UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
Office of Research and Development
Washington, D.C. 20460

ENVIRONMENTAL TECHNOLOGY VERIFICATION PROGRAM
VERIFICATION STATEMENT

TECHNOLOGY TYPE:	**ULTRAVIOLET RADIATION USED IN PACKAGED DRINKING WATER TREATMENT SYSTEMS**
APPLICATION:	**MICROBIOLOGICAL CONTAMINANT INACTIVATION**
TECHNOLOGY NAME:	**SENTINEL™ ULTRAVIOLET REACTOR (R-11, Model 6-1)**
COMPANY:	**CALGON CARBON CORPORATION OXIDATION TECHNOLOGIES**
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The U.S. Environmental Protection Agency (EPA) has created a program to facilitate the deployment of innovative technologies through performance verification and information dissemination. The goal of the Environmental Technology Verification (ETV) Program is to further environmental protection by substantially accelerating the acceptance and use of improved and more cost effective technologies. The ETV Program is intended to assist and inform those involved in the design, distribution, permitting, and purchase of environmental technologies. This verification statement provides a summary of the performance results for the Calgon Carbon Corporation (CCC) Sentinel™ Ultraviolet Reactor, R-11, Model 6-1 (Sentinel™). The Sentinel™ is a package drinking water treatment system that uses medium-pressure ultraviolet (UV) lamps operating at a higher temperature than low-pressure lamps to produce a broad spectrum of UV light with a higher irradiance to inactivate microbiological contaminants.

ABSTRACT

The EPA and NSF International (NSF) verified the performance of the Sentinel™ under the EPA's ETV program. The Sentinel™ obtained an estimated 3.9 $\log_{10}$ inactivation of *Cryptosporidium parvum* (*C. parvum*) as determined by animal infectivity methods, at an estimated UV dose of 20 mW-s/cm^2, when fed finished (treated but not chlorinated) water that was seeded with *C. parvum* at a flow rate of approximately 215 gallons per minute (gpm). When using other methods (vital dyes and *in vitro* excystation), a maximum of 1.2 $\log_{10}$ inactivation of *C. parvum* was observed. During the microbiological seeding challenge, the finished water fed to the system had these characteristics:

- turbidity less than or equal to 0.11 NTU
- nitrate less than or equal to 4.0 milligrams per liter (mg/L)
- pH range of 7.40 - 7.76
- temperature range of 8.8 - 12.3 °C
- UV $_{254}$ absorption coefficient ranges 0.02-0.06 cm^{-1}.

At a flow rate of 25 gpm, the Sentinel™'s power requirements were verified as 1.046 ± 0.046 kW per lamp at full power. Three of the UV irradiance sensors failed and some of the automatic quartz sleeve wipers had operational difficulties including a broken weld. CCC informed NSF of their intent to improve these portions of the Sentinel™.

Details of the verification testing, including the testing data and discussion of results, may be found in the report entitled "Environmental Technology Verification Report: Inactivation of *Cryptosporidium parvum* oocysts in Drinking Water: Calgon Carbon Corporation's Sentinel™ Ultraviolet Reactor" (EPA/600/R-98/160).

PROGRAM OPERATION

The EPA, in partnership with recognized verification organizations, objectively and systematically evaluates the performance of innovative technologies. Together, with the full participation of the technology developer, they develop plans, conduct tests, collect and analyze data, and report findings. The evaluations are conducted according to a rigorous demonstration plan and established protocols. NSF, a not-for-profit organization dedicated to public health safety and protection of the environment, assured data quality objectives were met during testing through their oversight and management of verification activities. The verification testing of the Sentinel™ was performed by Cartwright, Olsen and Associates, LLC (COA), an NSF-qualified Field Testing Organization for the Package Drinking Water Treatment Systems (PDWTS) ETV Pilot.

TECHNOLOGY DESCRIPTION

The Sentinel™ is a medium pressure UV water treatment system designed to inactivate microbiological contaminants. There are two major UV light technologies: low-pressure and medium pressure lamps. The low-pressure lamp UV light technology emits most of its energy at the 253.7 nm wavelength. The medium pressure lamps produce a broad spectrum of UV light (extending over the 200-300 nm range with a maximum output at about 255 nm) with a higher irradiance and operating at a much higher operating temperature (surface temperatures >500°C) than low pressure lamps. The linear power density is also much higher (typically 100-300 W/cm).

The system is a skid-mounted, stand-alone system equipped with a control panel, power supply, transformer, and fail-safe and monitoring controls. The system has two UV reaction chambers contained within a stainless steel column (dimensions: 10" diameter, 80" tall). Each reaction chamber has three 1 kW medium pressure ultraviolet lamps. Each lamp can be operated at full or reduced power. Each lamp is contained within a quartz sleeve aligned perpendicular to and across the flow of the water. The UV dose for the system is calculated using a multiple point source summation (MPSS) model that is undergoing a peer review. The hydraulic design for the system is for continuous flow rates up to 500 gpm (0.7 mgd). Throughout the verification testing period, the system was operated at a flow rate of 25 gpm during regular flow conditions and at approximately 215 gpm (814 L/min) during inoculated feedwater conditions.

