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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 ECP-113-5**
VENDOR:	**ENGINEERED TREATMENT SYSTEMS LLC**
ADDRESS:	**9652 BEAVERLAND PARKWAY BEAVER DAM, WISCONSIN**
PHONE:	**877-885-4628**
WEBSITE:	**HTTP://ETS-UV.COM**
EMAIL:	**INFO@ETS-UV.COM**

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 ECP-113-5 (Model ECP-113-5). 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 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 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 ECP-113-5 was tested to validate the UV dose delivered by the system using biodosimetry and a set line approach. The set line for 40 mJ/cm^2 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/cm^2 RED is achieved. The microorganism used for the validation was MS2 coliphage virus. ETS selected flow rates for testing of 50, 75, and 100 gpm based on the unit design and preliminary screening tests. The lowest irradiance tested was 82 W/m^2 which occurred with full power to the unit and a feed water ultraviolet transmittance (UVT) of 78%.

ETS also requested an additional set point be tested at a higher flow rate of 175 gpm. The purpose was to demonstrate that a 3 log reduction of *Cryptosporidium* could be achieved at this higher flow rate based on the validation factor and validated dose calculations specified in the USEPA Ultraviolet Design Guidance Manual (UVDGM-2006). The goal was to use this additional set point in combination with the set points at 50, 75 and 100 gpm to develop a setline for flow rate and irradiance combinations that would achieve a 3-log reduction of *Cryptosporidium.* A calculated 3 log reduction credit for *Cryptosporidium* was achieved at all set points including the highest flow rate of 175 gpm at an intensity of 105 W/m^2.

TECHNOLOGY DESCRIPTION

The Model ECP-113-5 uses one (1) medium pressure mercury amalgam lamp and one intensity sensor mounted in a stainless steel flow chamber. The inlet pipe size is 3 inch diameter, the unit is designed for an operating pressure of 60 psi, and operating power consumption is 1300 W. The medium pressure lamp has a lamp life of 4000 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 100 W/m^2. The system has a control panel that provides data on the lamp condition, operating hours, irradiance measured by the sensor, and operating conditions such as temperature. 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 + 2.7% 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^o elbow at the inlet to the unit. The effluent sampling port was located downstream of the 90^o 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 factors 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) Reactor, Medium Pressure Lamps, June 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 biodosimetry 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 (50 gpm - 80 W/m^2; 75 gpm - 90 W/m^2; 100 gpm - 105 W/m^2) 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 fourth set point for 3-log reduction of *Cryptosporidium* was run at 175 gpm and a target intensity of 105 W/m^2, which was expected to be the intensity for a UVT of 94%.

The main validation tests were run on two days, July 18 and July 19, 2012. Additional testing at the lower flow rates (50 gpm, 75 gpm) was performed on September 11, 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 (95%) was used and the lamp power was reduced to achieve the target intensity level. On the third day of testing, both low UVT water (<79%) with full power at a flow rate of 50 gpm and high UVT water with reduced power for flow rates of 50 and 75 gpm were used. Collimated beam tests were run in duplicate on all three test days and included minimum UVT water (79%) and maximum UVT water (97%). For this validation test, there were four sets of duplicate collimated beam test data, two at low UVT and two 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 M5873-2 standard (June 2002). 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 3.5% to 7.3% of the average of the two reference sensors, which meets the QC goal of <10%. The two reference sensors showed a variance of 0.0 to 1.0% at 100% power and 0.0 to 1.8% % at 64% power.

Set Line for 40 mJ/cm^2 RED

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 is 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 100 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 82 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 – 50 gpm; 82 W/m^2
Set Point 2 – 75 gpm; 89 W/m^2
Set Point 3 – 100 gpm; 105 W/m^2

