THE ENVIRONMENTAL TECHNOLOGY VERIFICATION PROGRAM

U.S. Environmental Protection Agency

NSF International

ETV Joint Verification Statement

TECHNOLOGY TYPE:	**ULTRAVIOLET DISINFECTION**
APPLICATION:	**DISINFECTION OF SECONDARY EFFLUENT**
TECHNOLOGY NAME:	**LPX200 UV DISINFECTION SYSTEM**
COMPANY:	**SUNTEC *environmental*, Inc.**
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NSF International (NSF) manages the Water Quality Protection Center (WQPC) under the U.S. Environmental Protection Agency's Environmental Technology Verification (ETV) Program. The WQPC evaluated the performance of the SUNTEC *environmental*, Inc. (SUNTEC) LPX200 UV Disinfection System (LPX200) for use with secondary wastewater effluent at UV transmittances of 55 and 65 percent. HydroQual, Inc. (HydroQual) performed the verification testing.

The U.S. Environmental Protection Agency (EPA) created the ETV Program to facilitate 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 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 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 verifiable quality are generated and that the results are defensible.

Technology Description

The following description of the technology was provided by the vendor and does not represent verified information.

The LPX200 uses high-output, low-pressure ultraviolet (UV) lamps, oriented horizontally and parallel to the direction of water flow. Each lamp has a UV output rating of approximately 68 W at 254 nm and a total power draw of 210 W. The lamps have an effective arc length of 162.6 cm. The quartz sleeves are test-tube type, with one sealed end and an outer diameter of 23 mm. The sleeves are composed of Type 214 clear fused quartz with a wall thickness of 1.50 mm, resulting in a UV transmittance of approximately 90 percent. SUNTEC supplies the UV lamps in modules that can be linked together to form systems based on the design flow requirements.

The lamp modules supplied for the verification test consisted of two columns of five lamps each. Two modules were mounted parallel in the channel for a 20-lamp, 5 by 4 matrix configuration. The resulting lamp array had a uniform lamp spacing of 8.9 cm. Each lamp had a dedicated electronic ballast that was enclosed in a round, stainless steel housing at the head end of the quartz sleeve assembly and was submerged in the wastewater for cooling. Each lamp module was equipped with an automatic sleeve cleaning system designed to simulate its effect on the hydraulic behavior of the standard module assembly. In accordance with the testing protocol, the wipers were not actively operational during the verification testing, and the sleeves were cleaned manually before each flow series.

The LPX200 system was controlled with the standard Power Distribution Center (PDC) computerized control. The PDC system, enclosed in a NEMA 4X enclosure, had a user interface and display and contained a control card (microprocessor) that monitored individual lamp status, elapsed time, and detector inputs for controlling the disinfection process. The power supply to the system was 120/240V single-phase AC. The PDC contained Lamp Rack Control Modules (LRCM). Each LRCM controlled five ballasts and was interfaced with the control card, to allow adjustment of lamp ballast power from 60 to 100 percent.

The LPX200 modules were housed in a 6.5 m long, open, stainless steel channel. The effective disinfection zone was approximately 0.36 m wide and 1.62 m long. The channel was fitted with a 1.07 m square influent approach box with a flow diverting baffle, a 2.4 m straight approach before the UV reactor, and a 1.0 m straight exit after the reactor and before the weir. An automatic level control gate regulated the water level in the channel with a pivoting weight system that operated over a wide range of flow rates.

Verification Test Description

Test Site

The test site was located at the Parsippany-Troy Hills Wastewater Treatment Plant (PTRH) in Parsippany, New Jersey. The test site had two, 80,000-Liter tanks for preparation of challenge water and a 71 hp centrifugal pump to provide challenge water to the LPX200 at flow rates up to 7,600 L/min or recirculation flow rates of 1,100 L/min for mixing in the tanks. Flow to the LPX200 was metered using a magnetic flow meter, which was calibrated before testing using the tank drawdown method.

