Biodosimetry of a Full-Scale UV Disinfection System to Achieve Regulatory Approval for Wastewater Reuse

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ABSTRACT

In order to respond to the stringent disinfection requirements for reclaimed wastewater in the United States, Ozonia North America (ONA) undertook a bioassay validation study of a low-pressure very high-output (LPVHO) ultraviolet (UV) disinfection system. The disinfection performance of this process technology was verified via biodosimetry in accordance with the Ultraviolet Disinfection Guidelines for Drinking Water and Water Reuse, 2nd Edition (NWRI/AwwaRF, May 2003). The biodosimetry test program utilized full-scale reactors having 36-lamps with the goal to simplify extrapolation of the results to full scale design. Dose-flow relationships were obtained for both granular media-filtered and membrane-filtered wastewater reuse effluents. Although the influent velocity profiles were non-homogeneous during testing, the performance of the most upstream reactor was not compromised and dose additivity with the number of reactors arranged in series was demonstrated.

Based on the results of this verification testing, the LPVHO UV disinfection system can be sized for wastewater reuse applications using a ratio of target dose to dose delivered per reactor. The bioassay validation report has been submitted to the State of California Department of Health Services for conditional acceptance of the LPVHO UV system for reclaimed wastewater disinfection applications.

Keywords: UV, Wastewater Reuse, Ultraviolet Disinfection, Biodosimetry

INTRODUCTION

Inadequate water supplies and increasing pollution in many parts of the world have become a growing concern during the past quarter century. Several factors have contributed to these problems, including sustained population growth in urban areas, contamination of surface and ground water supplies, uneven distribution of water resources and frequent drought linked to extreme global weather patterns. Through careful engineering and management, wastewater reuse is a viable process to augment traditional water resources (Asano, 2001). Wastewater reuse is most commonly practiced for non-potable water demands such as agricultural use and irrigation for landscapes, public parks, and golf courses. Other non-potable applications include cooling water supplies for power plants and oil refineries. Additionally, reclaimed wastewater may be used indirectly for potable purposes, such as recharging of ground water aquifers to augment ground water supplies and to prevent salt water intrusion in coastal areas (USEPA Region IX, 1998).

Chlorination continues to be the most utilized disinfection treatment for wastewaters. However, the production of carcinogenic disinfection by-products (DBPs) and safety concerns with transportation, storage and handling of chlorine gas have caused alternate disinfection technologies such as UV irradiation to garner increased consideration in recent years. In order to gain acceptance for the UV disinfection technology wastewater reuse effluents, Ozonia North America (ONA) performed an extensive validation testing of a low-pressure very high-output (LPVHO) ultraviolet (UV) disinfection system. This testing was pursued in collaboration with HydroQual, Inc., serving as the third party engineering consultant and field-testing organization. This paper presents the results obtained from this test program.

EXPERIMENTAL

Description of the LPVHO UV Reactor

The LPVHO UV reactor consists of a rectangular stainless steel frame equipped with 36 low pressure amalgam lamps as shown in Figure 1. Each lamp yields a minimum of 160 watts UVC, based on measurements performed in air with an IL 1700 radiometer, SED240 cell, NS254 filter and W-diffuser (International Light, Inc., Peabody, MA). The lamps are oriented vertically in a staggered grid of 6 rows by 6 lamps. A low-profile triangular-shaped side deflector is present for each row of lamps and is located on the side of the reactor where the lamp to wall spacing is greatest.

