THE ENVIRONMENTAL TECHNOLOGY VERIFICATION PROGRAM

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ETV Joint Verification Statement

TECHNOLOGY TYPE:	**REVERSE OSMOSIS MEMBRANE FILTRATION USED IN PACKAGED DRINKING WATER TREATMENT SYSTEMS**
APPLICATION:	**REMOVAL OF ARSENIC IN DRINKING WATER AT PARK CITY, UTAH**
TECHNOLOGY NAME:	**HYDRANAUTICS ESPA2-4040 REVERSE OSMOSIS MEMBRANE ELEMENT MODULE**
COMPANY:	**HYDRANAUTICS**
ADDRESS:	**401 JONES ROAD PHONE: (760) 901-2500** **OCEANSIDE, CALIFORNIA 92054 FAX: (760) 901-2578**
WEB SITE:	**http://www.membranes.com**
E-MAIL:	**info@hydranautics.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 Drinking Water Treatment Systems (DWTS) pilot, one of 12 technology areas under ETV. The DWTS pilot recently evaluated the performance of a reverse osmosis membrane system used in package drinking water treatment system applications. This verification statement provides a summary of the test results for the Hydranautics ESPA2-4040 Reverse Osmosis Membrane Element Module System. Cartwright, Olsen and Associates, LLC, an NSF-qualified field testing organization (FTO), performed the verification testing.

ABSTRACT

Verification testing of the Hydranautics ESPA2-4040 Reverse Osmosis Membrane Element Module was conducted over a 34-day period from March 15, 2000 through April 17, 2000. The test was conducted at Park City Spiro Tunnel Water Filtration Plant in Park City, Utah. The source water was the Spiro Tunnel Bulkhead water, which is considered a groundwater source. Based on manufacturer's recommendations, the unit was set to operate at 150 psi inlet pressure, a water recovery of 15%, and a specific flux of 0.15-0.16 gfd/psi (25°C). The total arsenic (As) concentration in the feedwater averaged 65 µg/L during the test period. The Hydranautics unit reduced total As to an average of 0.5 µg/L in the treated water. The Hydranautics unit reduced the dissolved As in the feedwater from an average of 42 µg/L to less than 0.8 µg/L in the permeate (treated water). The dominant As species in the feedwater is As (V). The feedwater average concentration of As (V) was 35 µg/L and was reduced to an average level of 0.5 µg/L in the treated water. As (III) was also rejected by the membrane, reducing the average feedwater level from 7 µg/L to 0.5 µg/L in the permeate. The system operated continuously over the verification test period and achieved an average total As removal of 99%. Dissolved As, which represented 65% of the As in the feedwater, showed an average removal of 98%. The system was cleaned at the end of the test period to demonstrate the cleaning procedures. There was no significant fouling of the membrane during the verification test period operating at 15% recovery.

TECHNOLOGY DESCRIPTION

Reverse Osmosis (RO) processes are generally used to remove dissolved salts and ionic solids, such as As, sodium, chloride, and other dissolved materials from drinking water. RO membranes will also remove particulate contaminants, but high particulate loads can lead to membrane fouling. Certain polymers can reject more than 99% of all ionic solids and have a molecular weight cut-off in the range of 50 to 100 daltons. The Hydranautics ESPA2-4040 membrane is a hollow membrane made from a composite polyamide material with a molecular weight cut-off of 300-500 daltons. RO membranes are designed to reject dissolved salts and operate at pressures that are typically an order of magnitude higher than membrane filtration processes designed to remove only particulate matter. RO operating pressure requirements are a function of the concentration of the contaminants in the feedwater. Larger contaminant levels in the water will require higher pressure to effect the separation. The Hydranautics membrane is rated for a maximum pressure of 600 psi and normal design pressure of 150 psi.

The Hydranautics ESPA2-4040 Elements are enclosed in a Codeline U4B membrane pressure vessel, which is part of the element module. Each element is 4 x 40 inches and has an active membrane surface of 85 ft^2. The element is designed to operate at a minimum flow rate of 3 gallons per minute (gpm) and a maximum flow rate of 16 gpm. The elements are designed for a maximum recovery of 20% and a design specific flux of 0.24 gfd/psi at 25°C.

