THE ENVIRONMENTAL TECHNOLOGY VERIFICATION PROGRAM

U.S. Environmental Protection Agency

NSF International

ETV Joint Verification Statement

TECHNOLOGY TYPE:	**ULTRAFILTRATION AND REVERSE OSMOSIS**
APPLICATION:	**REMOVAL OF INORGANIC, MICROBIAL, AND PARTICULATE CONTAMINANTS FROM SECONDARY TREATED WASTEWATER**
PRODUCT NAME:	**EXPEDITIONARY UNIT WATER PURIFIER (EUWP), GENERATION 1**
VENDOR:	**VILLAGE MARINE TEC.**
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NSF International (NSF) manages the Drinking Water Systems (DWS) Center under the U.S. Environmental Protection Agency's (EPA) Environmental Technology Verification (ETV) Program. The DWS Center evaluated the performance of the Village Marine Tec. Generation 1 Expeditionary Unit Water Purifier (EUWP). The EUWP, designed under U.S. Military specifications for civilian use, employs ultrafiltration (UF) and reverse osmosis (RO) to produce drinking water from a variety of sources. This document provides the verification test results for the EUWP system evaluated using secondary wastewater effluent from the Gallup, New Mexico wastewater treatment plant (WWTP).

EPA created the 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 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 voluntary 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.

PRODUCT DESCRIPTION

The following technology description was provided by the manufacturer for informational purposes only and has not been verified.

The EUWP was developed to treat challenging water sources with variable turbidity, chemical contamination, and very high total dissolved solids (TDS) including seawater, during emergency situations when other water treatment facilities are incapacitated. The EUWP components are designed to operate with a generator and include feed pumps, a UF pretreatment system, a one or two pass RO desalination system with an energy recovery device, storage tanks, and product pumps. The first pass part of the RO system has two arrays. One of the arrays is driven by the normal RO feed pump and the other array is driven by the energy saving device. There is only one array in the second pass part of the RO system. The EUWP has chemical feed systems for optional pretreatment coagulation and post treatment chlorination. Clean-in-place systems are included with the UF and RO skids. During this verification test, ferric chloride coagulation pretreatment was used at a dose of 5 mg/L as Fe. There was no post-treatment chlorination.

Design specifications indicate that the UF system alone has a production capacity up to 250,000 gallons per day (gpd) from a fresh water source with up to 500 mg/L TDS and a temperature of 25°C. The combined UF and RO system is designed to produce from 98,000 gpd up to 162,000 gpd, depending on the TDS of the source water and the recovery settings of the RO process.

VERIFICATION TEST DESCRIPTION

Test Site

The test was performed at the City of Gallup WWTP at 800 Sweetwater Place, Gallup, New Mexico. The WWTP treats an average of 3 million gallons per day (MGD) of wastewater with a peak of 5.5 MGD in the summer. The source water for testing was secondary wastewater effluent prior to chlorination. Initial characterization samples, which consisted of six grab samples, were collected in May and June of 2006. Highlights of the source water characterization are presented in Table VS-i. Parameters in the source water that exceed the EPA's National Primary Drinking Water Regulations (NPDWR) included nitrate, bromide, gross alpha, and biological components. Secondary drinking water standards were exceeded for color, sulfate, TDS, surfactants, aluminum, and odor. The source of the city's drinking water is high in TDS and sulfate with some radioactivity. The rest of the exceedances are caused by municipal use and the wastewater treatment process. Detailed results of the source water characterization can be found in the report.

