THE ENVIRONMENTAL TECHNOLOGY VERIFICATION PROGRAM

U.S. Environmental Protection Agency

NSF International

ETV Joint Verification Statement

TECHNOLOGY TYPE:	**MEDIUM-PRESSURE ULTRAVIOLET RADIATION TECHNOLOGY USED IN DRINKING WATER TREATMENT**	
APPLICATION:	**INACTIVATION OF MS2 VIRUS IN DRINKING WATER**	
TECHNOLOGY NAME:	**UVSWIFT MODEL 4L12**	
COMPANY:	**TROJAN TECHNOLOGIES INCORPORATED**	
ADDRESS:	**3020 GORE ROAD** **LONDON, ONTARIO N5V 4T7** **CANADA**	PHONE: **(519) 457-3400** FAX: **(519) 457-3030**
WEB SITE:	**http:\\www.trojanuv.com**	
EMAIL:	**jcosman@trojanuv.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 Systems (DWS) Center, one of 12 technology areas under ETV. The DWS Center recently evaluated the performance of a medium-pressure ultraviolet radiation system used in drinking water treatment system applications. This verification statement provides a summary of the test results for the Trojan Technologies Inc. UVSwift 4L12 System. Montgomery Watson Harza (MWH), an NSF-qualified field testing organization (FTO), performed the verification testing.

ABSTRACT

Verification testing of the Trojan Technologies UVSwift 4L12 system was conducted over a 45 day period from 9/1/01 to 10/15/01. The feedwater to the ultraviolet (UV) unit during the testing was the effluent from the Otay Water Treatment Plant (OWTP), a conventional plant with flocculation, sedimentation, and dual-media filtration of Otay lake water. In the first part of the testing, a virus seeding experiment was conducted at a flow rate of 695 gpm, UV transmittance of 84%, and at 81% lamp power setting. During this experiment the log inactivation of virus ranged from 2.1 logs to 3.0 logs as shown in Table below:

Virus Seeding Summary

Parameter	Unit	Count	Median	Range	Average	Standard Deviation	95 Percent Confidence Interval
Feed MS2 conc.	pfu/100mL	9	7E+04	5E+04 - 1.1E+05	8E+04	2E+04	6E+04 - 9E+04
Effluent MS2 conc.	pfu/100mL	9	2E+02	1E+02 - 4E+02	2E+02	1E+02	1E+02 - 3E+02
Log Inactivation	logs	9	2.7	2.1 - 3.0	2.6	0.3	2.4 - 2.9

UV estimated effective dose using MS2 virus is used as an indicator to obtain the inactivation of other microorganisms such as Cryptosporidium and Giardia. A collimated beam test was performed using feed water collected during the seeding experiment and a dose-response curve generated to determine the UV sensitivity of the MS2 virus used as the seed stock during the flow-through reactor challenge study. The dose response curve determined that an effective dose of 42.8 mJ/cm^2 was necessary to achieve 2-log inactivation of MS2. The log inactivation achieved during the virus seeding experiment was between 2.1 and 3.0 logs corresponding to an equivalent dose between 40.3 and 67.6 mJ/cm^2 obtained from the collimated beam dose response curve. The reactor was operated for a period of more than 27 days at a flow rate of 400 gpm and 81% lamp power setting with daily cleaning. During the first 320 hours the following operating parameters were monitored regularly: flow rate, total flow, UV sensor readings, lamp cleaning frequency, lamp hours, lamp shut-down periods, lamp electric power consumption, operating pressure and headloss through the UV unit. Data indicate that the system can operate reliably under these testing conditions. Water quality data collected from both the UV feedwater and UV effluent included: temperature, pH, total alkalinity, hardness, total organic carbon (TOC), UV-254 absorbance, turbidity, true color, nitrate, iron, free chlorine, and total chlorine. No significant change in these water quality parameters was seen from the feed water to the effluent water. Heterotrophic Plate Count (HPC) and total coliforms were both below the detection limit in both the feed and effluent water. Continuous monitoring of the UV irradiance did not indicate a clear fouling trend during the testing period since the UV irradiance measured is a strong function of the UV transmittance of the water, which varied between 81% and 90% (field measurements). However, at the end of the testing period visual inspection of the lamp and sensor sleeves indicated that while the lamp sleeves were relatively clean, the sensor sleeve had fouled. A 7% increase in the UV irradiance was observed when the fouled sensor sleeve was replaced by a new sensor sleeve. Replacing the lamp sleeve caused no further improvement. The sensor was found to drift from 1.8% to 11% of the reference sensor reading during the testing period but handling of the sensor window was found to contribute to approximately half of the sensor drift.