Methods and Procedures

All methods and procedures followed the *ETV Verification Protocol for Secondary Effluent and Water Reuse Disinfection Applications* (protocol), dated October 2002. The LPX200 was tested under Element 1, dose delivery verification of the protocol for secondary effluent at transmittances of 55 and 65 percent.

HydroQual installed the LPX200 at the test site in conjunction with SUNTEC. Before dose delivery verification testing began, the lamps were aged for 100 hours to allow the lamp intensity to stabilize. One lamp was replaced during the initial startup before burn-in. The burn-in period spanned five days, during which the lamps were not turned off or restarted. There were no further lamp failures.

Power consumption for the LPX200 system was measured separately from the dose delivery tests. The power measurements included: (1) overall power consumption, as measured by a kilowatt-hour meter connected to the main power supply; (2) power consumption after the power was stepped down through the transformer; and (3) discrete power readings of voltage, current, and power to each of the four ballast boards.

Headloss measurements were determined by monitoring the channel depth at seven locations that were spaced before and after the LPX200. Hydraulic behavior of the LPX200 was also characterized using a UV absorbing tracer to perform the step-feed tracer method.

The microorganism, MS2, an F-specific RNA bacteriophage, was used for all bioassay tests. The dose-response calibration of the MS2 stock batch and seeded influent samples was achieved using a collimated beam apparatus.

Before each flow test series, the lamp racks were lifted from the channel, manually cleaned, and inspected. The lamp racks were returned to the channel and kept on overnight at 100 percent power with water flowing. The lamps were turned down to the target intensity (end-of-lamp life) of 70 percent by adjusting the control panel and were allowed to stabilize for a minimum of 30 minutes. Finally, the wiping system was manually activated for one cleaning cycle to remove any accumulated debris or lint and to ensure that the wiper assembly was returned to its proper, idle position.

A batch of challenge water was prepared immediately before each flow test series by filling the tank with potable water and adding sodium thiosulfate to remove residual chlorine. Once onsite testing verified the absence of residual chlorine, instant coffee was progressively added to reduce the transmittance to the target level of either 55 or 65 percent. Finally, MS2 bacteriophage was added to the tank to achieve the target level of 10^5 to 10^7 pfu/mL, and the tank was mixed for 30 minutes. Flow testing was conducted by pumping the water through the channel at the specified flow rate with the lamp intensity set at the simulated end-of-lamp life condition of 70 percent. Each of the five flow conditions was replicated at least four times for each transmittance tested. Flow rates for the 55 percent transmittance test were 379, 757, 1,890, 3,030, and 4,160 L/min**.** Two runs were also made at 5,680 L/min. Flow rates for the 65 percent transmittance test were 757, 1,890, 3,030, 4,160 and 5,680 L/min.

Influent and effluent samples were collected simultaneously and in triplicate, resulting in six samples for each flow test. The concentration of viable MS2 bacteriophage in flow test and dose-response samples was enumerated using a microbiological technique based on ISO 10705-1. Transmittance of the challenge waters was measured on every influent sample and on the seeded influent samples used for dose-response analysis. Quality assurance/quality control (QA/QC) requirements included field duplicates, laboratory duplicates and spiked samples, and appropriate equipment/instrumentation calibration procedures. Details on all field procedures, analytical methods, and QA/QC procedures are provided in the verification report.

Verification Performance

Power Consumption and Headloss Results

The power consumption of the SUNTEC system was monitored while operating at the 100 percent power setting, which represents the unit's maximum power consumption level. Power consumption measured at the 480 V three-phase service was 4,860 W; power consumption at the 120/240 V supply was 4,560 W.

This indicates a transformer and transmission efficiency of 94 percent. The total power draw of the four LRCMs was 4,360 W. (The additional 200 W represents power consumed by the enclosure heater and other circuitry in the control box.)

Headloss though the lamp modules exists at any non-negligible flow rate, arising from the hydraulic resistance of obstacles such as lamps and mounting hardware. In ideal, turbulent systems, the headloss increases as a function of the square of flow velocity. For the LPX200 system used in this test, the headloss (cm) as a function of flow velocity (cm/s) is approximated by the relation:

$$headloss = 3.91 \text{ X } 10^{-4} \, (velocity)^2 + 0.0242 \, (velocity) + 0.475$$

The headlosses were measured in the range of velocities used for the bioassay validations in this verification. They cannot be extrapolated to different velocities or channel configurations. The flow velocity through a full-scale system must be determined before these headloss data can be applied.