Table VS-i. Source Water Characterization Data

Parameter	Background Samples, 2006					
	5/25	6/01	6/08	6/15	6/22	6/28
Color (color units)	35	30	75	40	40	35
Bromide (mg/L)	<0.20	<0.20	0.21	<0.20	0.20	<0.20
Sulfate (mg/L)	320	340	330	340	310	340
Nitrate (as Nitrogen) (mg/L)	19.5	13.8	N/A	10.9	10.8	8.7
TDS (mg/L)	1100	1100	1100	1100	1200	1100
Surfactants (mg/L)	0.75	0.75	0.75	0.50	0.50	0.75
Aluminum (µg/L)	<100	N/A	310	130	110	130
Odor (Threshold Odor Number)	12	12	17	17	12	17
Gross Alpha (pCi/L)	9.8	0	30	7.5	1.9	16
Total Coliform (MPN/100 mL)	N/A	24,000	≥160,000	70,000	1,600,000	4,000
Fecal Coliform (MPN/100 mL)	N/A	5,000	140,000	70,000	900,000	<2,000
Heterotrophic Plate Count (HPC) (CFU/mL)	N/A	6,600	≥160,000	11,000	190,000	11,000

Methods and Procedures

The EUWP verification test was conducted from July 12 to August 16, 2006 by the U.S. Bureau of Reclamation (USBR), with assistance from the U.S Army Tank-Automotive Research, Development, and Engineering Center (TARDEC). The test was intended to determine if the EUWP could produce 100,000 gpd of finished water meeting the NPDWR from secondary treated wastewater, based on contaminants found in the source water during the initial water characterization phase of ETV testing (see Table VS-i).

The testing activities followed a test/quality assurance plan (TQAP) prepared for the project. The TQAP was developed according to the ETV Protocols *EPA/NSF Protocol for Equipment Verification Testing for Removal of Inorganic Constituents* – April 2002, and the *EPA/NSF Protocol for Equipment Verification Testing for Physical Removal of Microbiological and Particulate Contaminants* – September 2005.

The system was shut down for two days (July 24 and 25, 2006) for RO cleaning and for two days (July 30 and 31, 2006) for UF cleaning. An additional RO cleaning was performed from August 7 to August 8, when the system was down for approximately 24 hours. The system was in operation on 32 calendar days, which met the test plan goal for collecting operating data for a minimum of 30 days. The system was operated as continuously as possible. Shut downs occurred each day to perform a pressure decay test on the UF system, to calibrate sensors, clean the strainers, etc. The RO system also shut down periodically for various maintenance activities, or when alarms occurred and shut the system down. When alarms and shutdown occurred during unattended operation at night, the entire system would remain shut down until an operator arrived in the morning. Turbidity and conductivity were selected as two key parameters. Turbidity removal by the system would indicate the ability to remove particulate related contaminants, and a reduction in conductivity (indicator of total dissolved solids content) would show the ability of the RO system to remove dissolved contaminants. Flow, pressure, conductivity, and temperature recordings were collected twice per day when possible to quantify membrane flux, specific flux, flux decline, and recovery. Grab sample turbidity and pH readings were also recorded twice per day. The UF and RO skids also included in-line turbidimeters for the raw water, UF filtrate, and RO permeate streams. The in-line turbidimeters recorded measurements every 15 minutes.

Once per week samples were collected from the UF and RO process streams for alkalinity, hardness, sulfate, total silica, dissolved organic carbon (DOC), TDS, total organic carbon (TOC), total suspended solids (TSS), ultraviolet light absorbance at 254 nanometers (UV_{254}), dissolved metals, total metals, total and fecal coliforms, *Escherichia coli* (*E. coli*), and HPC. Samples were also collected from the UF system weekly for color, biological oxygen demand (BOD) and chemical oxygen demand (COD).

VERIFICATION OF PERFORMANCE

Finished Water Quality

The UF system reduced turbidity from a mean of 11.1 Nephelometric Turbidity Units (NTU) in the feed water to a mean of 0.74 NTU in the UF filtrate as measured by the daily grab samples. The 95% confidence level shows that filtrate turbidity can be expected to be in the range of 0.62 to 0.86 NTU. The operators manually recorded in-line turbidity measurements at least once per day. The feed water turbidity, as recorded from the in-line analyzer, showed a mean value of 8.7 NTU. The UF filtrate in-line analyzer showed a mean turbidity of 0.69 NTU. Statistics for in-line turbidity measurements were not calculated for the test because the in-line turbidity data for the process streams was inadvertently erased for the period July 27 through the end of the test.