TECHNOLOGY DESCRIPTION

The technology tested during the ETV was the Trojan UVSwift Model 4L12 UV System. The UVSwift system utilizes UV light to disinfect waterborne microorganisms and is designed specifically for municipal drinking water applications. UV light is capable of disinfecting waterborne organisms including viruses, bacteria and protozoa. UV light accomplishes disinfection by altering the genetic material of the microbes and thus eliminating their ability to reproduce and cause infection (Jagger,

1967). *Giardia* and *Cryptosporidium*, two waterborne pathogens that are relatively resistant to chemical disinfection, are particularly susceptible to UV disinfection (Bukhari et al, 1998). This makes the use of UV technology an attractive alternative for drinking water treatment, especially in cases where the potential for formation of disinfection by-products, from chemical disinfectants, is high. UV units are typically tested for proper performance using surrogate microbes such as MS2 virus. UV estimated effective dose using MS2 virus is used as an indicator to obtain the inactivation of other microorganisms such as *Cryptosporidium* and *Giardia*.

The UVSwift line of reactors utilizes a compact, inline design that allows retrofitting into existing pipe galleries in a minimum of space. The UVSwift is available in sizes compatible with 12-inch, 18-inch, 24-inch and 30-inch pipe. The unit tested during the ETV utilized 4 UV lamps, specified by "4L" in the model number, and had flanged fittings for inline mounting in 12-inch pipe. The UVSwift 4L12 uses 2.8 kilowatt medium pressure lamps, housed in quartz sleeves, that produce a spectrum of UV and visible light and operate at a typical surface temperature of 300 °C. The lamp pinch temperature can be as high as 500 °C. Trojan specifies the UVSwift to be mounted with at least 5 pipe diameters of straight pipe length before the unit and at least 3 pipe diameters after. This ensures a minimum of reactor turbulence created by upstream and downstream pipe components. The UVSwift system includes a proprietary flow-modifying baffle plate that mounts on the inlet to the reactor. To control lamp fouling, the UVSwift system includes an automated cleaning mechanism. The cleaning mechanism uses an NSF certified food-grade acid and food-grade rubber seals to loosen and remove lamp foulants. The cleaning mechanism can be set to run at regular intervals. The unit includes one UV irradiance sensor and one UV transmittance sensor to continuously monitor lamp fouling and changes in the UV transmittance of the influent water respectively. The UV irradiance sensor measures the output from one lamp and can be verified against a calibrated reference sensor. Both the sensors have an automated cleaning mechanism, operating on the same schedule as the UV lamps. The UV-254 transmittance sensor was not used during the ETV test. The control panel includes adjustment of UV lamp output to any of 16 power settings and includes readouts for the UV irradiance sensors.

VERIFICATION TESTING DESCRIPTION

Test Site

The verification test site was the City of San Diego's Aqua 2000 Research Center located at the Otay Water Treatment Plant, 1500 Wueste Road, Chula Vista, California. The Research Center includes an office and lab trailer, a covered test pad and a dedicated operations staff with substantial experience. The source water for testing was Otay Lake water. Otay Lake receives water from natural runoff. In addition, Otay Lake can receive diversions from other reservoirs and the San Diego Aqueduct system, when needed.

Methods and Procedures

After an initial operations period of approximately 2 weeks to establish operating conditions, the unit was operated for approximately 30 days with all tasks being conducted concurrently. The objective of Task 1 was the characterization of the UV technology in terms of efficiency and reliability using the OWTP effluent as the feedwater to the UV unit. The goal of this task was to operate the unit continuously for 320 hours or more. The following operating parameters were monitored regularly during this task: flow rate, total flow, UV sensor readings, lamp cleaning frequency, lamp hours, lamp shut-down periods, lamp electric power consumption, operating pressure and headloss through the UV unit. The objective of Task 2 was the characterization of the UV system feedwater and effluent. The following water quality parameters were sampled from both the UV feedwater and UV effluent: temperature, pH, total alkalinity, hardness, TOC, UV-254 absorbance, turbidity, color, nitrate, iron, free chlorine, total chlorine and HPC. Turbidity, pH and chlorine residuals were analyzed at an onsite laboratory. All other parameters were analyzed by City of San Diego water quality and microbiology laboratories, which are State Certified laboratories. All analyses were conducted using Standard Methods and EPA methods.

The objective of Task 3 was to evaluate the UV unit in terms of lamp fouling and cleaning efficiency. During this task, all parameters of Tasks 1 and 2 were monitored. In addition, UV sensor readings before and after cleaning, and changes in UV sensor readings that might indicate lamp fouling, lamp aging or sensor fouling were monitored.