The hydraulic parameters derived from the step-response behavior of the SUNTEC unit were within accepted engineering limits, as determined by five typical methods of analyzing the tracer data. These methods are detailed in the verification report. One exception was for the ratio of mean residence time to theoretical residence time for the higher flow rates. However, additional parameters representing the mean detention time were well within accepted limits, and the detention times were generally within accepted limits. While these data showed no evidence of short-circuiting or significant dead spots, it is important to realize that the tracer test was conducted in the central part of the lamp array. Non-idealities in the water flow near the channel walls would not have been identified in these tests.

Dose-Response Calibration Curve

Thirteen, valid, dose-response tests were conducted during this verification test. The delivered doses were corrected for 2.5 percent reflectance at the surface of the sample. The calibration curve for the MS2 bacteriophage stock was:

$$Dose = 1.6191(survival)^2 - 12.782(survival) + 1.6009$$

$$survival = Log_{10}\left(\frac{N}{N_0}\right)$$

$N_0 = \text{MS2 concentration in undosed sample}$

$N = \text{MS2 concentration in dosed sample}$

The calibration curve was validated using QC criteria for the acceptance of the dose-response data based on statistical analysis of MS2 dose-response data from several independent labs. The dose-response data generated for this verification test met the established criteria.

Dose Flow Assays

Demonstrating the effective delivered dose for a specific UV system's reactor is the technical objective of the protocol. The delivered dose for a specific UV system is the UV dose providing the equivalent degree of inactivation of a target pathogen as measured with a collimated-beam apparatus. The collimated beam apparatus can accurately monitor the UV intensity that reaches the fluid as well as the exposure time to an organism. Therefore, the MS2 bacteriophage log survival ratios measured on samples from the field, and presented in the final report for the LPX200 reactor, are converted to an effective delivered dose using the calibration curve from the dose response data. MS2 bacteriophage is used for the testing as it has a high tolerance for UV light, typically requires a larger delivered dose for inactivation than most bacterial and

viral organisms, and has a consistent dose-response over repeated applications. This allows development of dose-response and delivered dose relationships that encompass dose levels required for most disinfection applications. The calculated, effective, delivered dose is used to design a UV reactor for a specific application, based on site-specific criteria for inactivation of a target microorganism.

As described in the protocol, the final analysis of the test flow data is based on the lower 75 percent confidence interval (C.I.) results. The results for the 20-lamp system are shown in Figure 1, where they are fitted with a power function. For comparison, the average dose delivery curve is also shown, and it tracks closely with the lower 75 percent C.I curve.