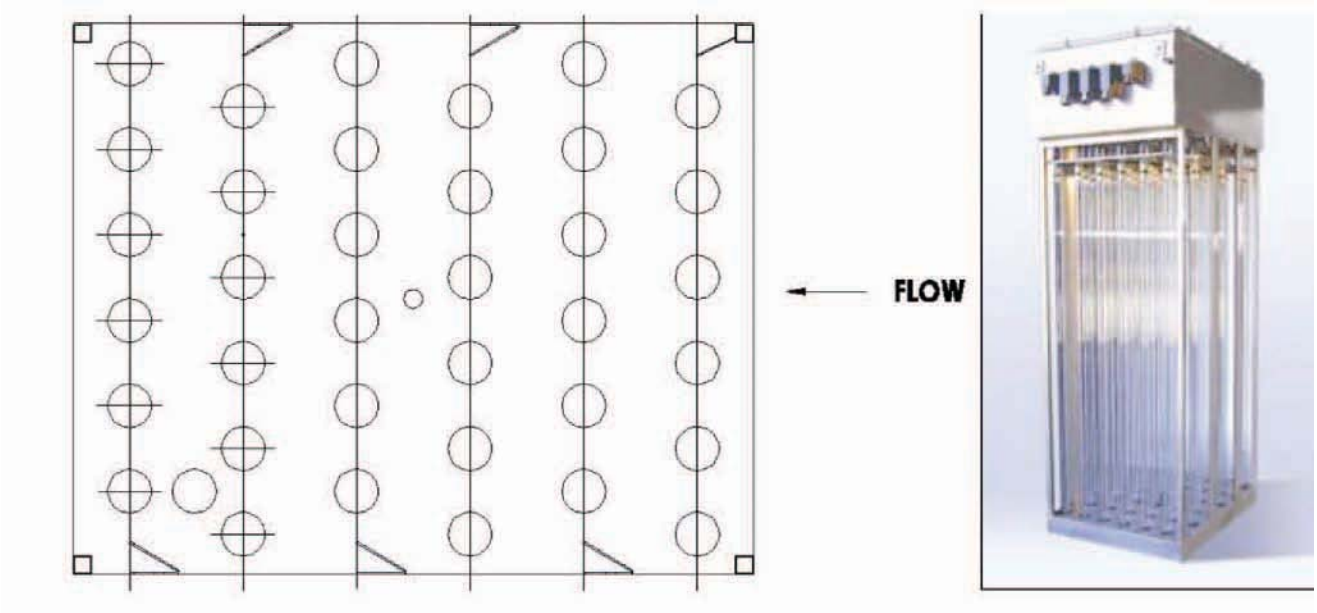

Figure 1. *Lamp arrangement for the LPVHO UV reactor.*

Figure 2 depicts how the reactors of a LPVHO UV system are typically arranged in series, within open concrete channels that may contain up to 4 reactors wide. Once wastewater flows through the reactors in the channels the presence of a staggered lamp array and side deflectors minimizes pathogen shortcircuiting, while preserving a near plug-flow hydraulic behavior.

Validation Approach

Due to an initial lack of regulatory standards and reproducible test methods to assess the disinfection performance of UV disinfection systems, various regulatory authorities in the United States enforced performance validation testing based on biodosimetry. The protocols for the validation test program of the LPVHO UV system