The RO permeate had a mean turbidity of 0.15 NTU based on the handheld meter readings. The 95% confidence interval for the handheld meter results showed an expected range of 0.13 to 0.17 NTU for the RO permeate. The RO permeate turbidity, as manually recorded from the in-line analyzer, had a mean value of 0.016 NTU.

The UF system was found to have faulty seals, which is discussed in the verification report. This may explain why the turbidity reductions by the UF system did not meet the NPDWR of <0.3 NTU 95% of the time. While the UF system alone did not meet the NPDWR, the RO system which followed it sufficiently reduced the turbidity to the meet NPDWR. The RO permeate turbidity levels manually recorded from the in-line meter show that the system did meet the NPDWR of <0.3 NTU 95% of the time, with all values below 1.0 NTU.

A second turbidity requirement is an action level of 0.15 NTU in the EPA Long Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR). The rule states that if the in-line turbidity measurement exceeds 0.15 NTU over any 15-minute period, the system must be shut down and a direct integrity test performed. Throughout the period for which in-line turbidity data exists (July 12-27), the RO system produced permeate with turbidity meeting the LT2ESWTR action level criteria. There were a few single data points that exceeded 0.15 NTU, but never two readings in a row, which would indicate that the turbidity did not exceed the action level over an entire 15-minute period. All of the manually recorded turbidity data was 5 to 10 times lower than the 0.15 NTU action level.

The RO system reduced the dissolved ions in the feed water, as measured by conductivity, by a mean of 99.3%. The mean conductivity in the RO permeate was 11 µS/cm compared to the mean conductivity in the RO feed water of 1,600 µS/cm. The direct measurement of TDS shows that the mean concentration in the RO permeate was <10 mg/L compared to a mean RO feed water level of 1,100 mg/L. The overall TDS rejection was 99.5%.

The UF system had no impact on the pH of the water with the feed water having a mean pH of 7.53 and the filtrate having a mean pH of 7.54. The RO system did lower the pH of the permeate. The pH in the permeate ranged from 5.38 to 7.30 with a mean of 6.27. The UF and RO systems did not have an effect on the temperature of the water as it passed through the systems.

After RO treatment, the RO permeate met all primary and secondary drinking water standards measured during the verification test. The RO unit served as an effective treatment system for removing inorganic and organic constituents present in the secondary wastewater. To be acceptable for transmission or drinking, the RO permeate would need stabilization and residual chlorination.

UF and RO Membrane Integrity

Daily pressure decay tests were used to document UF membrane integrity. Turbidity, fecal and total coliforms, *E. coli*, and HPC were measured in the UF feed and filtrate as indirect membrane integrity indicators.

During the test audit, representatives from Koch Membrane Systems, Village MarineTec., NSF, and USBR were present to observe the pressure decay test. During that test the filtrate side of the membranes was drained and both arrays were simultaneously pressurized to 20 pounds per square inch, gauge (psig). The feed valve and retentate valves were in their operating positions. The filtrate valves were closed. After 15 minutes the system had lost 1.5 psig. This rate of pressure decline was acceptable to Koch.

As pressure testing continued, it became apparent that the procedure was not giving an accurate test of the system. After further inspection of the system, USBR realized that the check valve on the feed side and the long run of piping filled with water on the retentate side would not allow air to escape from the system at 20 psig. In effect the system was completely closed. Opening a sample port on the feed side remedied this, but also revealed that the system had lost integrity, as was apparent from the turbidity readings and biological analysis results that had started arriving by this time.