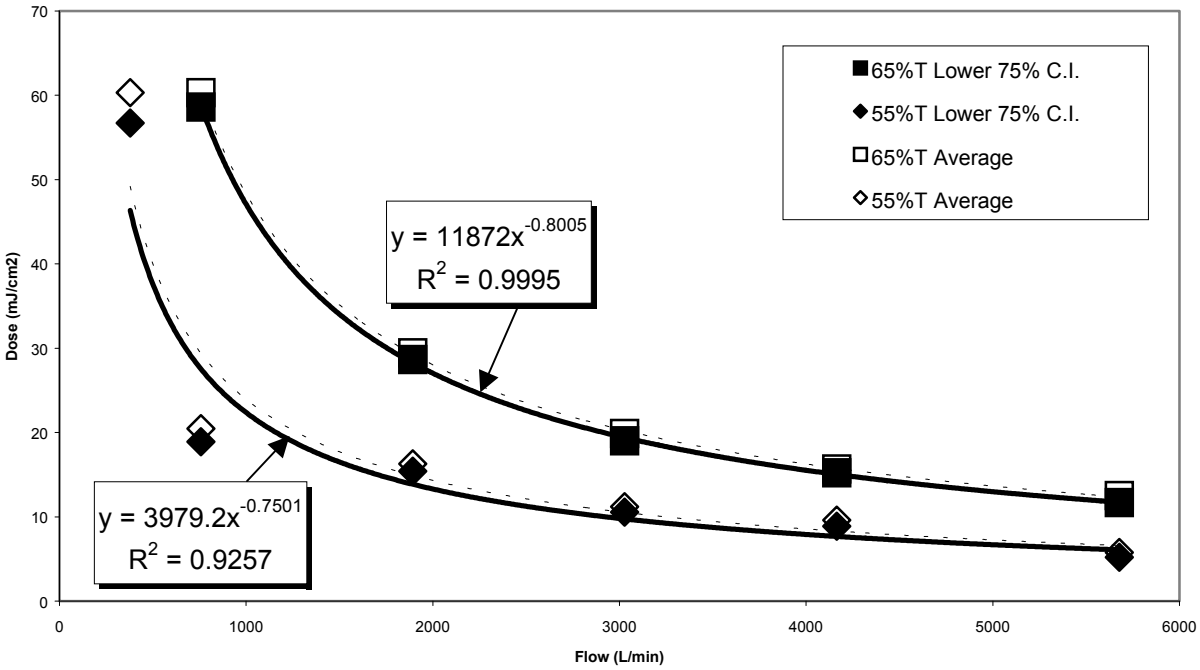

Figure 1. Dose Delivery Curves Based on Lower 75 Percent Confidence Intervals.

A second approach to understanding the dose delivery in the LXP200 is to relate it to lamp power. The power used in these calculations was for lamps at full power at the end-of-lamp life (70 percent). The data were rescaled and the relationship of flow per unit of power consumed (L/min/kilowatt) to the average dose delivery was determined using a power function. The relationships derived for the end-of-lamp life at 55 and 65 percent transmittance are:

For 55% Transmittance: $power\ usage(L/\min/kW) = 11163(dose)^{-1.2341}$

For 65 % Transmittance: $power\ usage(L/\min/kW) = 28721(dose)^{-1.2485}$

An alternative way to view the results from these dose delivery verification tests is to normalize the dose delivery to L/min per lamp. This allows a potential UV disinfection system user to estimate the number of lamps that would be needed for a certain application. The data are analyzed in the same manner as in Figure 1, except the vertical (y) axis is rescaled to reflect the hydraulic loading per lamp. The relationships derived for the end-of-lamp life for 55 and 65 percent transmittance are:

For 55% Transmittance: $hydraulic\,loading\,(L/\min\,/lamp) = 2422.3(dose)^{-1.2341}$

For 65 % Transmittance: $hydraulicloading\,(L/\min\,/lamp) = 6134.8(dose)^{-1.2485}$

Further discussion on these equations is included in the verification report.

Scalability

The protocol identifies the elements of UV system design that are critical for designing larger systems based on the data obtained from the verification. The appropriate data for these design elements were obtained during the verification and are reported in detail in the verification report. The report also provides a further discussion on application of the data.

Quality Assurance/Quality Control

NSF performed QA/QC audits of the test site at PTRH and HydroQual during testing. These audits included: (1) a technical systems audit to assure the testing was in compliance with the test plan, (2) a performance evaluation audit to assure that the measurement systems employed by HydroQual were adequate to produce reliable data, and (3) a data quality audit of at least 10 percent of the test data to assure that the reported data represented the data generated during the testing. In addition to quality assurance audits performed by NSF International, EPA QA personnel conducted a quality systems audit of NSF International's QA Management Program, and accompanied NSF during audits of the HydroQual facilities.

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Availability of Supporting Documents

Copies of the *ETV Verification Protocol for Secondary Effluent and Water Reuse Disinfection Application*, dated October 2002, the Verification Statement, and the Verification Report are available from the following sources:

ETV Water Quality Protection Center Manager (order hard copy)
NSF International, P.O. Box 130140, Ann Arbor, Michigan 48113-0140

NSF web site: http://www.nsf.org/etv (electronic copy)

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

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