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 DISSOLVED SALTS AND PARTICULATE CONTAMINANTS FROM SEAWATER**
PRODUCT NAME:	**EXPEDITIONARY UNIT WATER PURIFIER (EUWP)**
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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 using seawater at Naval Base Ventura County in Port Hueneme, California.

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 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.

PRODUCT DESCRIPTION

The following technology description was provided by the manufacturer 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 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. It 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, coagulation pretreatment was employed, but chlorination was not.

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 testing site was the Seawater Desalination Test Facility (SDTF) operated by the Naval Facilities Engineering Service Center (NFESC) at Naval Base Ventura County (NBVC) in Port Hueneme, California. The source water was from an open ocean intake in the Port of Hueneme, a deep-water port. The port has no appreciable fresh water outlets; therefore, the water closely resembles that of the Pacific Ocean salinity.

Initial characterization samples of seawater were collected in April, June and September 2006, and again in April and August 2007. Highlights of the initial characterization data are presented in Table VS-i. In addition to the data presented in Table VS-i, nitrite, nitrate, total silica, fluoride, and 29 metals were analyzed and the concentrations were either below the laboratory reporting limits (not detected) or below the National Primary Drinking Water Regulations (NPDWR) limits and are presented in the final report. Samples for many of the metals were analyzed by EPA Method 1640, which achieved detection limits much lower than Method 200.7 and provided data on seawater that could be compared to the NPDWR.

Table VS-i. Initial Raw Water Characterization Sampling Results

	Sample Date			
Parameter	**04/01/06**	**06/08/06**	**09/05/06**	**04/24/07**
pH	7.77	7.96	7.8	
Conductivity (µmhos/cm)	50,000	50,000	51,100	
TOC (mg/L)			ND (0.3)	
UV254 (l/cm)			0.016	
TSS (mg/L)			30	
TDS (mg/L)	34,000	37,000	35,700	
Alkalinity (mg/L $CaCO_3$)			100	
Total Hardness (mg/L as $CaCO_3$)			6,580	
Sodium (mg/L)				11,000
Heterotrophic Plate Count (CFU/mL)			4	
Total Coliforms (CFU/100 mL)			80	

Methods and Procedures

The U.S Army Tank-Automotive Research, Development, and Engineering Center (TARDEC) conducted the EUWP test with assistance from the U.S. Bureau of Reclamation (USBR). Field testing was conducted from October 16, 2007 to November 12, 2007. The ETV test protocol calls for testing to run for 30 days with the intent to operate the equipment until at least one chemical cleaning is performed. NSF allowed TARDEC to stop testing two days early because over the course of testing, the UF system was cleaned four times. Per a requirement of the ETV test, a chemical cleaning was performed on the RO system at the end of the test, although the RO system had not yet reached its cleaning level criteria.

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

Turbidity and conductivity were selected as two key water quality parameters, as turbidity removal by the system indicated the ability to remove particulate related contaminants, and a reduction in conductivity (indicator of total dissolved solids content) showed 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 when possible. 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. In addition, the UF skid was equipped with in-line particle counters that recorded particle counts every five minutes. Pressure decay tests were conducted daily on the UF system to verify membrane integrity.

Total dissolved solids (TDS) were measured once per day on samples collected from the UF raw water and the RO process streams and once per week on the UF discharge and RO feed water. Once per week samples collected from the UF and RO process streams were analyzed for alkalinity, bicarbonate, total hardness, boron, calcium, chloride, lithium, magnesium, barium, selenium, ortho-phosphate, phosphorus (total), potassium, sodium, Stiff and Davis Stability Index (S&DSI), sulfate, total suspended solids (TSS), UV absorbance at 254 nm (UV_{254}), and total coliforms. Samples were collected for *Bacillus* endospores once per day from the UF and RO process water.