As discussed above, the UF filtrate turbidity was much higher than expected. None of the remedies of chemically cleaning the system, cleaning the turbidimeter, and recalibration of the turbidimeter solved the problem. The leakage was so severe that it was believed to be more than broken fibers. However, the testing schedule had to be maintained, as the City of Gallup needed the space and the EUWP had to be off-site by the scheduled end of the test period.

Biological analyses were performed for fecal and total coliform, *E. coli*, and HPC. Virus counts were measured for one set of UF feed, filtrate, and RO permeate. The enteric virus results showed 176 MPN/100 mL in the RO feed and <1 MPN in the RO permeate. Coliform species were present in the feed water in great enough numbers to allow for a log reduction value (LRV) greater than 3 from the UF filtrate to the RO permeate.

Dye-marker direct integrity tests were performed on the RO system at the start and end of the test period. The RO membranes rejected the dye at a rate higher than 99%. The rejection rate improved at the end of the test. These results, supported by the high rejection rate for conductivity, the low turbidity in the permeate, and the 3 LRV for coliform samples, indicate that the RO membranes maintained integrity throughout the verification test. Although the UF membrane unit had lost integrity, the subsequent RO array provided a barrier to microorganisms, turbidity and other contaminants.

UF System Operation

UF process operations data for the test are presented in Table VS-ii. The mean UF operating hours during the verification test was 14 hours per day. The mean RO operating hours during the verification test was 18 hours per day. The UF operating hours were lower than the RO because the system is designed for the UF to operate at a higher filtrate flow rate than the RO feed rate to keep the RO feed tank full. Whenever the RO feed rate tank was at maximum level, the UF was automatically shut down until the RO feed tank level dropped to the pre-set level to restart the UF system. The intake flow is defined as the source water pumped into the UF feed water tank. The mean UF feed water flow rate of 250 gallons per minute (gpm) was slightly below the target feed flow rate of 259 gpm specified for the system. The mean filtrate flow rate of 229 gpm corresponds to a flow rate of 14.3 gpm for each of the 16 UF membrane modules. The UF water recovery was 91.6% based on the mean feed water and filtrate flow rates.

The UF system flow rate objective was 200,000 gpd for this test. Based on the mean net filtrate production of 178,000 gpd over the verification period, the UF system did not achieve the objective. The reason was that the unit did not operate a sufficient number of hours per day to meet the production goal. At a mean filtrate flow rate of 229 gpm, and accounting for a backwash volume of 900 gallons every 30 minutes, the UF system would need to operate an average of 17 hours per day to meet the objective. The UF system operated an average of only 14 hours of per day during the test.

Table VS-ii. UF Operations Productivity Data

Parameter	Count	Mean	Median	Minimum	Maximum	Standard Deviation	95% Confidence Interval
UF operation (hr/day)	30	14	15	4	20	4.1	±1.5
Intake flow (gpm)	53	281	288	217	301	21.0	+5.65
Feed flow (gpm)	53	250	251	179	314	24.3	±6.55
Filtrate flow (gpm)	53	229	229	154	289	25.0	±6.74
Retentate flow (gpm)	49	24	25	19	30	4.4	±1.2
Backwash flow (gpm)	Not measured. 900 gallons per backwash cycle(1); Backwash every 30 minutes						
Feed pressure (psig)	53	22	21	16	30	3.9	±1.1
Retentate pressure (psig)	53	19	19	0	28	5.4	±1.5
Filtrate temperature (°F)	54	78	78	76	82	1.5	±0.4

(1) Volume not measured. It was provided by the manufacturer.

RO System Operation

The RO process operations data are presented in Table VS-iii. The RO system did not achieve the permeate production of 100,000 gpd claimed in the statement of performance. The mean permeate production for the 32 calendar days of operation was 78,000 gpd. The mean feed water flows of 107 gpm for Array 1 and 41 gpm for Array 2 were below the target feed rates established in the test plan (Array 1 target 116 gpm and Array 2 target was 58 gpm). The percent recovery for Array 1 of 50% equaled the target specification of 50%. The Array 2 percent recovery of 42% was below the target specification of 48%. These recoveries, with the feed water flows, resulted in mean permeate flow rates of 53 gpm for Array 1 and 17 gpm for Array 2. At these flow rates, the RO unit would need to operate an average of approximately 24 hours per day to meet the target of 100,000 gpd. The RO unit averaged 18 hours per day of operation during the test.