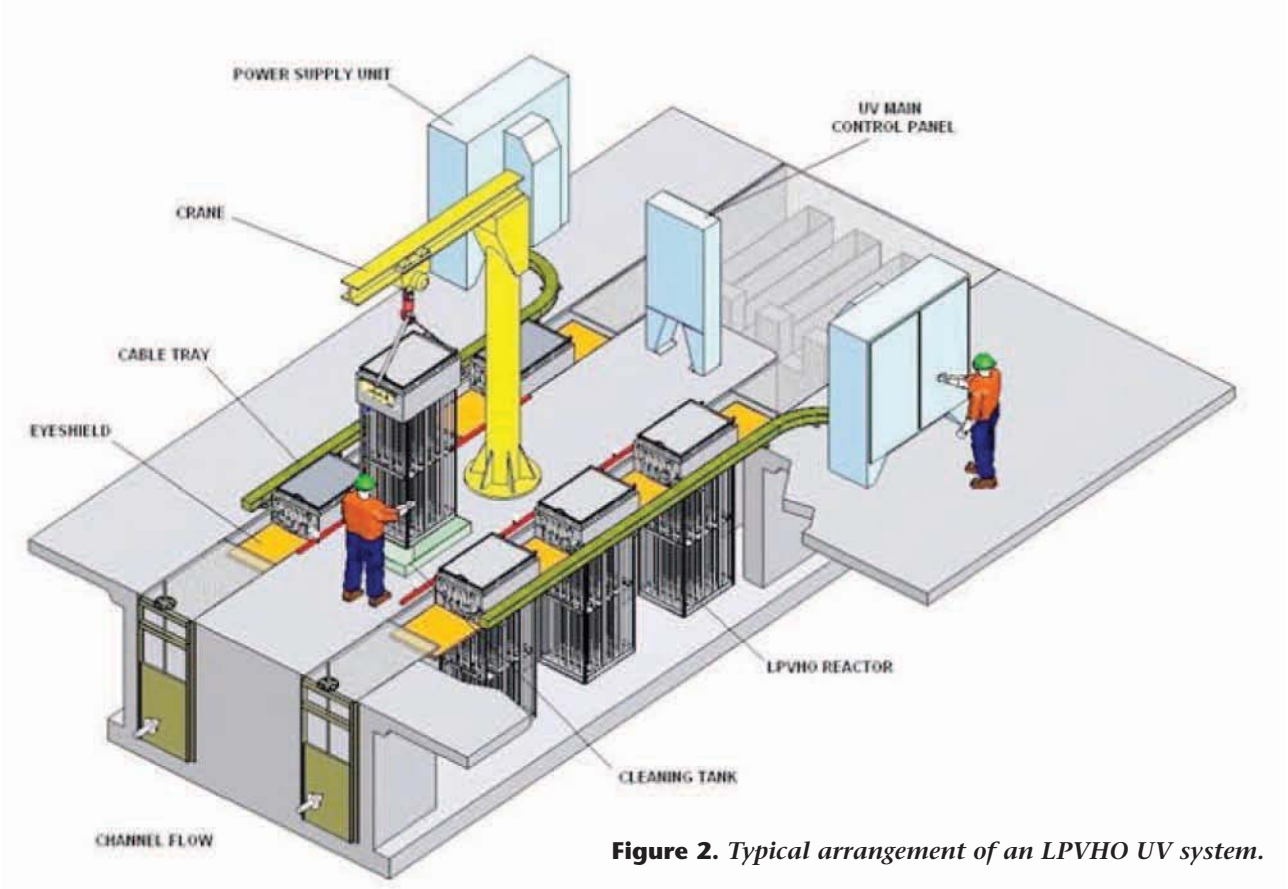

Figure 2. *Typical arrangement of an LPVHO UV system.*

were designed to conform mainly to the "Ultraviolet Disinfection Guidelines for Drinking Water and Water Reuse, 2nd Edition" (NWRI/AwwaRF, May 2003), hereafter referred to as the NWRI/AwwaRF Guidance. Additionally, with modifications that reflect current validation practice, the methods used for this test program generally followed the protocols presented in "ETV Verification Protocol for Secondary Effluent and Water Reuse Disinfection Applications" (NSF, October 2002).

HydroQual, Inc. was utilized as the third party engineering consultant responsible for all field testing and preparation of the final verification report. The overall objective of this validation test program was to validate the disinfection performance of the LPVHO UV system for wastewater reuse applications. Specifically, validation of six key performance criteria were identified as follows,

1) Verify the dose-flow relationship for the system at a nominal UV transmittance (T10) of 65% to simulate membrane-filtered effluent for reuse applications.
2) Verify the flow-dose relationship for the system at a nominal UV transmittance (T10) of 55% to simulate granular filtered effluent for reuse applications.
3) Verify the dose-delivery performance over an operating envelope defined by the system's effective output, flow rate and UVT.
4) Verify the velocity profiles at upstream and downstream locations for both reactors over the full operating range of the system.
5) Establish the power consumption characteristics of the LPVHO UV system and the relationships of power and sensor readings as a function of the water UV transmittance.
6) Determine the head loss through the reactors as a function of the flow and velocity.

