lb (4.0 kg) of citric acid. The manufacturer included an Operations and Maintenance manual with their system. The manual would be improved with better organization and better use of tables and graphics.

Original Signed by	
E. Timothy Oppelt	*8/21/00*
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	*8/25/00*
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 #00/02/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