**THE ENVIRONMENTAL TECHNOLOGY VERIFICATION PROGRAM**

**U.S. Environmental Protection Agency**

**NSF International**

# ETV Joint Verification Statement

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| TECHNOLOGY TYPE: | **ULTRAVIOLET DISINFECTION** | |
| APPLICATION: | **DISINFECTION OF GRANULAR OR FABRIC FILTERED EFFLUENT AND MEMBRANE FILTERED EFFLUENT FOR WATER REUSE** | |
| TECHNOLOGY NAME: | **AQUARAY® 40 HO VLS DISINFECTION SYSTEM** | |
| COMPANY: | **ONDEO DEGREMONT, INC.** | |
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NSF International (NSF) operates the Water Quality Protection Center (WQPC) under the U.S. Environmental Protection Agency's (EPA) Environmental Technology Verification (ETV) Program. The WQPC evaluated the performance of the Ondeo Degremont, Inc. (ODI) Aquaray® 40 HO VLS Disinfection System for disinfection of granular or fabric filtered secondary wastewater effluent and for membrane filtered secondary wastewater effluent, for water reuse applications. HydroQual, Inc. (HydroQual) performed the verification test.

The 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 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, 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 is provided by the vendor and does not represent verified information.

The Aquaray® 40 HO VLS system uses high-output, low-pressure, mercury discharge lamps, oriented vertically and perpendicular to the direction of flow. Each lamp has an ultraviolet (UV) output rating of approximately 52 watts (W) at 254 nm and a total power draw of 165 W. The lamps have an effective arc length of 146.7 cm. Each lamp is housed in a clear, fused quartz sleeve to isolate and protect the lamp from the wastewater. The sleeves have one open end, which is exposed only to the conditions in the sealed stainless steel ballast housing. The quartz sleeves are 170.2 cm long, have an outer diameter of 24.4 mm, and a wall thickness of 1.26 mm, resulting in a UV transmittance (UVT) of approximately 90%.

The test system consisted of three Aquaray® 10 HO VLS modules in series, with 10 lamps per module, mounted inside a baffled, rectangular frame. The lamps were positioned in a staggered rectangular array with centerline spacing of 7.14 x 12.7 cm to duplicate one-fourth of the Aquaray® 40 HO VLS full-size unit, which holds 40 lamps. Each electronic ballast, mounted vertically on top of the modules, powered two lamps in parallel. The ballasts were rated for 165 W of electrical power per lamp so that one lamp failure would not cause the peer lamp to turn off. A separate circuit powered each lamp module so the failure of one lamp module would not deactivate the other modules. The ballast control panel did not allow for lamp power dimming, as it is part of the ballast specification to keep the lamp power steady during fluctuation of supply line voltage. The control cabinet was powered by a 480-volt (V) delta power supply and had separate circuits for each lamp module, a dedicated power supply for the sensor amplifiers, and three digital displays showing the real time voltage output. The UV sensors used in the test system were identical to those supplied in commercial systems.

The test modules were not equipped with a sleeve cleaning system, or the ODI patented air scrub used with commercial systems, because a validation test was not planned for this cleaning system. The wiper drive rod was present on each test module to simulate related headloss and hydraulic behavior.

The reactors were housed in a 7.9 m long, open, stainless steel channel. The untreated water entered the channel through a 30.5 cm wide by 2.13 m high section. A baffle, located 0.46 m from the water inlet pipe, spread the flow over the submerged cross-section of the channel. At 0.92 m from the front of the channel, the width was reduced from 30.5 cm to 17.78 cm, and the height of the channel decreased from 2.13 m to 1.83 m. The first test module was located 1.06 m downstream of the channel narrowing. The space between each test module was 0.60 m, the same space as in full-scale commercial systems. At a distance of 1.06 m from the final lamp unit, the channel width increased to 30.5 cm; the height remained at 1.83 m. The flow in the influent channel had additional flow stabilization from a mixer with a 3-bladed impeller that operated at 350 rpm.

**Verification Test Description**

***Test Site***

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

***Methods and Procedures***

All methods and procedures followed the *ETV Verification Protocol for Secondary Effluent and Water Reuse Disinfection Application* (protocol), dated October 2002. The Aquaray® 10 HO VLS system was tested under Element 1 of the protocol, Dose Delivery Verification for Reuse Applications, for granular or fabric filtered effluent at a nominal transmittance of 55%, and for membrane filtered effluent at a nominal transmittance of 65%.