VERIFICATION TESTING DESCRIPTION

In March and April of 1998, the ability of the Sentinel™ Ultraviolet Reactor to inactivate the protozoa *C. parvum* oocysts was tested at the Mannheim Water Treatment Plant in Kitchener, Ontario, Canada.

The Grand River is the source water for the Mannheim Water Treatment Plant. Pretreated surface water (treated by coagulation, flocculation, sedimentation, ozonation, and filtration) was inoculated with *C. parvum* oocysts and fed to the Sentinel™. The pretreated surface water exhibited the following characteristics during the microbiological seeding portion of the verification testing: turbidity concentrations less than or equal to 0.11 NTU; pH range 7.40-7.76; temperature range 8.8-12.3 ^{o}C; nitrate concentration less than or equal to 4.0 milligrams per liter (mg/L); total organic carbon (TOC) concentration less than or equal to 4.5 mg/L; UV_{254} absorption coefficient range 0.02-0.06 cm^{-1}.

Methods

During each day of the verification test, samples of the feed and finished water were collected, labeled and analyzed. All analyses were performed in accordance with the procedures in *Standard Methods.*

The purpose of the microbiological challenge test was to demonstrate the effectiveness of the application of medium pressure UV lamps as configured in the Sentinel™ equipment in inactivating the protozoan oocysts in the field. The challenge testing was performed on finished water representing a uniform water quality matrix.

The Sentinel™ was challenged with live oocysts and consisted of the following steps:

1) the introduction of live oocysts into the water stream and their passage through the Sentinel™,
2) the recovery of the oocysts from the water stream,
3) the determination of their viability and/or infectivity,
4) the calculation of $\log_{10}$ inactivation.

The organisms were introduced upstream of a static mixer ahead of the reactor and collected on 1 µm filters after the reactor. The overall flow rate during the tests was approximately 215 gpm (814 L/min). The filters were shipped to Clancy Environmental Consultants, Inc. (CEC) in Vermont where the organisms were isolated, concentrated and subjected to analysis by *in vitro* methods to determine viability. Additionally, for *C. parvum* oocysts, animal infectivity experiments were also conducted to ascertain the levels of inactivation demonstrated by *in vitro* assays and to provide further evidence for the correlation between *in vitro* methods and neonatal mouse infectivity, following oocyst exposure to UV light. The details of the seeding, recovery, and viability assays are found in Clancy et al. (1998).

VERIFICATION OF PERFORMANCE

The following is a summary of the findings of the verification testing of the Sentinel™:

Water Quality Results

The following two tables present the mean, minimum, and maximum water quality parameter concentration results of the influent and effluent samples collected during the verification testing:

On-Site Water Quality Sampling Results (March 30 through April 13)

	Temp. (°C)[1]	pH[2]	Bench Turbidity[3]	In-Line Turbidity[4]
Mean	10.4/11.4	7.6/7.6	0.095/0.094	0.072/0.077
Minimum	8.8/8.8	7.4/7.4	0.056/0.053	0.041/0.041
Maximum	11.0/12.4	7.8/7.7	0.147/0.134	0.112/0.147

1 - Temperature from influent/effluent of reactor.
2 - pH from influent/effluent of reactor.
3 - Turbidity in NTU from bench influent/effluent of reactor.
4 - Turbidity in NTU from on-line turbidimeter, filter 3/filter 4.

Laboratory Water Quality Sampling Results (microbial challenge test days)

	Alk (mg/l)[1]	Al (mg/l)[1]	Color (TCU)[1]	Iron (mg/l)[1]	Mang (mg/l)[1]	NO3 (mg/l)[1]	UV254 (cm^{-1})[1]
Mean	164/164	0.26/0.3	5/5	0.15/ND	0.01/.01	3.58/3.34	0.0464/0.0366
Minimum	150/150	0.06/0.08	5/5	ND/ND	ND/ND	3/3	0.0365/0.0214
Maximum	180/180	0.86/0.48	5/5	0.5/ND	0.03/0.02	4/3.7	0.0551/0.0427

1 – Concentration from influent/effluent of reactor.
ND = Not Detected

Microbiological Results

Results of the *C. parvum* inactivation by the Sentinel™ as determined by animal infectivity, vital dyes, and *in vitro* excystation studies are presented in the following table:

