

THE ENVIRONMENTAL TECHNOLOGY VERIFICATION PROGRAM



U.S. Environmental Protection Agency



NSF International

ETV Joint Verification Statement

TECHNOLOGY TYPE:	UV DISINFECTION IN DRINKING WATER
APPLICATION:	REMOVAL OF MICROBIAL CONTAMINANTS
PRODUCT NAME:	ETS UV SYSTEM MODEL UVL-200-4
VENDOR:	ENGINEERED TREATMENT SYSTEMS LLC
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NSF International (NSF) manages the Drinking Water Systems (DWS) Center under the U.S. Environmental Protection Agency's (EPA) Environmental Technology Verification (ETV) Program. The DWS Center recently evaluated the performance of the ETS UV System Model UVL-200-4 (UVL-200-4). NSF performed all verification testing activities at its Ann Arbor, MI location.

EPA created the ETV Program to facilitate the deployment of innovative or improved environmental technologies through performance verification and dissemination of information. The ETV Program's goal 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 according to rigorous quality assurance protocols to ensure that data of known and adequate quality are generated and that the results are defensible.

ABSTRACT

The ETS UV System Model UVL-200-4 was tested to validate the UV dose delivered by the system using biosimetry and a set line approach. The set line for 40 mJ/cm² Reduction Equivalent Dose (RED) was based on validation testing at three (3) set points. A set point is defined at a single flow rate and irradiance

output that delivers the targeted UV dose. The results of the three set point tests were used to develop the setline that defined the maximum flow rate and minimum irradiance output required to ensure that a 40 mJ/cm² RED is achieved. The microorganism used for the validation was MS2 coliphage virus. ETS selected flow rates for testing of 15, 20, and 25 gpm based on the unit design and preliminary screening tests. The lowest irradiance tested was 7.0 W/m² which occurred with full power to the unit and a feed water Ultraviolet Transmission (UVT) of 79%.

The measured RED was adjusted for RED bias and uncertainty to determine the validation factor for calculating log inactivation of *Cryptosporidium*. The validation factor and validated dose calculations were performed as specified in the USEPA Ultraviolet Design Guidance Manual (UVDGM-2006). Based on the results of these tests and the calculated validation factor, the UVL-200-4 achieved a minimum of 4.0 log reduction credit for *Cryptosporidium* at all of the test flow rates and corresponding irradiance levels. Some regulatory agencies have established a standard for spray parks and other applications based on a validated dose (RED_{Val}) of 40 mJ/cm² based on MS2, as the pathogen. The calculation of the validation factor for a validated dose based on MS2 was performed using B_{RED} set equal to 1.0. The UVL-200-4 achieved a RED_{Val} of 40 mJ/cm² at all set points tested.

TECHNOLOGY DESCRIPTION

The UVL-200-4 uses one (1) low pressure UV lamp and one intensity sensor mounted in a stainless steel flow chamber. The inlet pipe size is 2 inch diameter, the unit is designed for an operating pressure of 145 psi, and operating power consumption is < 200 W. The low pressure lamp has a rated lamp life of 12,000 hours. The sensor is a UV-Technik SUV20.1 A2Y2C unit with a measuring field angle of 160 degrees and measuring range of 0 to 20 W/m². The system has a control panel that provides data on the lamp condition, operating hours, irradiance measured by the sensor, and other operating conditions. The operating manual provides schematics and tables with parts, dimensions and other specifications for the reactor, the sensors, the lamps and the quartz sleeves.

VERIFICATION TESTING DESCRIPTION

Test Site and Equipment

The verification test was conducted using a full scale unit installed at the NSF Engineering Laboratory in Ann Arbor Michigan. The water source for this test was City of Ann Arbor Michigan municipal drinking water that was de-chlorinated using activated carbon. Lignosulfonic Acid (LSA) was used to lower the UV transmittance (UVT) for the full power low UVT test runs. UVT was measured continuously using an in-line UVT meter (calibrated daily) to confirm that proper UVT was attained.

