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THE ENVIRONMENTAL TECHNOLOGY VERIFICATION PROGRAM



U.S. Environmental Protection Agency



NSF International

ETV Joint Verification Statement

TECHNOLOGY TYPE:	OZONATION-FILTRATION USED IN DRINKING WATER TREATMENT SYSTEMS		
APPLICATION:	REMOVAL OF ARSENIC VIA OZONATION-FILTRATION FROM DRINKING WATER		
TECHNOLOGY NAME:	CAMPWATER PORTA-5 SYSTEM		
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The U.S. Environmental Protection Agency (EPA) supports 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 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 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 Systems (DWS) Center, one of seven technology areas under the ETV Program. The DWS Center recently evaluated the performance of a Delta Industrial Services, Inc. (DISI) CampWater Porta-5 (CampWater) system for the reduction of arsenic in drinking water. This verification statement provides a summary of the test results for the CampWater system. University of Alaska Anchorage (UAA) Small Public Water System Training and Technical Assistance Center (ATTAC), an NSF-qualified field testing organization (FTO), performed the verification testing.

ABSTRACT

The CampWater system uses ozonation followed by cartridge filtration to remove arsenic via co-precipitation. The system utilizes ozone to oxidize iron and arsenic (III) to arsenic (V). The arsenic bound to the iron precipitates is then removed by cartridge filtration. No additional flocculation, solids separation or clarification is required. The CampWater system was tested on a ground water source with 27 µg/L arsenic and 0.62 mg/L iron. Operating the system at 550 mV oxidation-reduction potential (ORP) and the natural water pH of 7.9 reduced the arsenic by 33%. Subsequent tests at 550 mV ORP showed that decreasing pH to 7.5 improved arsenic removal.

TECHNOLOGY DESCRIPTION

The following technology description was provided by the manufacturer and has not been verified.

The CampWater system uses ozone to oxidize the naturally occurring iron in the feed water to form a ferric hydroxide solid and convert any arsenic (III) to arsenic (V). The CampWater system relies on the reduction of arsenic by filtration of the ferric hydroxide solid suspended in water upon which arsenic (V) is adsorbed. The CampWater system directly filters the ferric hydroxide solid without any additional flocculation, solid separation or clarification. The system consists of a raw water pump, an ozone generator and contact chamber, and a series of 20 µm, 5 µm, and 1 µm-absolute cartridge filters. The system is easily transportable and is designed to fit into a standard pickup truck or small aircraft.

VERIFICATION TESTING DESCRIPTION

Test Site

Verification testing occurred at Southwood Manor, a residential community located at 9499 Brayton Road, Anchorage, Alaska. The source water for the verification testing was ground water. The well is considered a back-up water source and was not used by local residents during the verification test. The test site was equipped with a 200-gpm submersible well pump. Because the existing well pump capacity exceeded the rated capacity of the CampWater system, two 300-gallon storage tanks were installed to feed the test unit. These tanks were periodically filled by the well pump resulting in a storage period of up to 3 hours when the CampWater system was continuously operating and significantly longer storage periods (up to several days) under start/stop operations. During the storage period, iron present in the well water could have been oxidized more readily than reduced arsenic. The unknown extent of oxidation during storage prior to treatment could have affected the feed water quality to the treatment system.

Methods and Procedures

ETV testing on the CampWater system occurred in three phases:

Phase A

Phase A was initiated on August 28, 2003. Start/stop operations were performed on the CampWater system for the first 48 hours and then the system was run continuously, except for filter change-outs, until September 13, 2003 for a total of 327 hours over the 17-day period. The system was operated at the natural pH of the feed water (approximately 7.9) and an ORP set point of 550mV. The average flow rate during this phase of testing was 3.85 gpm. During Phase A, 72 feed water samples and 73 treated water samples were collected for total arsenic analysis. During the 48 hours of start/stop operation in Phase A, feed and treated water samples for arsenic, iron, manganese, turbidity, ORP and pH analysis were collected within the first 15 minutes of operation and after 1 hour, 5 hours, and 9 hours of operation after each start-up. Water quality parameters including alkalinity and hardness were measured daily. Weekly samples for sulfate, arsenic speciation, total organic carbon, total suspended solids, total dissolved solids,

and ultraviolet light absorbance analysis were collected. Similar collection procedures and frequencies were used for Phases B and C. Ozone production, off-gas ozone concentration, and the dissolved ozone in the water were measured once per day during Phase A.