Task 4, the inactivation of microorganisms by the UV system, was conducted on September 14th, prior to Tasks 2 and 3. Task 4 was conducted at a flow rate of 695 gpm (1 million gallons per day (MGD)/158 m^3/hr) and a UV lamp power setting of 81%. The lamp power setting was selected based on the manufacturer's estimate that the setting could produce a 2 log reduction of the challenge organism, MS2 virus. MS2 virus was selected as a challenge species as it is not a human pathogen (Havelaar et al, 1990) and is more resistant to UV light than *Giardia* and *Cryptosporidium* (Stolarik et al, 2001). MS2 was continuously added to the UV feedwater to produce a concentration of approximately 4 to 5 logs MS2 /L. During Task 4, the 2.5 mg/L combined chlorine residual (approximate) in the OWTP effluent was quenched using sodium metabisulfite. After passing through the UV unit, sodium hypochlorite was added to inactivate any remaining virus before discharging the effluent to the backwash water recovery basin. A set of negative control samples was collected at the beginning of the experiments, prior to seeding and with the UV lamps turned off, to confirm the absence of MS2 virus in the reactor. Three challenge experiments were conducted. In each, three feed samples and three effluent samples were collected. A set of positive control samples was collected with the UV lamps turned off to demonstrate the inactivation of the challenge organism was due only to the UV light. A 1-2 liter sample of dechloraminated feedwater was collected for conducting collimated beam tests. Samples of the feedwater used during the full-scale UV challenge testing were spiked with MS2 virus and exposed to UV doses of 20 to 145 millijoules per square centimeter (mJ/cm^2) using a collimated beam apparatus. The dose-response curve generated from the collimated beam data was used to determine the UV sensitivity of the MS2 virus used as the seed stock during the flow-through reactor challenge study. The response of the MS2 virus challenge organism in the Trojan unit was then converted to a dose equivalent value based on the collimated beam dose-response curve.

The objective of Task 5 was to develop a data management plan to ensure the accurate collection, transmission and compilation of all data generated during the ETV. The plan developed allowed for the tracking of all data from final report figures or summary tables to handwritten data collection form. Task 6 details the quality assurance and quality control (QA/QC) procedures followed during the ETV. These procedures ensure the defensibility of all operational and analytical results presented in the ETV.

VERIFICATION OF PERFORMANCE

System Operation

Verification testing was conducted under manufacturer specified operating conditions. The system was operated at 695 gpm (1 MGD) during the virus seeding experiments and at 400 gpm at other times. The lamp power setting was at 81% throughout the testing period with the lamp cleaning frequency set at 24 hours. The system ran for more than 700 hours under these operating conditions between 9/14/01 and 10/15/01. During the first 320 hours the following operating parameters were monitored regularly: flow rate, total flow, UV sensor readings, lamp cleaning frequency, lamp hours, lamp shut-down periods, lamp electric power consumption, operating pressure and head loss through the UV unit. Data collected indicate that the system can operate reliably under the testing conditions. Also water quality data collected from both the UV feedwater and UV effluent included: temperature, pH, total alkalinity, hardness, TOC, UV-254 absorbance, turbidity, color, nitrate, iron, free chlorine, total chlorine and HPC and no significant change in these water quality parameters were seen from the feed water to the effluent water.

Summary of General Water Quality Parameters

Parameter	Unit	Count	Median	Range	Average	Standard Deviation	95 Percent Confidence Interval
Feed							
Alkalinity	mg/L as $CaCO_3$	7	148	127 - 168	149	N/A	N/A
Total Hardness	mg/L as $CaCO_3$	7	208	196 - 227	209	N/A	N/A
Calcium Hardness	mg/L as $CaCO_3$	7	132	120 - 146	131	N/A	N/A
Iron	µg/L	7	50	50 - 85.1	55	N/A	N/A
Managanese	µg/L	7	3.91	0.91 - 9.28	4.74	N/A	N/A
Nitrate	mg/L	7	0.2	0.2 - 0.573	0.3	N/A	N/A
TOC	mg/L	17	4.31	2.96 - 5.11	4.11	0.81	3.69 - 4.53
Color	Pt-Co	6	4	2 - 5	4	N/A	N/A
UV_{254}	1/cm	17	0.067	0.034 - 0.083	0.063	0.015	0.055 - 0.071
pH	std. Unit	38	8.4	7.3 - 8.9	8.4	0.39	8.3 - 8.5
Desktop Turbidity	NTU	38	0.1	0.10 - 0.20	0.10	0.03	0.10 - 0.10
Temperature	degC	38	21	20.3 - 24.7	22.1	1.4	21.6 - 22.6
Free Chlorine	mg/L	38	0.2	0.04 - 1.4	0.3	0.3	0.2 - 0.4
Total Chlorine	mg/L	38	2.2	1.5 - 3.0	2.2	0.3	2.1 - 2.3
Effluent							
Alkalinity	mg/L as $CaCO_3$	7	153	122 - 178	153	N/A	N/A
Total Hardness	mg/L as $CaCO_3$	7	213	199 - 220	210	N/A	N/A
Calcium Hardness	mg/L as $CaCO_3$	7	130	123 - 159	136	N/A	N/A
Iron	µg/L	7	50	50 - 131	68	N/A	N/A
Managanese	µg/L	7	3.41	1.18 - 9.07	4.64	N/A	N/A
Nitrate	mg/L	7	0.2	0.2 - 0.669	0.3	N/A	N/A
TOC	mg/L	17	4.12	2.98 - 12	4.52	2.08	3.45 - 5.59
Color	Pt-Co	6	3	1 - 5	3	N/A	N/A
UV_{254}	/cm	17	0.064	0.037 - 0.084	0.063	0.015	0.055 - 0.071
pH	std. Unit	38	8.4	7.3 - 8.9	8.4	0.40	8.3 - 8.5
Desktop Turbidity	NTU	38	0.10	0.10 - 0.20	0.10	0.03	0.10 - 0.10
Temperature	degC	38	22	20.4 - 24.8	22.2	1.4	21.7 - 22.7
Free Chlorine	mg/L	38	0.2	0.04 - 1.6	0.2	0.3	0.1 - 0.3
Total Chlorine	mg/L	38	2.1	1.6 - 3.0	2.1	0.3	2.0 - 2.2

