

**THE ENVIRONMENTAL TECHNOLOGY VERIFICATION
PROGRAM**



U.S. Environmental Protection Agency



NSF International

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:	KOCH MEMBRANE SYSTEMS TFC[®] - ULP4 REVERSE OSMOSIS MEMBRANE MODULE	
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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 permittees; 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) program, one of 12 technology areas under ETV. The DWTS program recently evaluated the performance of a reverse osmosis membrane module used in package drinking water treatment system applications. This verification statement provides a summary of the test results for the Koch Membrane Systems TFC[®] - ULP4 Reverse Osmosis Membrane Module. Cartwright Olsen and Associates, LLC, an NSF-qualified field testing organization (FTO), performed the verification testing.

ABSTRACT

Verification testing of the Koch membrane 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 operated at a specific flux of 0.24-0.27 gfd/psi (25°C) during the first days of operation. The total arsenic concentration in the feedwater averaged 60 ug/L during the test period. The Koch membrane module reduced total arsenic to an average of 0.9 ug/L in the treated water. The Koch membrane module reduced the dissolved arsenic in the feedwater from an average of 42 ug/L to 1.3 ug/L in the permeate (treated water). The dominant arsenic species in the Spiro Tunnel feed water is As (V). The feedwater average concentration of Arsenic (V) was 32 ug/L and was reduced to an average level of 0.8 ug/L in the treated water. Arsenic (III) was also rejected by the membrane, reducing the average feedwater level from 8 ug/l to 0.6 ug/L in the permeate. The system operated continuously over the verification test period and achieved an average total arsenic removal of 99%. Dissolved arsenic, which represented 70% of the arsenic in the feedwater, showed an average removal of 97%. 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. There was a steady decrease in specific flux over the 34-day test period from 0.27 gfd/psi (25°C) to 0.20 gfd/psi (25°C).

TECHNOLOGY DESCRIPTION

Reverse Osmosis (RO) processes are generally used to remove dissolved salts and ionic solids, such as arsenic, 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 membrane 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 Koch membrane module is a spiral wound polyamide membrane with a fiberglass outer wrap. The molecular weight cut-off is approximately 100 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 Koch membrane module is rated for a maximum pressure of 350 psi and normal design pressure of 125 psi.

The Koch membrane module is enclosed in CHAMP-440 RO Membrane Housing. Each element is 4X40 inches and has an active membrane surface of 81 ft². The element is designed to operate at a minimum flow rate of 3 gpm and a maximum flow rate of 10 gpm. The elements are designed for a typical water recovery of 15% and a design specific flux of 0.18 gfd/psi at 25°C.

The verification testing was performed using a ROSY-200 pilot test unit. The test unit is a self-contained system, housing a Gould 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 5-micron cartridge was placed in the feedwater line prior to 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 setup to provide a cleaning solution supply that was pumped to the unit through a 5-micron 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 protection program. Water is developed from water bearing fissures in abandoned silver mine tunnel. A five-foot bulkhead built approximately two miles into the tunnel holds back the water and creates a reservoir. The water is piped 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 arsenic.

Methods and Procedures

Conductivity, pH and turbidity measurements were conducted on-site, using equipment setup in the filtration plant laboratory and in accordance with Standard Methods for the Examination of Water and Wastewater, 20th edition, (APHA, et. al., 1998). 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, a measure of the quantity of suspended solids in the feedwater, was determined on-site on seven occasions using ASTM D 4189-95. Samples for total dissolved solids 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, manganese, and sulfate on a weekly basis, and alkalinity, suspended solids, silica, total organic carbon and LSI 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 for the Examination of Water and Wastewater, 20th edition, (APHA, et. al., 1998). 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 arsenic analysis. Special on-site procedures were used to prepare the samples so that arsenic speciation could be determined. Field procedures included collecting a total arsenic sample, filtering an aliquot of sample for the determination of dissolved arsenic, and passing an aliquot of filtered sample through an ion exchange resin so that the concentration of arsenic (III) and arsenic (V) could be determined. All samples were preserved with acid mixtures described in the arsenic speciation procedure. The daily results for total arsenic, dissolved arsenic, arsenic (III) and arsenic (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 analyses were performed on a daily basis by the off-site laboratory using Method 200.8.

VERIFICATION OF PERFORMANCE

System Operation

The Koch membrane module was setup 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, which gave a specific flux of 0.27 gfd/psi (at 25⁰C). The system operating conditions during the initial two day period (flux stabilization period) varied slightly with the specific flux decreasing from 0.27 to 0.25 gfd/psi (at 25⁰C) and the permeate flow rate dropping from 1.22 to 1.12

gpm. No significant changes were made in the operating conditions of the system during this initial operations period.