The verification testing was performed using a Hydranautics ROSY-200 pilot test unit. The test unit is a self-contained system, housing a Goulds G & L Model 25VBK 11 high pressure pump, two pressure vessels, each containing a reverse osmosis membrane element, and all piping, wiring, and flow/pressure controls for operation. A pre-filter, using a 5µ cartridge was placed in the feedwater line prior the high pressure pump. This pre-filter removed larger particulate matter that could foul the membranes.

The ROSY-200 pilot test unit is equipped with three way valves for use in cleaning and backwashing the membrane. A 50-gallon cleaning tank was set up to provide a cleaning solution supply that was pumped to the unit through a 5µ filter. The unit was designed so that permeate and concentrate streams were redirected back to the cleaning tank for recirculation during the cleaning process.

VERIFICATION TESTING DESCRIPTION

Test Site

The verification testing site was the Park City Spiro Tunnel Water Filtration Plant in Park City, Utah. The source water was the Spiro Tunnel Bulkhead water, which is considered a groundwater source under the State of Utah source water protection program. Water is developed from water bearing fissures in an abandoned silver mine tunnel. A five-foot bulkhead built approximately two miles into the tunnel holds back the water and creates a reservoir. Water is piped from this reservoir to the treatment plant through a 12-inch diameter pipe. The water is considered stable with respect to quality and quantity, and is known to contain As.

Methods and Procedures

Conductivity, pH and turbidity measurements were conducted on-site, using equipment set up in the filtration plant laboratory and in accordance with *Standard Methods for the Examination of Water and Wastewater*, 18th edition, (APHA, et. a!., 1992). Conductivity was monitored twice per day, while pH and turbidity were monitored once per day. Turbidity information was also collected daily from the filtration plant continuous in-line monitor. Temperature was recorded daily from the calibrated in-line thermometer located on the test unit. The Silt Density Index (SDI), a measure of the quantity of suspended solids in the feedwater, was determined on—site at six occasions using ASTM D 4189-95. Samples for total dissolved solids (TDS) were collected twice per week and sent to the State of Utah Division of Drinking Water Laboratory. Other analyses performed at the State of Utah laboratory included fluoride, iron (Fe), manganese, and sulfate on a weekly basis, and alkalinity, suspended solids, silica, total organic carbon (TOC) and Langlier Saturation Index (LS1) on a monthly basis. The off-site laboratory followed test procedures as described in *Methods for Chemical Analysis of Water and Wastes* (EPA, 1979), except for TOC, which was analyzed in accordance with *Standard Methods.* Magnesium and chloride were also measured during the verification test period.

Samples of the feedwater, concentrate, and permeate were collected on a daily basis and sent to the State of Utah Laboratory for As analysis. Special procedures were used to prepare the samples so that As speciation could be determined. Field procedures included filtering an aliquot of sample for the determination of dissolved As, and passing an aliquot of filtered sample through an ion exchange resin so that the concentration of As (III) and As (V) could be determined. All samples were preserved with acid mixtures described in the As speciation procedure. The daily results for total As, dissolved As, As (III) and As (V) were obtained using ICP/MS analysis in accordance with USEPA Method 200.8 as described in *Methods for the Determination of Metals in Environmental Samples Supplement* I(EPA, 1994). Antimony (Sb) analyses were performed on a daily basis by the off-site laboratory using Method 200.8.

VERIFICATION OF PERFORMANCE

System Operation

The Rosy-200 pilot test unit was set up in accordance with the manufacturer's recommendations and operated for a one-week period to establish optimum operating conditions. The major operating parameters monitored during the initial operating period were specific flux, net driving pressure and percent water recovery. Initial operating conditions were set to achieve a water recovery of 15% with an inlet pressure of 150 psi and specific flux of 0.16 gfd/psi (at 25°C). The system operating conditions were very stable during the initial startup period with the permeate flow rate remaining steady at 0.79 to 0.81 gpm. No significant changes were required in the operating conditions of the system during the startup period.

The unit was operated at an inlet operating pressure of 150 psi (range 144- 151 psi). Inlet water temperature was 49°F (9.44°C) based on twice-daily measurements. Flow rates for the concentrate and permeate streams were monitored twice per day. The permeate flow averaged 0.77 gpm with a range of 0.74 to 0.81 gpm. Water recovery data calculated twice per day ranged from 13.5% to 15%. The twice-daily conductivity measurements were correlated with the TDS data to obtain twice daily TDS estimates for calculating specific flux. The specific flux remained stable throughout the entire test period. The average specific flux was 0.15 gfd /psi (at 25°C) with a range of 0.15 to 0.16 gfd/psi (at 25°C).