It was apparent during the test that the UF treated secondary wastewater was putting a heavier load on the RO than expected. For this type of application, lower percent recoveries and lower flows were achieved compared to design specifications for groundwater and seawater. During the last few days of testing the recovery was set to 40% to protect the system from heavy loading from the WWTP. While this may not have been necessary, it explains the drop in flows and pressure near the end of the test.

It should be noted that while the RO only achieved approximately 78% of the performance objective for permeate production, additional operating time each day would have increased the total production. As noted in the UF system discussion, operators were only present during daylight hours and there was no coverage over night. Therefore, if an alarm sounded and shutdown the unit, the system remained off-line until an operator arrived the next morning. While it may not be realistic to operate the RO unit continuously 24 hours per day for several days, additional operator coverage could increase operating hours and achieve permeate production closer to the target.

Table VS-iii. RO System Operations Productivity Data

Parameter	Count	Mean	Median	Minimum	Maximum	Standard Deviation	95% Confidence Interval
Array 1 feed flow (gpm)	54	107	107	104	110	1.29	±0.34
Array 1 permeate flow (gpm)	54	53	55	42	64	5.44	±1.45
Array 1 concentrate flow (gpm)	54	54	53	43	67	5.52	±1.47
Array 2 feed flow (gpm)	54	41	41	32	48	4.14	±1.10
Array 2 permeate flow (gpm)	54	17	18	11	22	2.74	±0.73
Array 2 concentrate flow (gpm)	54	24	23	20	29	1.70	±0.45
Array 1 feed pressure (psig)	54	290	293	222	366	26.1	±6.96
Array 1 concentrate pressure (psig)	53	197	199	134	263	24.8	±6.67
Array 2 feed pressure (psig)	54	193	195	133	261	23.6	±6.28
Array 2 concentrate pressure (psig)	54	138	138	91	182	19.0	±5.06
Array 1 and 2 combined permeate pressure (psig)	54	20	19	9	42	5.82	±1.55

QUALITY ASSURANCE/QUALITY CONTROL (QA/QC)

NSF provided technical and quality assurance oversight of the verification testing as described in the verification report, including a review of 100% of the data. NSF QA personnel also conducted a technical systems audit during testing to ensure the testing was in compliance with the test plan.

In-line field meters for particle counts were factory calibrated and certificates were provided as required in the TQAP. However, incorrect calibration certificate data for bin voltages was entered into the software program for the particle counters. This resulted in rendering the particle count data inaccurate and not meeting the Data Quality Objectives. Because of this problem, particle count data could not be used for documenting system performance for particle count and the data are not included in this report.

Samples were collected for *Cryptosporidium* and *Giardia* enumeration, but the analyses did not meet the QA/QC objectives for the ETV test. Therefore, these data are not included in the verification report.

A complete description of the QA/QC procedures is provided in the verification report.

Original signed by Sally Gutierrez 01/31/11	*Original signed by Robert Ferguson 01/17/11*
Sally Gutierrez Date	Robert Ferguson Date
Director	Vice President
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Office of Research and Development	NSF International
United States Environmental Protection Agency	

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Availability of Supporting Documents
Copies of the test protocol, the verification statement, and the verification report (NSF report # NSF 10/27/EPADWCTR) are available from the following sources:

1. ETV Drinking Water Systems Center Manager (order hard copy)
   NSF International
   P.O. Box 130140
   Ann Arbor, Michigan 48113-0140
2. Electronic PDF copy
   NSF web site: http://www.nsf.org/info/etv
   EPA web site: http://www.epa.gov/etv