The unit was operated at an inlet operating pressure of 150 psi (range 144-151 psi) for the remaining 32 days of the test. The unit was considered to be stabilized after the two-day stabilization period. 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 1.01 gpm with a range of 0.90 to 1.12 gpm. Water recovery data calculated twice per day ranged from 13.1% to 15.4%. The twice-daily conductivity measurements were correlated with the total dissolved solids data to obtain twice daily TDS estimates for calculating specific flux. The specific flux slowly decreased throughout the entire test period. The average specific flux was 0.23 gfd/psi (25°C) with a range of 0.20 to 0.25 gfd/psi (25°C) during the main operating period.

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 1-¾ hour soaking time. The unit was then rinsed with feed water 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 1.10 gpm and a specific flux of 0.25 gfd/psi (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 5-micron cartridge filter. The feedwater from the Spiro Tunnel Bulkhead had the following average water quality during the verification test period: TDS 543 mg/l, pH 7.31, iron 0.166 mg/l, sulfate 274 mg/l, alkalinity 147 mg/l, and temperature 49°F (9.44°C). The turbidity, as measured before the 5 micron cartridge filter, ranged from 0.78 to 3.65 NTU with one spike to 11.83 NTU on the in-line meter. The feedwater total arsenic levels averaged 60 ug/l. Results of the dissolved arsenic analysis showed that 70% of the arsenic present in the feedwater was in the dissolved form. Arsenic speciation for valence states (III) and (V) showed that arsenic (V) represented 76% of the dissolved arsenic in the source water. Antimony levels in the feedwater averaged 8.7 ug/l.

The Koch membrane module averaged 99% removal of the total arsenic in the feedwater over the verification test period. As shown by the data, the unit was able to produce a consistent high quality permeate with total arsenic levels below 1 ug/l over the range of feedwater concentrations (48.8-77 ug/l).

Total Arsenic Data Summary

	Feed (µg/L)	Concentrate (µg/L)	Permeate (µg/L)	% Rejection
Minimum	48.8	45.1	0.7	98
Maximum	77	87.9	1.0	99
Average	60	64	0.9	99
Standard Deviation	7.5	11	0.09	0.21
Confidence Interval	(58, 63)	(61, 68)	(0.8, 0.9)	(99, 99)

Dissolved arsenic results show that the system achieved an average rejection of 97% for dissolved arsenic with a range of 92% to 98%. The unit was very effective in removing dissolved arsenic. The calculated rejection percentages were influenced by a possible analytical problem at the low levels being monitored in the permeate. Some type of contamination or interference due to the procedures used to preserve and handle the samples for dissolved arsenic and arsenic speciation may have caused the analytical difficulties.

Dissolved Arsenic Data Summary

	Feed (µg/L)	Concentrate (µg/L)	Permeate (µg/L)	% Rejection
Minimum	19.4	34.7	0.79	92
Maximum	52	61	1.5	98
Average	42	48	1.3	97
Standard Deviation	7.0	7.4	0.15	1.0
Confidence Interval	(39, 44)	(45, 50)	(1.3, 1.4)	(96, 97)

The arsenic speciation results show that arsenic (V) is the predominate species present in the feedwater with 76% of the dissolved arsenic determined to be arsenic (V). The Koch membrane module averaged 97% removal of the arsenic (V) and generated a permeate that averaged 0.8 ug/l and had a maximum level of 1 ug/l. The system also removed arsenic (III) to an average concentration of 0.6 ug/l.

Arsenic (V) Data Summary

	Feed (µg/L)	Concentrate (µg/L)	Permeate (µg/L)	% Rejection
Minimum	16.7	23.5	<0.5	94
Maximum	49.95	57.5	1	98
Average	32	40	0.8	97
Standard Deviation	8.7	8.1	0.1	1.0
Confidence Interval	(29, 36)	(37, 43)	(0.7, 0.8)	(97, 98)

Total antimony results showed that the permeate concentration was less than 3.0 ug/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 9.1 ug/l and a laboratory MDL of 3.0 ug/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. Cleaning at the end of the test was performed using manual procedures.

There was no evidence during the test period of significant or catastrophic chemical fouling of the membrane element. There was a steady decrease in permeate flow rate and specific flux over the 34 day test period, which indicated that cleaning would be required soon. Mass balances using the iron and arsenic data did indicate the possible buildup of some materials within the membrane. The cleaning at the end of the test period was to evaluate the cleaning procedures and any effects on the membrane. The cleaning was very effective in returning the membrane to operating conditions similar to the clean conditions at the beginning of the test (after flux stabilization).

The Operation and Maintenance Manual provided by Koch Membrane Systems was available for review and to assist with on-site operations. The Manual gave a basic overview of reverse osmosis 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 (5 μ , 20 inches long) was replaced daily. The citric acid cleaning chemical was USP/FCC quality. The quantity required was 50 gallons of 2% (wt/wt) per module.

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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 #01/25/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)