The system was operated with a 5µ cartridge filter in the feedwater line to the system. The filter was initially changed on an every two-day basis for the first 18 days of the test period. Following a high turbidity measurement by the filtration plant in-line monitor, the cartridge filter was changed daily for the remaining 16 days of the verification test.

The RO membrane elements were operated for the entire 34-day test period without shutting down for cleaning. Membrane cleaning was performed at the end of the test period to test the cleaning process. The unit was cleaned using 50 gallons of 2% (wt/wt) citric acid solution. The cleaning solution was circulated through the membrane module for one hour followed by a 1¾ hour soaking time. The unit was then rinsed with feedwater for approximately ½ hour and placed back on-line. Operating data collected after the cleaning showed that the unit returned to typical operating conditions prior to the cleaning process with permeate flow of 0.77 gpm and a specific flux of 0.15 gfd/psi (at 25°C).

Water Quality Results

All of the feedwater samples, with the exception of the samples for turbidity, were collected immediately before the membrane and after the raw water had passed through the 5µ cartridge filter. The feedwater from the Spiro Tunnel Bulkhead had the following average water quality during the verification test period: TDS 547 mg/L, pH 7.33, Fe 0.154 mg/L, sulfate 278 mg/L, alkalinity 144 mg/L, and temperature 49°F (9.44°C). The turbidity, as measured before the 5µ cartridge filter, ranged from 0.78 to 3.65 NTU with one spike to 11.79 NTU on the in-line meter. The feedwater total As levels averaged 65 ug/L. Results of the dissolved As analysis showed that 65% of the As present in the feedwater was in the dissolved form. Arsenic speciation for valence states (III) and (V) showed that As (V) represented 83% of the dissolved As in the source water. Sb levels in the feedwater averaged 8.6 µg/L.

The Hydranautics ESPA2-4040 Reverse Osmosis Membrane Element Module averaged 99% removal of the total As in the feedwater over the verification test period. The calculated removal is most likely a conservative number as the As concentration in the permeate was reported as less than *0.5* µg/L (minimum laboratory reporting limit) for all but two days of the test period. As shown in the table below, the unit was able to produce a consistent high quality permeate with total As levels below *0.5* µg/l over the range of feedwater concentrations (49.4-114 (µg/L).

Total Arsenic Data Summary

	Feed (µg/L)	Concentrate (µg/L)	Permeate (µg/L)	% Rejection
Average	65	62	0.5	99
Minimum	49.3	44.2	<0.5	99.0
Maximum	114	99	0.52	99.6
Standard Deviation	12	11	0.0	.0035
Confidence Interval	(61, 69)	(59, 66)	(0.5, 0.5)	(99, 99)

Dissolved As results showed that the system achieved an average rejection of 98% for dissolved As with a range of 97.1% to 99%. The calculated rejection percentages were influenced by a possible analytical problem

at the low levels being monitored in the permeate. This may have been caused by some type of contamination or interference due to the procedures used to preserve and handle the samples for dissolved As and As speciation.

Dissolved Arsenic Data Summary

	Feed (µg/L)	Concentrate (µg/L)	Permeate (µg/L)	% Rejection
Average	42	47	0.8	98
Minimum	32.2	21.9	<0.5	97.1
Maximum	52	61	1	99
Standard Deviation	5.6	8.3	0.1	0.41
Confidence Interval	(40, 44)	(44, 50)	(0.8, 0.9)	(98, 98)

The As speciation results showed that As (V) was the predominate species present in the feedwater with 83% of the dissolved As determined to be As (V). The Hydranautics unit averaged 99% removal of the As (V) and generated a permeate that was less than 0.5 µg/L on most operating days. The system also removed As (III) to less than 0.5 µg/L on all but two days of the test period. The calculated As (III) removal averaged 84%, but this calculation was strongly influenced by the low feedwater levels (average of 7 µg/L) and the laboratory detection limit of 0.5 µg/L.

Arsenic (V) Data Summary

	Feed (µg/L)	Concentrate (µg/L)	Permeate (µg/L)	% Rejection
Average	35	40	0.5	99
Minimum	20.4	19.2	<0.5	97.6
Maximum	50.2	55.8	0.5	99.0
Standard Deviation	7.3	8.9	0.0	0.35
Confidence Interval	(32, 38)	(36, 43)	(0.5. 0.5)	(98, 99)

Total Sb results showed that the permeate concentration was less than 3.0 µg/l in all samples analyzed. The unit achieved the highest possible rejection percentage (67%) that could be calculated based on a maximum feed concentration of 9.2 µg/L and a laboratory MDL of 3.0 µg/L.