NSF used a test rig and system setup that is designed to conform to the specifications described in the UVDGM-2006. The UV reactor inlet and outlet connections were installed according to the ETS installation and assembly instructions. Two 90 degree elbows were attached directly to the inlet and outlet of the system to eliminate stray UV light. The feed water pump was a variable speed pump. Flow rate was controlled by adjusting the power supplied to the pump and by a control valve. A turbine water flow meter was used to monitor flow rate. The meter was calibrated and achieved an accuracy of $\pm 1.6\%$ over the range of flow rates. A chemical feed pump (injector pump) was used to inject MS2 coliphage upstream of an inline static mixer. The inline mixer ensured sufficient mixing of the microorganism prior to the influent sampling port, which was located upstream of the 90° elbow at the inlet to the unit. The effluent sampling port was located downstream of the 90° elbow and a second inline static mixer. The sampling location met the UVDGM-2006 requirement to ensure good mixing of the treated water prior to the effluent sampling port. A power platform that measures amperage, volts, watts, and power factor was used to monitor power use by the test unit. The unit was wired into the platform and power consumption was recorded for each test run.

Methods and Procedures

The tests followed the procedures described in the *Test/Quality Assurance Plan for the ETS UV Ultraviolet (UV) System Model UVL-200-4, Low Pressure Lamp, September 2010* (TQAP). The TQAP was adapted from *Generic Protocol for Development of Test/Quality Assurance Plans for Validation of Ultraviolet (UV) Reactors, 7/2010*. This generic protocol is based on the USEPA's UVDGM-2006. The TQAP was updated based on the GP of August 2011 prior to the start of the validation test.

The approach used to validate UV reactors was based on biosimetry which determines the log inactivation of a challenge microorganism during full-scale reactor testing for specific operating conditions of flow rate, UV transmittance (UVT), and UV intensity (measured by the duty sensor). MS2 coliphage ATCC 15597-B1 was used in collimated beam bench scale testing and for the full-scale reactor dose validation tests. A dose-response equation for the challenge microorganism (MS2 coliphage for this test) was determined using a collimated beam bench-scale test. The observed log-inactivation values from full-scale testing were input into the collimated beam derived-UV dose-response equations to estimate a measured "Reduction Equivalent Dose (RED_{meas})". The RED_{meas} value was adjusted for uncertainties and biases to produce the validated dose of the reactor for the specific operating conditions tested.

The UV lamp was new and therefore the system was operated for 100 hours with the lamps turned on at full power prior to the start of the test.

VERIFICATION OF PERFORMANCE

System Operation

Each set point represented a given flow rate - irradiance pair with testing under two conditions, (1) lowered UVT-max power and (2) high UVT-reduced power. The first test condition involved reducing the UVT while operating the UV system at full power until the UV intensity measured by the unit UV sensor equaled the target UV intensity set point. The second test condition was run with high UVT and with the power reduced until the unit UV intensity measured by the sensor was equal to the target UV intensity set point. Three target flow rates - irradiance set points (15 gpm - 7 W/m²; 20 gpm - 11 W/m²; 25 gpm - 13 W/m²) were tested for the set line with each condition being performed in duplicate. The irradiance targets were based on expected irradiance at UVT's of 79%, 90%, and 94%.

The validation tests were run on two days, June 20 and 21, 2012. The first day of testing was dedicated to the test conditions and duplicate runs where the UVT of the feed water was lowered to the target levels (<79%, <90%, and <94%) and the lamps were operated at full power. The second day of testing was dedicated to the test conditions and duplicates where high UVT feed water (97%) was used and the lamp power was reduced to achieve the target intensity level. Collimated beam tests were run in duplicate on both test days and included minimum UVT water (79%) on Day 1 and maximum UVT water (97%) on Day 2. For this validation test, there were two sets of duplicate collimated beam test data, one at low UVT and one at high UVT.

Test Results

Sensor Assessment

The test unit duty sensor was evaluated according to the UV sensor requirements in the UVDGM-2006 prior to the verification testing. All UV intensity sensors (the duty and two reference sensors) were new sensors designed according to the DVGW guideline W 294 (June, 2006) and the ÖNORM M5873-1 standard (March, 2001). Evidence of calibration of the sensors, traceable to a standard of the Physikalisch Technische Bundesanstalt (PTB) in Braunschweig, was provided by ETS as provided to them by the sensor manufacturer (*UV-TECHNIK*).

The same duty sensor was used for monitoring intensity (irradiance) for all test runs. The control panel provided direct readings of intensity in W/m^2 . The duty sensor was compared against two reference sensors before and after the validation test runs. These data demonstrate that the duty sensor was within the range of 0.1% to 0.7% of the average of the two reference sensors, which meets the QC goal of <10%. The two reference sensors showed a variance of 2.7% at 100% power and 22.7% to 3.0% at 60% power.