Before dose delivery verification testing began, the lamps were aged for 100 hours to allow the lamp intensity to stabilize. During the burn-in period, the lamps were not turned off or restarted. There were no lamp failures during the burn-in period.

Power consumption for the test unit was measured at two positions in the power distribution system. The single-phase 240 V power supply to each lamp module was measured for two hours during the lamp stability test. The total power consumption of the system was measured during the burn-in, shakedowns, and all flow tests.

Headloss measurements for five flow rates were determined by monitoring the channel depth at five locations, spaced before and after the three modules. The hydraulic characterization of the Aquaray® 10 HO VLS module included the measurement of flow-velocity fields at four positions along the channel length. Each flow field consisted of a 2 by 13 matrix of monitoring positions. The flow field was measured in triplicate for the five flow rates, providing 1,560 velocity measurements.

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 modules were manually cleaned and inspected. The modules were placed back in the channel, water was allowed to flow, and the lamps were turned on to verify all lamps were operating.

A batch of challenge water was prepared immediately before each flow test series by filling the tank with either potable water (65 percent transmittance (%T) tests) or filtered secondary effluent (55%T tests), 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. 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. Five flow conditions (568, 1,325, 1,703, 2,082, and 2,839 L/min) were replicated at least four times for each transmittance. The system was tested using a three-module configuration for the 55%T and 65%T tests. The 55%T test was repeated using a two-module configuration (by turning off the third module).

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 Aquaray® 10 HO VLS module was measured at the 480 V, three-phase power supply (total service power) and at the individual module 240 V, single-phase power supplies. Total power consumption for the three-module system, which included power use by the auxiliary circuitry in the control panels and the slight loss of power through the step-down transformer, was 5,260 W. The discrete power measurements taken at the 240 V, lamp-module power supply showed a power consumption of 166 W per lamp, which was very close to the 165 W per lamp specified by ODI.

Headloss through the lamp modules exists at any non-negligible flow rate, due to the hydraulic resistance from obstacles such as lamps and mounting hardware. In ideal, turbulent systems, the headloss increases as a function of the square of flow velocity. The headloss (cm) as a function of flow rate (L/min) for the three-module Aquaray® 10 HO VLS module used in this test is approximated by the relation:

$$headloss\ (cm) = 5.69E\text{-}08\ (flow\text{-}L/min)^2 - 3.87E\text{-}04\ (flow\text{-}L/min) + 6.02E\text{-}01$$

The headlosses are measured for the flow rates used in this verification, and are dependent on the channel configuration and the number of reactor modules. The basis and assumptions for direct extrapolation of headloss through the test modules to a full-scale Aquaray® 40 HO VLS system is provided in the verification report.

The protocol required the influent flow velocities to be between 0.8 and 1.2 of the theoretical value. The data show that the influent velocity profile at all flow rates had a significantly non-uniform character, while the three downstream positions had velocity profiles that were quite uniform and well within ±20% of the theoretical flow rates. The average velocity at the influent position was consistently low, due to the inlet geometry of the test system, which introduced a large-scale rolling motion in the influent to the channel. This caused low (or negative) velocities at the bottom and higher velocities at the top. The Aquaray® 10 HO VLS test system design did not attempt to idealize the influent hydraulic characteristics of the system used for this verification. Based on the dose delivery data, the non-uniform influent velocity did not degrade the performance of the Aquaray® 10 HO VLS system.

***Dose Response Calibration Curve***

Thirteen, valid, dose-response tests were conducted during this verification test. The delivered doses were corrected for 2.5% reflectance at the surface of the sample. The calibration curve for the MS2 bacteriophage stock, using a second-order polynomial equation, is:

$$Dose = 1.4822(survival)^2 - 15.063(survival) - 0.1633$$

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

$N_0 =$ MS2 concentration in undosed sample

$N =$ MS2 concentration in dosed sample

The calibration curve was validated using QC criteria for the acceptance of the dose-response data that was 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 that provides 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 reaching the fluid and the exposure time to an organism.