Operation and Maintenance Results

The system ran continuously throughout the duration of the verification test (34 days). The feed pump was shut down for five minutes each day to change the 5µ cartridge filter. Once the flows, pressures, and water recovery conditions were established during the Initial Operations period, no adjustments were made throughout the duration of the test. A manual cleaning was performed at the end of the test.

There was no evidence during the test period of any operationally significant chemical fouling of the membrane element. The cleaning at the end of the test period was performed only to evaluate the cleaning procedures and any effects on the membrane. Mass balances using the Fe and As data did indicate the possible buildup of some materials within the membrane. However, there was no change in basic operating conditions during the 34-day test, and any buildup that might have occurred did not seem to affect the membrane operation or performance.

The Operation and Maintenance Manual provided by Hydranautics was available for review and to assist with on-site operations. The Manual gave a basic overview of RO systems operation and gave helpful information on how to troubleshoot the system.
The consumables used by the system were the prefilter cartridges and citric acid cleaning chemical. A prefilter cartridge (5µ, 20 inches long) was replaced daily. The quantity of citric acid cleaning chemical was 50 gallons

of 2% (wt/wt) per module. The total power consumed throughout testing was 90.740 Kilowatt/hours.

Original Signed by
E. Timothy Oppelt *04/18/01*
E. Timothy Oppelt Date
Director
National Risk Management Research Laboratory
Office of Research and Development
United States Environmental Protection Agency

Original Signed by
Gordon Bellen *04/27/01*
Gordon Bellen Date
Vice President
Federal Programs
NSF International

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Availability of Supporting Documents
Copies of the *ETV Protocol for Equipment Verification Testing for Removal of Arsenic (Chapter One General Requirements)* dated March 30, 2000, *ETV Protocol for Equipment Verification Testing for Removal of Inorganic Chemical Constituents (Test Plan: Reverse Osmosis for the Removal of Inorganic Contaminants)* dated February 25, 2000, the Verification Statement, and the Verification Report (NSF Report #01/20/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)

Table 4-15: Arsenic (Ill) Data

Date	Feed (µg/L)	Concentrate (µg/L)	Permeate (µg/L)	% Rejection	Date	Feed (µg/L)	Concentrate (µg/L)	Permeate[1] (µg/L)	% Rejection[2]
3/15/00	NS	NS	NS	-	4/2/00	10.4	5.3	<0.5	95
3/16/00	NS	NS	NS	-	4/3/00	9	13.8	<0.5	94
3/17/00	2	2.2	<0.5	75	4/4/00	14.1	8.1	<0.5	96
3/18/00	1.8	3.1	<0.5	72	4/5/00	2.7	2.9	<0.5	81
3/19/00	NS	NS	NS	-	4/6/00	2.8	2.8	<0.5	82
3/20/00	2.1	2.4	<0.5	76	4/7/00	2.4	2.4	<0.5	79
3/21/00	2.2	2.5	0.64	71	4/8/00	2.2	2.2	<0.5	77
3/22/00	2.1	2.3	<0.5	76	4/9/00	2.6	2.7	<0.5	81
3/23/00	20	25	<0.5	98	4/10/00	2.9	2.6	<0.5	83
3/24/00	8.3	6.3	<0.5	94	4/11/00	2.7	2.7	<0.5	81
3/25/00	8.7	11	<0.5	94	4/12/00	2.5	2.4	<0.5	80
3/26/00	19	18	<0.5	97	4/13/00	2.4	2.3	<0.5	79
3/27/00[3]	13	<0.5	8.6	NA	4/14/00	2.5	2.3	<0.5	80
3/28/00	17.3	8.9	0.5	97	4/15/00	2.3	2.2	<0.5	78
3/29/00	2.2	2.1	<0.5	77	4/16/00	2.3	0.8	<0.5	78
3/30/00	16.9	26	<0.5	97	4/17/00	2.3	2.1	<0.5	78
3/31/00	12	12	<0.5	96					
4/1/00[3]	10.5	6.4	10.5	NA					