Phase B

Phase B was a series of five tests conducted between October 11, 2003 and December 12, 2003 to understand the influence of pH and ORP on system performance. Six pairs of pH and ORP operating conditions were tested: pH 7.9/ORP 550 mV, pH 7.5/ORP 550 mV, pH 7.0/ORP 550 mV, pH 7.9/ORP 650 mV, pH 7.5/ORP 650 mV, and pH 7.0/ORP 650 mV. Since the system ran at pH 7.9 (natural pH) and ORP 550 mV during Phase A, the data from Phase A was used for that pair of conditions. A chemical metering pump with an integrated pH controller was used to dose muriatic acid (HCl) to the raw water prior to entry to the CampWater system. The controller was calibrated and used to maintain the desired pH within an error of ± 0.1 . Tests were conducted using a pH range of 7.0–7.9. The ORP controller was adjusted to set the target ORP point, either 550mV or 650mV. On-site measurements of pH, ORP, and turbidity were taken concurrently with water samples. Flow rate was monitored to maintain constant flow. Instrument calibration, sample handling and storage, and system monitoring procedures outlined in the verification test plan were followed. A total of 31 feed and treated water sample pairs were analyzed for arsenic, iron and manganese concentrations. All samples were sent to NSF for laboratory analysis. No measurements of ozone were performed during Phase B.

Phase C

The intent of Phase C was to verify the improved removal efficiency at a lower feed water pH shown in Phase B under start/stop operating conditions. Phase C was a 48-hour verification test of the CampWater system, operated with an adjusted pH of 7.5 and an ORP set point of 550mV. This phase was conducted over eight days, between February 17, 2004 and March 18, 2004. Phase C followed the same testing procedures, sampling times, and quality control/quality assurance requirements followed during Phase A. The average flow rate during this phase of testing was 3.93 gpm. A total of 29 feed water and 29 treated water samples were collected to test arsenic, iron and manganese concentrations over the course of Phase C. Two sets of arsenic speciation and other weekly water analyses were collected. All samples were sent to NSF for laboratory analysis. Site conditions only allowed for three to nine hours of operation at one time. Ozone production and ozone off-gas concentration were measured once per day during Phase C.

Complete descriptions of the verification testing procedures, results and quality assurance/quality control (QA/QC) procedures are included in the verification report.

VERIFICATION OF PERFORMANCE

System Operation

The CampWater system is designed to use ozone to oxidize the naturally occurring iron in the feed water to form a ferric hydroxide solid and convert any arsenic III to arsenic V. The CampWater system uses filtration of the ferric hydroxide solid suspended in water upon which arsenic V is adsorbed, to reduce arsenic in the treated water.

Raw water is first passed through an Amiad 1 ½" y-strainer and then through a 20 mm FlowMax pleated cartridge filter in a stainless steel Shelco Model 4FOS4 filter housing. Ozone is injected into the pre-filtered water by a Mazzei Model 584K venturi-type injector. Ozone is supplied to the injector by a Clearwater Tech Model CD2000 ozone generator. Contact time is provided in a 54-gallon (approximately) cylindrical stainless steel reaction chamber equipped with an air release valve and a 1" vent that was piped outside the building during the verification test. After the contact chamber, ozonated

water passes through 5mm and 1mm absolute FlowMax pleated cartridge filters in Shelco Model 4FOS4 filter housings.

Water Quality Results

Phase A

The average feed water total and soluble arsenic concentrations during Phase A were 27 $\mu\text{g/L}$ and 18 $\mu\text{g/L}$, respectively. Speciation of feed water soluble arsenic samples resulted in an average of 4 $\mu\text{g/L}$ arsenic (III) and 14 $\mu\text{g/L}$ arsenic (V). The feed water contained approximately 0.62 mg/L of iron which corresponds to iron-to-arsenic weight ratio of 23:1, and a molar iron-to-arsenic ratio of 31:1.