VERIFICATION OF PERFORMANCE

Finished Water Quality

The UF system reduced turbidity from a mean of 1.34 NTU in the raw water to a mean of 0.06 NTU in the UF filtrate, as measured by the daily grab samples. This equates to a mean percent reduction of 94.9%. The 95% confidence interval shows that filtrate turbidity can be expected to be in the range of 0.05 to 0.07 NTU. The raw water turbidity, as measured by the in-line analyzer, had a mean value of 1.38 NTU. The in-line turbidity data for the UF filtrate had a mean of 0.019 NTU. The UF filtrate turbidity levels met the NPDWR of <0.3 NTU 95% of the time and all values below 1.0 NTU throughout the test. A second turbidity requirement is an action level of 0.l5 NTU in the EPA Long Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR). This rule states that if the filtrate turbidity exceeds 0.15 NTU over any 15-minute period, the system must be shut down for a direct integrity test. Since the data logger recorded turbidity every 15 minutes, the evaluation criteria was two consecutive turbidity measurements exceeding 0.15 NTU. There were three single data points where the UF filtrate turbidity exceeded 0.15 NTU. In each instance, the previous and following turbidity values were significantly below the 0.15 NTU level. Based on these data and evaluation criteria, it appears that the UF system did not exceed the LT2ESWTR action level during the verification test. It should be noted that the EUWP was not set up to

be compliant with the LT2ESWTR, as the in-line turbidity meters were not tied to an automatic system shutdown if the turbidity level exceeded 0.15 NTU for any 15 minute period.

The RO system provided little additional reduction of the turbidity levels, with the RO permeate having a mean turbidity of 0.05 NTU, based on the grab samples collected each day. The in-line RO permeate turbidimeter measurements had a mean turbidity of 0.013 NTU. The final treated water, the RO permeate, also met the NPDWR turbidity requirements. In addition, the RO system produced permeate with turbidity below the LT2ESWTR action level of 0.15 NTU throughout the test. As with the UF system, there were only three single RO permeate data points above the action level, and at no time were there two consecutive 15-minute readings above the action level.

The RO system reduced the dissolved ions in the water, as measured by conductivity by a mean of 99%. The mean conductivity in the RO permeate was 592 µS/cm, while that for the RO feed was 51,380 µS/cm. The direct measurements of TDS also show 99% reduction, with the RO permeate in the 280-300 mg/L range, compared to 34,000-39,000 mg/L in the RO feed. Sodium was reduced by 98% and chloride was reduced by 99%. These data are consistent with the conductivity data. The other inorganic materials measured such as hardness, alkalinity, metals, sulfate, and phosphorus were also effectively reduced in the RO permeate.

The UF system had no impact on the pH of the water with the feed water having a mean pH of 7.78 and the filtrate having a mean pH of 7.73. The RO system did lower the pH, the permeate having a mean pH of 6.29.

UF Membrane Integrity

Pressure decay tests, microorganism reduction, and particle counts were used to document UF membrane integrity. *Bacillus* endospores and total coliforms were measured in the feed and filtrate to provide data on the microbial reduction achieved by the UF system. In-line analyzers also collected particle count data from the feed and filtrate streams as an additional indicator of membrane integrity and the capability of the system to remove particulate and microbial contaminants.

Pressure decay tests on the UF system were performed on most operating days during the verification test. The mean pressure decay rates ranged from 0.02 to 0.15 psig/min. The overall mean pressure decay rate was 0.08 psig/min. These direct integrity test results were indicative of membrane modules with no significant observable breaches.

The particle counters recorded the particle counts in the UF feed and UF filtrate every five minutes and stored the data for transfer to a personal computer. The mean 2-3 µm particle count for the feed water was 5,559/mL, with a range of 53-17,843/mL. The UF filtrate had a mean 2-3 µm particle count of 42/mL, with a range of 0-773/mL. The UF system reduced the 2-3 µm particles by a mean value of 2.3 $\log_{10}$. However, the maximum particle count of 773/mL may not be indicative of the typical UF separation performance. The UF system went through a backflush cycle every half-hour, and during these backflushes the particle counts were still being recorded. Consequently, the filtrate particle count data included numerous spikes. The backflushes were not time-stamped, so the spikes due to backflushes could not be identified with certainty and removed from the data set.