1) The reliability of the low-level data (MDL of 0.1 µg/L to approximately 2 µg/L should be considered as only qualitative (not quantitative).
2) The MDL value (0.5 (µg/L) was used as the permeate reading (except where indicated) for % rejection calculations.
3) Indicates likely mislabeled sample containers of concentrate and/or permeate.
4) NS — No sample

Table 4-16: Arsenic (Ill) Data Summary

	Feed (µg/L)	Concentrate (µg/L)	Permeate (µg/L)	% Rejection
Average	7	6.2	0.5	84
Minimum	1.8	0.8	0.5	71
Maximum	20	26	0.64	98
Standard Deviation	6	6.8	0.03	9.0
Confidence Interval	(4, 9)	(3.8, 8.5)	(0.5, 0.5)	(81, 88)

formulae. A value of 0.5 μg/I is used in the calculation for the permeate concentration whenever the reported concentration was below the MDL (0.5 μg/L), which is the result in 27 of the 31 samples analyzed. Thus, the reported percent rejection is most likely a conservative value as the actual arsenic (V) present in the permeate is undoubtedly less than the 0.5 μg/L value used in the calculation.

The arsenic (V) results show that this species of arsenic represented 83% of the dissolved arsenic present in the feedwater (see Table 4-19). The feedwater concentration averaged 35 μg/L with a range of 20.4 to 50.2 μg/L. The Hydranautics membrane module handled the arsenic (V) very effectively with an average rejection percentage of 99%. The permeate contained less than 0.5 μg/L (MDL) for 27 samples and three samples tested at the 0.5 μg/L level. There was one sample for March 27 reported at a value of 42.4 μg/L but the concentrate for that day is reported at <0.5 μg/L. The sample bottles were apparently mislabeled on this day.

The performance of the RO unit for removing arsenic (V) was as good or better than for any other arsenic species. The arsenic (V) measured in the test procedure is dissolved arsenic (V) so the results also show the ability of the RO unit to handle dissolved arsenic species. The ability of the RO unit to reject soluble species of arsenic at a high level demonstrates that the performance of this unit is excellent.

Table 4-17: Arsenic (V) Data

Date	Feed (μg/L)	Concentrate (μg/L)	Permeate (μg/L)	% Rejection	Date	Feed (μg/L)	Concentrate (μg/L)	Permeate[1] (μg/L)	% Rejection[2]
3/15/00	NS	NS	NS	-	4/2/00	21.8	29.4	<0.5	97.7
3/16/00	NS	NS	NS	-	4/3/00	25.8	23.8	<0.5	98.1
3/17/00	50	55.8	<0.5	99	4/4/00	20.4	31.2	<0.5	97.5
3/18/00	50.2	53.9	<0.5	99.0	4/5/00	30.8	34.8	<0.5	98.4
3/19/00	NS	NS	NS	-	4/6/00	30.5	33.9	<0.5	98.4
3/20/00	45.9	49.6	<0.5	98.9	4/7/00	37.2	41.3	<0.5	98.7
3/21/00	44.8	49.5	<0.5	98.9	4/8/00	35.2	41.1	<0.5	98.6
3/22/00	42.9	49.7	<0.5	98.8	4/9/00	36.3	40.4	<0.5	98.6
3/23/00	25	25	<0.5	98	4/10/00	36.3	40.3	<0.5	98.6
3/24/00	34.7	42.7	<0.5	98.6	4/11/00	36.2	19.2	<0.5	98.6
3/25/00	34.3	41	<0.5	98.5	4/12/00	36.3	40.8	<0.5	98.6
3/26/00	28	35	<0.5	98	4/13/00	35.3	41	0.5	98.6
3/27/00[3]	32	<0.5	42.4	NA	4/14/00	32.9	35.9	0.5	98.5
3/28/00	28.2	43.4	<0.5	98.2	4/15/00	36.2	39.2	<0.5	98.6
3/29/00	43.5	49.3	<0.5	98.9	4/16/00	36.7	41.7	0.5	98.6
3/30/00	30.3	26	<0.5	98.3	4/17/00	38.5	41.5	<0.5	98.7
3/31/00	29.6	41.5	<0.5	98.3					
4/1/00	37.7	47.6	<0.5	98.7					

1) The reliability of the low-level data (MDL of 0.1 μg/L to approximately 2 μg/L) should be considered as only qualitative (not quantitative).
2) The MDL value (0.5 μg/L) was used as the permeate reading (except where indicated) for % rejection calculations.
3) Indicates likely mislabeled sample containers of concentrate and/or permeate.
4) NS - No Sample