The treated water during Phase A had an average concentration of 18 $\mu\text{g/L}$ total arsenic and an average concentration of soluble arsenic of 15 $\mu\text{g/L}$, with an average removal efficiency of arsenic of 33%. Treated water turbidity averaged 1.3 NTU. However, a noticeable improvement in the treated water turbidity occurred in the last third of the testing period. During the first two-thirds of the test, the nut used to seal the plate against the filter elements was inadequately tightened thus allowing untreated water to occasionally bypass the filter elements. When additional force was systematically applied to the nut to properly seat the top filter plate, the average turbidity of the treated water was 0.25 NTU, compared to an average turbidity of 1.5 NTU in the treated water before the vessel was properly tightened. The iron concentration of the treated water also showed improved removal after the vessel was properly tightened. The iron concentration prior to this procedure was 0.20 mg/L, whereas the concentration after was 0.03 mg/L. No significant improvement in arsenic removal was recorded as a result of the change in operating procedure.

Phase B

The arsenic concentrations in the feed and treated water during Phase B are presented in Table VS-1. Reducing the pH to 7.5 improved the arsenic removal efficiency in all operation conditions. Maintaining the ORP at 550mV and reducing the pH of the feed water stream to pH 7.5 produced the best removal efficiency of 77%. These conditions were selected as the conditions for the 48-hour start/stop verification test in Phase C.

Table VS-1. Phase B Test Series Results

	Number of Samples	Units	Average	Minimum	Maximum	Removal Efficiency
pH 7.9/ORP 550mV (Phase A data)						
Feed Arsenic	72	(µg/l)	27	19	33	
Treated Arsenic	73	(mg/l)	18	8	27	33%
pH 7.5/ORP 550mV						
Feed Arsenic	5	(µg/l)	26	22	29	
Treated Arsenic	5	(mg/l)	6	4	9	77%
pH 7.0/ORP 550mV						
Feed Arsenic	5	(µg/l)	24	23	27	
Treated Arsenic	5	(µg/l)	11	8	16	54%
pH 7.9/ORP 650mV						
Feed Arsenic	6	(µg/l)	23	21	24	
Treated Arsenic	6	(µg/l)	7	6	8	70%
pH 7.5/ORP 650mV						
Feed Arsenic	5	(µg/l)	22	14	35	
Treated Arsenic	5	(µg/l)	9	6	11	59%
pH 7.0/ORP 650mV						
Feed Arsenic	6	(µg/l)	23	17	28	
Treated Arsenic	6	(µg/l)	9	7	13	61%

Phase C

Phase C was operated with an adjusted feed water pH of 7.5 and an ORP set point of 550 mV. Laboratory analyses of the feed water samples summarized in Table VS-2 show average total and soluble arsenic concentrations of 18 µg/L and 10 µg/L, respectively. No detectable (<2 µg/L) arsenic (III) and 8 µg/L arsenic (V) were present, on average, in the feed water samples. The feed water contained 0.51 mg/L iron and 540 µg/L manganese during Phase C. The treated water contained an average of 9 µg/L arsenic, which corresponds to a 50% reduction in feed water arsenic concentration. Improvements in iron and turbidity removal were also observed.