The mean 3-5 µm particle count for the UF feed was 3,616/mL, with a range of 1,355-9,505/mL. The filtrate had a mean 3-5 µm particle count of 22/mL, with a range of 1-352/mL. Again, spikes due to backflushes could not be identified with certainty. The UF system reduced the 3-5 µm particles by a mean value of 2.5 $\log_{10}$.

Bacillus endospores and total coliform levels in the seawater were low during the test, with geometric mean concentrations of 64 CFU/100 ml and 10 CFU/100 ml, respectively. The UF system reduced the *Bacillus* endospores to a geometric mean of 1.3 CFU/100 ml. The UF filtrate endospores counts were 1 or <1 CFU/100mL on all but two days. No total coliforms were found in any UF filtrate samples.

UF System Operation

The UF system performance operations data for the test are presented in Table VS-ii. The intake flow is the intake from the source water into the UF feed water tank.

Table VS-ii. UF System Operations Data

Parameter	Count	Mean	Median	Minimum	Maximum	Standard Deviation	95% Confidence Interval
UF Operation per day (hr)	19	18.6	19.8	7.3	22.7	4.11	± 1.85
Intake Flow (gpm)	74	287	288	272	296	4.98	± 1.13
Feed Flow (gpm)	74	249	251	212	279	11.4	± 2.60
Filtrate Flow (gpm)	74	222	225	187	252	10.9	± 2.48
Retentate Flow (gpm)	74	26	26	25	34	1.66	± 0.38
Backwash Flow (gpm)	900 gallons per backwash cycle*; Backwash every 30 minutes						
Feed Pressure (psig)	74	20.6	20.0	14.0	30.0	3.74	± 0.85
Retentate Pressure (psig)	74	16.3	16.0	10.0	23.0	2.89	± 0.66
Filtrate Temperature (°F)	74	58.3	59.0	55.0	61.0	1.62	± 0.37

*Volume not measured. It was provided by the manufacturer.

The mean UF feed water flow was 249 gpm. The UF water recovery was 89.2% based on the mean feed water and filtrate flows. The net UF filtrate production over the 28 calendar-day test period (27 – 24 hour periods) was 4,673 kilogallons (kgal), which represents an average production rate of 173.1 kgal/day. The total UF filtrate volume (including filtrate used for backwash) produced was 5,249 kgal, which gives an average total production rate of 194.4 kgal/day. This production rate includes the two days when the UF was not operated as part of the cleaning cycle and includes other days with limited production due to cleaning or system maintenance issues.

A chemical coagulant (ferric chloride) was added to the UF feed water to improve operation of the UF system and to lengthen run time between chemical cleanings. The coagulant addition was planned for a feed rate of 4.37 ml/min, which would yield an iron dose (as Fe) of 0.75 mg/L in the UF feed water (4.6 x 10^{-6} gallons of ferric per gallon of feed water). Based on the tank records, a total of 22.4 gallons of ferric chloride were fed into 5,259,625 gallons of feed water (4.3 x 10^{-6} gallons of ferric per gallon of feed water), which is approximately 10% less than the feed rate measured by the pump calibration.

RO System Operation

The RO system operations data for the test are presented in Table VS-iii. The mean feed water flows of 115 gpm for Array 1 and 63 gpm for Array 2 were very close to the target feed rates established in the test plan (Array 1 target 116 gpm and Array 2 target was 58 gpm) to achieve an overall RO target flowrate of 100,000 gpd. The Array 1 recovery of 61% exceeded the target specification of 50%. The Array 2 recovery of 50% also exceeded the target specification of 48%. These recoveries, in conjunction with the feed water targets, resulted in mean permeate flow rates of 70 gpm for Array 1 and 32 gpm for Array 2. At these flows, the RO unit would need to operate an average of approximately 16.3 hours/day to meet the target of 100,000 gpd.