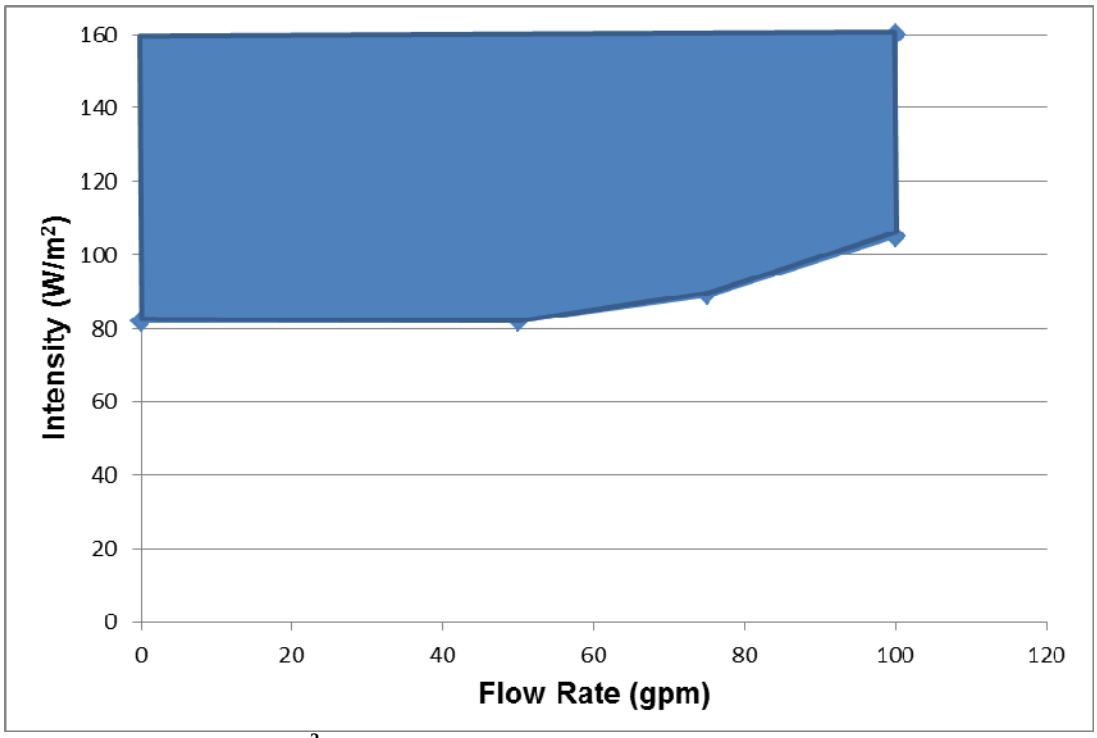

Figure 1. Set line for 40 mJ/cm^2 RED_{meas} for ETS UV *Model ECP-113-5.*

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 July U_{DR} results for low and high UVT waters (27.48% and 20.74%, respectively) are less than 30%, and therefore U_{DR} was not used in calculating U_{Val} for the test runs corresponding to these days of testing. The September U_{DR} results for low and high UVT waters were 26.99% and 33.46%, respectively. Since the U_{DR} was >30% at the UV dose corresponding to 1-log inactivation of the challenge organism, the uncertainty of the dose response (U_{DR}) was included in the calculation of uncertainty (U_{Val}) for the test runs performed in September. The 75 gpm flow rate test with the power turned down included one test run in July and one test run in September. The September test run had the highest U_{DR} of 33.46%. The highest Udr measured in September was applied to both test runs and was included in determining the uncertainty (U_{Val}) for both test runs.

The U_{SP} and U_{DR} factors were used for calculating U_{Val} per the equation:

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

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

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

The three set points tested to demonstrate a minimum RED_{meas} of 40 mJ/cm^2 and the additional set point at the higher flow rate of 175 gpm and an intensity of 105 W/m^2 met the objective of achieving a 3.0 log reduction credit for *Cryptosporidium*. The set line for a 3.0 log reduction credit for *Cryptosporidium* is shown in Figure 2. This set line was based on the following set points:

Set Point 1 – 50 gpm; 82 W/m^2
Set Point 2 – 75 gpm; 89 W/m^2
Set Point 3 – 100 gpm; 105 W/m^2
Set Point 4 - 175 gpm; 105 W/m^2

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.

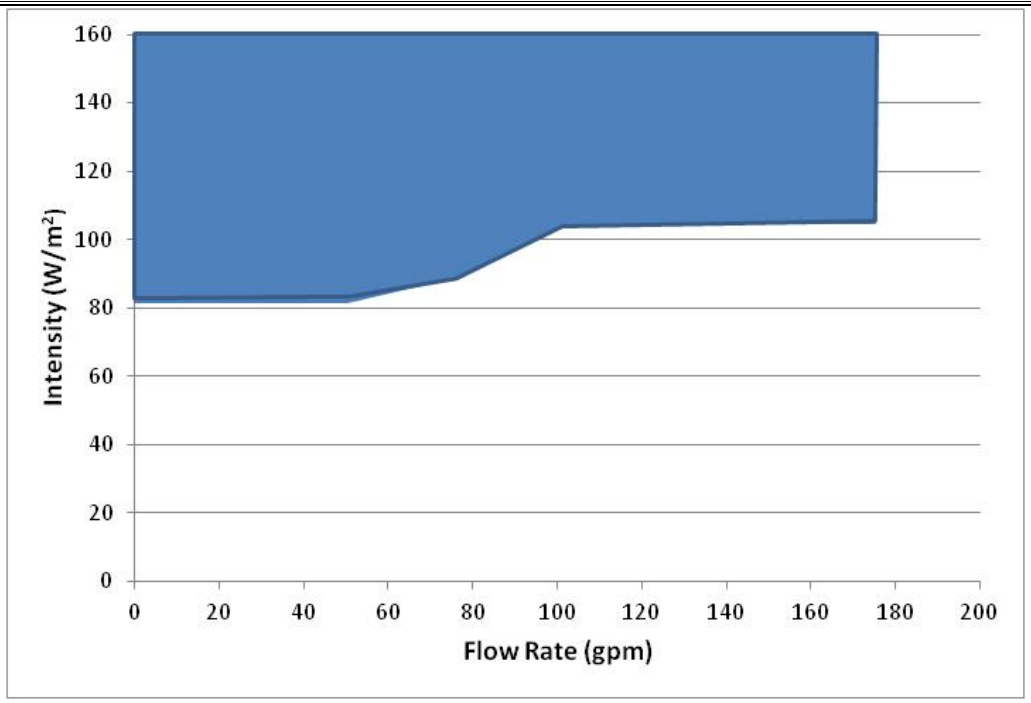

Figure 2. Set Line for Minimum 3-log *Cryptosporidium* Inactivation for ETS UV *Model ECP-113-5*.

Original signed by Cynthia Sonich-Mullin on 01/23/2014

Cynthia Sonich-Mullin Date
Director
National Risk Management Research Laboratory
Office of Research and Development
United States Environmental Protection Agency

Original signed by David Purkiss on 01/16/2014

Date
Vice President
Water Systems
NSF International

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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