Therefore, the MS2 bacteriophage log survival ratios measured on samples from the field test unit, and presented in the final report for the Aquaray® 10 HO VLS, are converted to an effective delivered dose using the calibration curve from the dose-response data. MS2 bacteriophage is used for the testing because 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 flow test data is based on the lower 75% confidence interval (C.I.) results. The results for the two-module and the three-module test systems are shown in Figure 1, where they are fitted with a power function. For comparison, the average dose delivery curves are also shown, which track closely with the lower 75% C.I. curve.

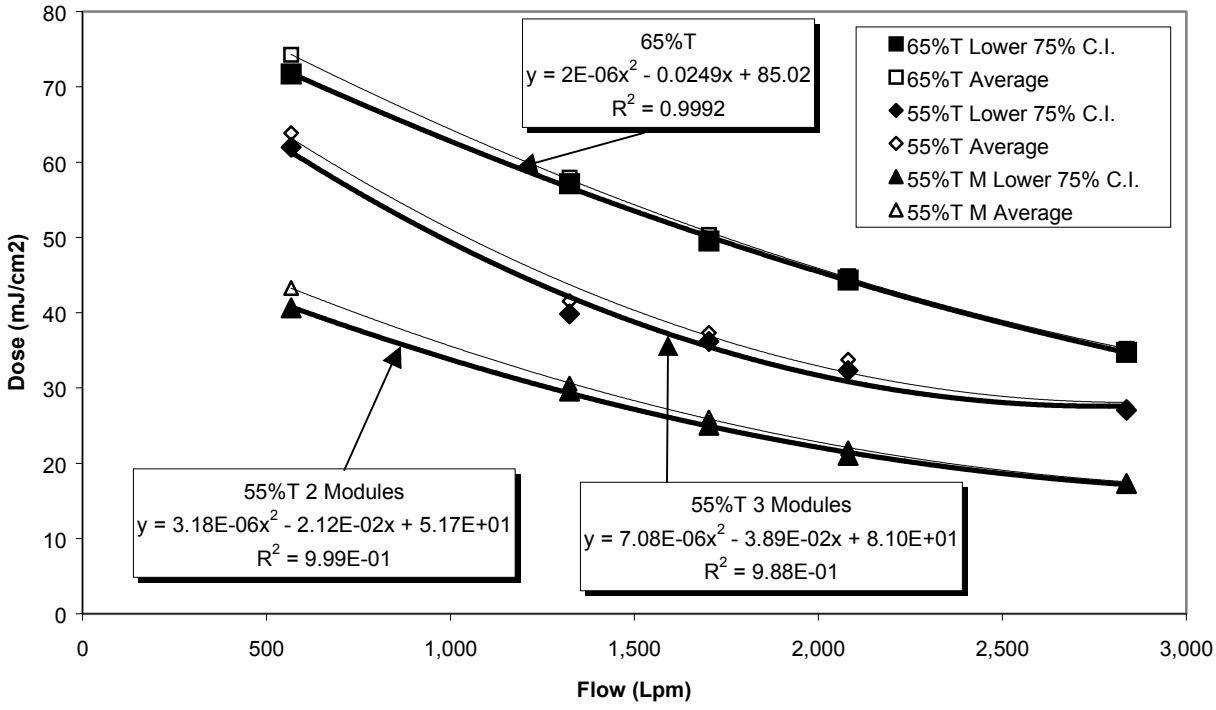


**Figure 1. Dose Delivery Curves Based on Lower 75% C.I. For Granular and Fabric Filtered Effluent (55%T) and For Membrane Filtered Effluent (65%T)**

***Scalability***

The protocol identified the elements of UV system design that are critical for designing larger systems that are based on the data obtained from the verification. The appropriate data for these design elements

were obtained during the verification testing. The ODI verification test was specifically designed to show that the use of multiple reactor modules produces additive results. The results of the dose-response testing can be used to estimate the dose delivery for different sized systems, using multiple, 40-lamp modules. The verification report provides a detailed discussion on application of the data for larger systems.

***Quality Assurance/Quality Control***

NSF performed QA/QC audits of the test site at PTRH and HydroQual during testing. These audits included: (a) a technical systems audit to assure the testing was in compliance with the test plan, (b) a performance evaluation audit to assure that the measurement systems employed by HydroQual were adequate to produce reliable data, and (c) a data quality audit of at least 10% 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, EPA QA personnel conducted a quality systems audit of NSF'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* (Protocol), dated October 2002, the Verification Statement, and the Verification Report are available from the following sources:

1. ETV Water Quality Protection 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 (electronic copy)
3. 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.)