Set Line for 40 mJ/cm^2 RED_{meas}

The three set points selected for this validation all achieved a RED_{meas} of 40 mJ/cm^2 based on MS2, which was the target minimum RED_{meas} for developing the set line. Figure 1 shows the set line. The unit was validated for a minimum RED_{meas} of 40 mJ/cm^2 for any flow rate and intensity combination above and to the left of the set line. The maximum flow rate demonstrated was 24.9 gpm. A UV system cannot operate above the highest validated flow rate and claim a 40 mJ/cm^2 RED_{meas} . The lowest intensity demonstrating a RED_{meas} of 40 mJ/cm^2 was 7.0 W/m^2 . A UV system cannot operate below the lowest validated irradiance and claim a 40 mJ/cm^2 RED_{meas} . The three set points used to develop at set line were:

- Set Point 1 – 14.8 gpm; 7.0 W/m^2
- Set Point 2 – 19.9 gpm; 11.0 W/m^2
- Set Point 3 – 24.9 gpm; 12.8 W/m^2

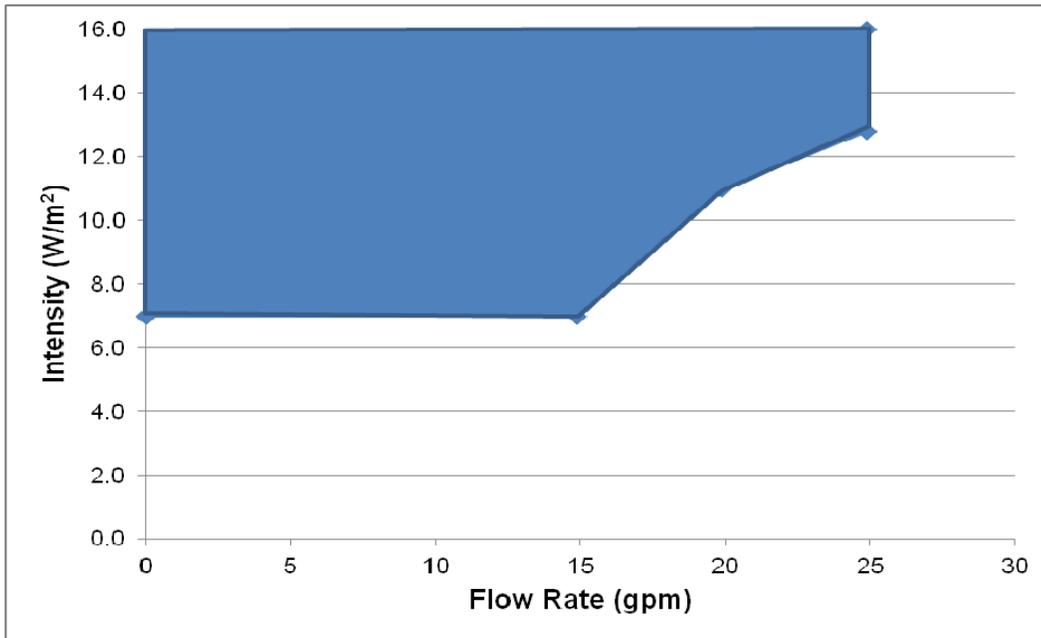


Figure 1. Set line for 40 mJ/cm^2 RED_{meas} for ETS UV Model UVL-200-4.

Deriving the Validation Factor and Log Credit for *Cryptosporidium*

As described in UVDGM, several uncertainties and biases are involved in using experimental testing to define a validated dose and validated operating conditions. The validation factor (VF) for *Cryptosporidium* was determined quantitatively to account for key areas of uncertainty and variability.

The equation for the VF is:

$$VF = B_{RED} \times [1 + (U_{val} / 100)]$$

where:

VF = Validation Factor;

B_{RED} = RED bias factor;

U_{val} = Uncertainty of validation expressed as a percentage.

The highest B_{RED} value found among the replicates at a given set point was selected for the B_{RED} value for use in the VF calculation per the UVDGM-2006. U_{val} was calculated based on the U_S (uncertainty of sensor value), U_{DR} (uncertainty of the fit of the dose-response curve) and U_{SP} (uncertainty of set-point). The QC requirement that the duty sensor measurements should be within 10% of the average of two or more reference sensors eliminates the need to calculate the U_S factor per the UVDGM-2006. The U_{DR} results for low and high UVT waters (26.73% and 18.14%, respectively) were less than 30%, and therefore U_{DR} was not used in calculating U_{val} for the test runs.