Table VS-iii. RO System Operations Data

Parameter	Count	Mean	Median	Minimum	Maximum	Standard Deviation	95% Confidence Interval
Array 1 Feed Flow (gpm)	74	115	115	112	117	0.74	± 0.17
Array 1 Permeate Flow (gpm)	74	70	70	68	72	0.82	± 0.19
Array 1 Concentrate Flow (gpm)	74	45	45	43	48	1.03	± 0.23
Array 2 Feed Flow (gpm)	74	63	63	56	68	2.05	± 0.47
Array 2 Permeate Flow (gpm)	74	32	32	25	37	2.11	± 0.46
Array 2 Concentrate Flow (gpm)	74	31	31	30	32	0.36	± 0.08
Array 1 Feed Pressure (psig)	74	954	960	860	977	19.5	± 4.44
Array 1 Concentrate Pressure (psig)	74	905	903	870	992	15.5	± 3.53
Array 2 Feed Pressure (psig)	74	902	900	880	995	15.4	± 3.51
Array 2 Concentrate Pressure (psig)	74	868	865	850	885	7.65	± 1.74
Array 1 and 2 Combined Permeate Pressure (psig)	74	23.4	23.5	21.0	28.5	1.34	± 0.31

Over the 28 calendar-day (27 24-hour periods) verification test, the RO feed water totalizer showed 4,673 kgal of water was fed to the RO unit. Based on the daily percent recoveries for each array (typically Array 1 at 61% and Array 2 at 50%), the total volume of permeate produced was approximately 2,671 kgal, giving an average of 98.9 kgal/day over the 28-day test.

The primary reason the RO system did not achieve or exceed the production goal of 100 kgal/day was a lack of feed water when the UF system was shut down for cleaning. The UF system also shutdown anytime the RO system feed water tank was full. The test was designed to evaluate the entire system with both UF and RO in operation. The UF system produced enough water to meet the 100 kgal/day production goal; however, because of limited UF filtrate storage capacity, long downtime periods for the UF system cleaning did impact the RO production. With more storage capacity for UF filtrate, the UF system would have been able to meet the feed requirements for the RO system to achieve the overall goal of producing 100 kgal/day, even with the more frequent cleaning schedule. Whenever, there was feed available, the RO system operated continuously producing permeate at a flow rate of 100 to 102 gpm. The RO system operated greater than 20 hours on 12 of the 25 actual operating days. During those days, when the UF was also operating most hours of the day, the RO system did meet and exceed the target production rate. The RO mean operating hours were 17.0 hours/day with a median of 19.0 hrs/day. These mean and median hours match closely to the UF hours (mean – 16.9 hrs and median 19.1 hrs). The maximum RO operating hours were 24 hours and the minimum was 4 hours.

Antiscalant was added to the RO feed water throughout the test. The mean dose rate was 5.7 mg/L versus a target feed of 5 mg/L. The RO system did not appear to experience any scaling or fouling problems during the test. The S&DSI varied from -0.71 to -0.84 during the test. This indicates that the concentrate was a non-scaling water (S&DSI <0.0 is non-scaling). The combination of non-scaling water and the addition of antiscalant reduced or eliminated the problems of scaling on the RO membranes.

The system operated consistently throughout the test with little change in flows or pressures. This would suggest that for this source, the RO could have met and exceeded production targets, if sufficient water could have been provided from the UF system. The buildup of solids on the UF system and need for frequent UF system cleaning was the limiting factor over the test period.

The RO system specific flux was consistent over the test period and indicates that the RO membranes were not being fouled over time. The membranes were still functioning at the end of the test at a specific flux that was 97% of the starting specific flux; therefore, it cannot be projected when the membranes would require cleaning. The RO system was chemically cleaned in place on November 13 and 14, 2007 at the end of the test. This cleaning was performed because it was a requirement of the verification test to demonstrate the cleaning process; however the RO system had not actually reached its target cleaning level criteria.

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

Original signed by Sally Gutierrez 08/12/10
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Availability of Supporting Documents
Copies of the test protocol, the verification statement, and the verification report (NSF report # NSF 09/29/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