Table VS-2 Phase C Water Quality

	Number of Samples	Units	Average	Minimum	Maximum	Standard Deviation	95% Confidence Interval
<i>Feed Water</i>							
Arsenic	29	(µg/L)	18	13	25	3.1	17 – 20
Soluble As	3	(µg/L)	10	9	10	N/A	N/A
As (III) ¹	3	(µg/L)	<2	<2	<2	N/A	N/A
As (V) ²	3	(µg/L)	8	7	8	N/A	N/A
Iron	29	(mg/L)	0.51	0.04	1.0	0.25	0.40 – 0.62
Manganese	29	(µg/L)	540	260	780	147	480 – 600
Total Alkalinity	8	(mg/L)	180	155	240	29.1	151 – 209
Total Hardness	8	(mg/L)	244	228	280	17.2	227 – 262
TDS	2	(mg/L)	300	270	320	N/A	N/A
TSS	2	(mg/L)	4	3	4	N/A	N/A
TOC	2	(mg/L)	1.7	1.6	1.7	N/A	N/A
UVA	2	(cm ⁻¹)	0.0619	0.0510	0.0728	N/A	N/A
Sulfate	3	(mg/L)	13	13	14	N/A	N/A
Turbidity	36	(NTU)	7.7	4.9	15.5	2.2	6.8 – 8.6
pH ³	29	--	7.44	7.21	7.62	N/A	N/A
<i>Treated Water</i>							
Arsenic	29	(µg/L)	9	5	15	3.0	8 – 10
Soluble As	3	(µg/L)	9	6	12	N/A	N/A
As (III) ¹	3	(µg/L)	<2	<2	<2	N/A	N/A
As (V) ¹	3	(µg/L)	7	4	10	N/A	N/A
Iron ¹	29	(mg/L)	0.04	< 0.02	0.19	0.04	0.03 – 0.06
Manganese	29	(µg/L)	51	2	130	36	35 – 67
Total Alkalinity	8	(mg/L)	174	145	190	15.1	158 – 189
Total Hardness	8	(mg/L)	229	213	248	11.3	218 – 240
TDS	2	(mg/L)	280	260	300	N/A	N/A
TSS ¹	2	(mg/L)	<2	<2	<2	N/A	N/A
TOC	3	(mg/L)	1.6	1.5	1.7	N/A	N/A
UVA	2	(cm ⁻¹)	0.0261	0.0225	0.0296	N/A	N/A
Sulfate	3	(mg/L)	15	13	20	N/A	N/A
ORP	42	(mV)	559	399	782	83.9	529 – 590
Turbidity	36	(NTU)	0.60	0.15	1.8	0.45	0.40 – 0.80
pH ³	29	--	7.41	7.20	7.59	N/A	N/A

N/A = Standard Deviation and 95% Confidence Interval calculated on data sets of eight value or more.

¹ The value of lab analysis' LOD was used to calculate statistical information when a value was non-detect.

² No direct measurement. Calculated by subtracting arsenic (III) values from soluble values.

³ The median is reported for the pH data, not the mean.

Operation and Maintenance Results

During the verification test, there were no operational problems with the system operation, system equipment, or monitoring equipment. Several operating conditions and equipment performance factors were monitored during the verification test, including power usage, volume of treated flow, flow rates, head loss across filters, ozone generation, and ambient parameters such as temperature, dew point, and atmospheric pressures.

Operators were needed to monitor treated water turbidity, flow rate and pressure loss to determine when a filter change was needed. During the ETV test, filters were changed at least once per day. The ORP probe needed to be cleaned regularly and the ORP controller needed to be monitored to make sure the system operates at the set ORP point. The system was small and easily installed to provide easy access to all components for routine maintenance. The level of skill required for efficient operation was low, and the system had a low-flow switch that would shut the pump down under unfavorable operating conditions.

Consumables and Waste Generation

The only waste the CampWater system generated was spent filter cartridges. A total of 144 filter cartridges were used during Phase A. TCLP analyses of spent filters of each size were performed and satisfactorily passed the regulatory limits. California WET procedures on each filter size failed for arsenic. Waste disposal procedures would be dependent on the standards required by each state.

Quality Assurance/Quality Control

NSF provided technical and quality assurance oversight of the verification testing as described in the verification report, including an audit of nearly 100% of the data. NSF 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 for
Lawrence W. Reiter*

09/30/04

Lawrence W. Reiter
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Availability of Supporting Documents

Copies of the *ETV Protocol for Equipment Verification Testing for Arsenic Removal* dated September 2003, the verification statement, and the verification report (NSF Report #04/09/EPADWCTR) are available from the following sources:

(NOTE: Appendices are not included in the verification report. Appendices are available from NSF upon request.)

1. ETV Drinking Water Systems Center 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)