The U_{SP} and U_{DR} factors were used for calculating U_{val} per the equations:

$$U_{val} = (U_{SP}^2 + U_{DR}^2)^{1/2} \text{ if } U_{DR} > 30\%$$
$$U_{val} = U_{SP} \text{ if } U_{DR} < 30\%$$

After establishing the validation factor (VF), the validated dose was calculated as:

$$\text{Validated dose} = \text{RED} / \text{VF}$$

All of the set points achieved a validated dose that showed a minimum of a 4-log reduction credit for *Cryptosporidium*. The set line for a minimum 3.0 log reduction credit for *Cryptosporidium* (also 4.0 log reduction credit) is shown in Figure 2. This set line was based on the following set points:

Set Point 1 – 14.8 gpm; 7.0 W/m²

Set Point 2 – 19.9 gpm; 11.0 W/m²

Set Point 3 – 24.9 gpm; 12.8 W/m²

Some regulatory agencies, such as the New York Department of Health, have established a standard for spray parks and other applications based on a validated dose (RED_{val}) of 40 mJ/cm² based on MS2, as the pathogen. The calculation of the validation factor for a validated dose based on MS2 was performed using B_{RED} set equal to 1.0 because the pathogen selected was the same as the test organism, so there was no bias correction. The RED_{val} based on MS2 was calculated for each test run. All of the set point test runs achieved a 40 mJ/cm² validated dose based on MS2. The set line for a minimum validated dose of 40 mJ/cm² was the same as for the 3.0 and 4.0 log reduction credit for *Cryptosporidium*, as the set points were the same. Figure 2 represents the set line for a minimum RED_{val} of 40 mJ/cm².

QUALITY ASSURANCE/QUALITY CONTROL

The NSF QA Department performed a QA review of the analytical data. A complete description of the QA/QC procedures is provided in the verification report.

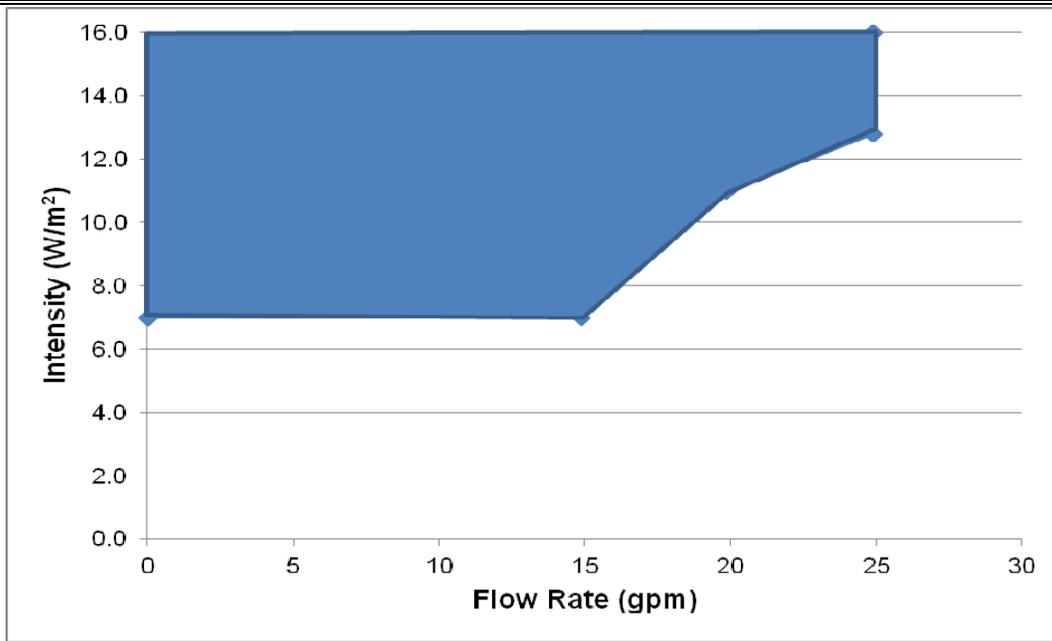


Figure 2. Set Line for Minimum 3-log and Minimum 4.0 log *Cryptosporidium* Inactivation for ETS UV Model UVL-200-4.

*Original signed by Cynthia Sonich-Mullin on
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Availability of Supporting Documents

Copies of the test protocol, the verification statement, and the verification report (NSF report # NSF 10/33/EPADWCTR) are available from the following sources:

1. ETV Drinking Water Systems Center Manager (order hard copy)
NSF International
P.O. Box 130140
Ann Arbor, Michigan 48113-0140
2. Electronic PDF copy
NSF web site: <http://www.nsf.org/info/etv>
EPA web site: <http://www.epa.gov/etv>