Summary of the Results of *C. parvum* inactivation by the Sentinel™

Challenge Date	**Sentinel™ UV Dose at 215 gpm (mW-s/cm²)**	**%Trans-mittance**	**Log_{10} Inactivation via animal infectivity**	**Vital dyes assay (DAPI/PI)**	***In vitro* excystation**
3/31/98	167 (High) – 2 lamps full	90.0	>4	1.2	0.4
4/6/98	152 (High) – 2 lamps full	89.4	Not Done	0.9	0.4
4/7/98	137 (High) – 2 lamps full	87.9	Not Done	0.5	0.2
4/1/98	69 (Medium) – 2 lamps reduced	90.1	>4	0	0
4/8/98	20 (Low) – 1 lamp reduced	91.1	3.9	0	0

Mouse infectivity assays with high and medium UV doses demonstrated no infection in neonatal mice despite oral inoculation of up to $1x10^5$ oocysts. The oocysts which had been exposed to a low UV dose resulted in 4.5% infection (1 of 22 mice) with an inoculum of $1x10^5$ UV exposed oocysts per mouse; however, no mice were infected when inocula of either $1x10^4$ or $1x10^3$ UV exposed oocysts were administered into a total of 36 mice.

Operations and Maintenance Results

During the verification period, aspects of the operation were evaluated to determine insofar as is possible over a brief period, the degree of maintenance and "hands on" attention required. For this observation the equipment was run continuously and monitored 24 hours a day until the completion of a period of 27 days. Results observed included:

- Three of the contained irradiance sensors failed due to unexpected electronics problems. CCC is taking action to redesign the sensor circuit board.
- The automatic quartz sleeve wipers ceased operating for many reasons including a broken weld. The wiper mechanism is being redesigned and will be the subject of a separate ETV evaluation. CCC has determined that the cause of wiper failure was the impact force of the brush with the wiper stop at the end of the extended travel position.
- During the maintenance period the power consumption was approximately 1.046 ± 0.046 kW per lamp. Assuming daily operation of six lamps at full power, the power demand is estimated at 150.6 kW per day.
- The O&M manual supplied by the manufacturer was specific to this equipment and included all the components of the pilot plant. Drawings and illustrations showing the positions of the meters and controls are included along with explanations of control functions and step-by-step instructions for common maintenance functions, such as: replacement of lamps, quartz tube cleaning and reactor cleaning. Complete instructions for equipment start-up and shut-down procedures were listed in this guide. The control panel is thoroughly explained so that all programmable functions, including wiper cycles, lamp set-points for alarms and other PLC parameters are easily learned by even inexperienced personnel. Safety measures included detailed instructions concerning high voltage, protection against UV irradiance, and the

procedures for mercury spills in the event of lamp breakage. A trouble shooting guide was furnished.

Conclusions

Through this testing it was established that at a process flow rate of approximately 215 gpm the Sentinel™ could obtain an estimated 3.9 $\log_{10}$ inactivation of *C. parvum* oocysts as determined by animal infectivity results with one lamp illuminated (out of six) at reduced power (0.5 kW). Greater (> 4 $\log_{10}$) inactivation was achieved at 215 gpm with higher UV doses, respectively, with two lamps at reduced power (0.5 kW each), and with two lamps at full power (1.0 kW each), again as determined by animal infectivity results.

Furthermore, the use of *in vitro* methods (vital dyes and *in vitro* excystation) significantly under-estimated oocyst inactivation when compared to neonatal mouse infectivity.

During the verification period, water quality parameters that influence UV absorbance were measured to assist in evaluating other waters for application of this UV system. During the challenge periods, UV_{254} absorption coefficient was between 0.02 and 0.06; turbidity was ≤0.11 NTU. No iron or manganese was detected in the sample water; nitrates were no greater than 3.7 mg/L and total organic carbon was no greater than 4.3 mg/L.

Also of importance to this study was the operation of the equipment in the field. Several deficiencies were noted with wiper failures, irradiance sensor, and attenuation tubes. CCC has informed COA and NSF that they are taking action to improve these portions of the system.

Limitations

The PDWTS ETV Pilot verifies the performance of innovative water treatment systems using consensus methods and procedures. This verification identified limitations associated with the use of non-standard methods. For example, the verification identified concerns about the methods for assessing oocyst viability and estimating UV dose. The lack of consensus on evaluation methods and procedures or the application of a technology is a reflection of the uncertainties associated with emerging technologies, developing analytical techniques and engineering applications. The resolution of these uncertainties is within the purview of rigorous scientific research and not the ETV program. A detailed description of the methodology limitations associated with this performance testing is provided in the Verification Report (EPA/600/R-98/160).

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Availability of Supporting Documents

Copies of the *ETV Protocol for Equipment Verification Testing for Inactivation of Microbiological Contaminants* dated March 8, 1998, the Verification Statement (EPA/600/R-98/160VS), and the Verification Report (EPA/600/R-98/160) 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/etv (electronic copy)

3. EPA web site http://www.epa.gov/etv (electronic copy)