Note: All calculations with below detection limit values used the detection limit value in the calculation as a conservative estimate.

Continuous monitoring of the UV irradiance did not indicate a clear fouling trend during the testing period as the UV irradiance measured is a strong function of the UV transmittance of the water, which varied between 81% and 90%. However at the end of the testing period visual inspection of the lamp and sensor sleeves indicated that while the lamp sleeves were relatively clean the sensor sleeve had fouled. A 7% increase in the UV irradiance was observed when the fouled sensor sleeve was replaced by a new sensor sleeve while replacing the lamp sleeve caused no further improvement. The sensor was found to drift from 1.8% to 11% from the reference sensor reading during the testing period. Handling of the sensor window was found to contribute to about half of the sensor drift.

Microbial Inactivation Results

To demonstrate the microbial inactivation ability of the Trojan UVSwift System, one collimated beam test and seeding experiments were conducted with MS2 virus on 9/14/01. The collimated beam test was conducted on the same day as the seeding tests with water collected during the same time period. This test was performed to determine the UV sensitivity of the microbial cultures used in the seeding experiment. A dose response curve was constructed based on the results of the collimated beam test. The dose response curve determined an effective dose of 42.8 mJ/cm^2 was necessary to achieve 2-log inactivation of MS2. The MS2 seeding was conducted at a flow rate of 695 gpm and a lamp power setting of 81%. During the three challenge experiments, the feed MS2 virus concentration ranged from 5×10^4

plaque forming units (pfu)/100mL to 1.1 x 10^5 pfu/100mL, while the effluent MS2 concentration ranged from 4 x 10^2 pfu/100mL to less than 1 x 10^2 pfu/100mL. Consequently, the microbial inactivation observed during the challenge tests ranged from 2.1 to 3.0 logs. No removal was observed during the positive control tests with the lamps off.

Operation and Maintenance Results

The UV system was operated from a control panel where the power level setting of the lamps could be input along with the mode of operation of the reactor. During the verification testing the reactor was operated in manual reactor mode where the power level setting for the reactor did not change with changes in UV transmittance of the water. The cleaning frequency was set to 24 hours using the control panel in the fixed mode. Manual override cleaning was performed to test the manual mode of cleaning control and when it was required to clean for sensor calibrations. The power usage was 0.32 kwh/1000 gal at a flow rate of 400 gpm and a power setting of 81%.

A proprietary cleaning chemical obtained from the manufacturer was used along with the mechanical cleaning mechanism to assist in cleaning the lamp sleeves. The sensor sleeve was cleaned with the same mechanical mechanism but without cleaning chemical. The manufacturer provided an Operations and Maintenance manual that was helpful in explaining the setup, operation and maintenance of the ETV test system.

Original Signed by		*Original Signed by*	
E. Timothy Oppelt	*06/07/02*	*Gordon Bellen*	*06/10/02*
E. Timothy Oppelt	Date	Gordon Bellen	Date
Director		Vice President	
National Risk Management Research Laboratory		Federal Programs	
Office of Research and Development		NSF International	
United States Environmental Protection Agency			

Availability of Supporting Documents

Copies of the *ETV Protocol for Equipment Verification Testing for Inactivation of Microbiological Contaminants*, dated August 9, 1999, the Verification Statement, and the Verification Report (NSF Report #02/03/EPADWCTR) 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 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/dws/dws_reports.html and from http://www.nsf.org/etv/dws/dws_project_documents.html (electronic copy)
3. EPA web site: http://www.epa.gov/etv (electronic copy)