Test Equipment

Two full-scale LPVHO UV reactors were arranged in series in an open steel channel 7.6 m (25 ft) long and 0.74 m (29.25 inches) inside width. Figure 3 presents dimensional sketches of the channel. Figure 4 is a photo of the channel, showing placement of the reactors. The sidewalls were 2 m (6.5 ft) tall. Water enters and exits the channel through 610-mm (24-inch) diameter flanged openings, with inverts approximately 2 inches above the channel floor. At the upstream end of the channel, cross bars are positioned downstream of the inlet wall, which were used to brace a flow spreader baffle and various inlet perforated baffle plates. The objective of the baffle plates was to break the inlet water rush and distribute the velocity across the entire channel cross-section, thus more closely simulating open channel configuration with longer, evenly distributed approach

The first reactor (UV Reactor 2) was positioned with the lead edge 1.52 m (5 ft) downstream of the perforated baffle. The spacing between the reactors was 0.91 m (3 ft). An adjustable weir was installed 1.52 m (5 ft) downstream of the second reactor (UV Reactor 1). This weir was used to maintain a constant water depth of 1676 mm (66 inches) at a location approximately 0.6 m (2 ft) upstream of the lead reactor.

Biodosimetry Procedures

All testing for the LPVHO UV disinfection system was conducted at the UV Validation and Research Center of New York (UV Center), located at the Gloversville-Johnstown Joint Wastewater Treatment Facility, Johnstown,

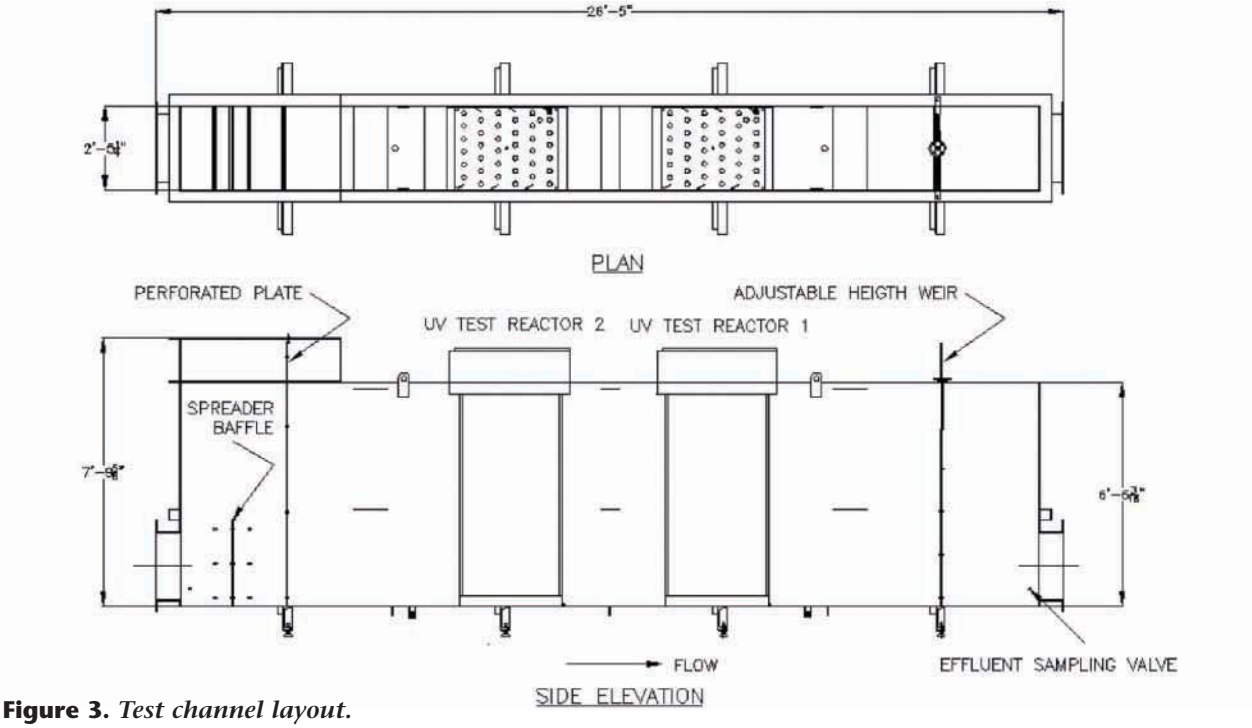

Figure 3. *Test channel layout.*

Figure 4. *Picture of the test channel.*

NY. The UV Center, which is operated by HydroQual, was installed at the plant under the auspices of the New York State Energy Research and Development Authority (NYSERDA), with a portion of the funding from the New York City Department of Environmental Protection (NYCDEP). Direct funding participation is also provided by a number of UV equipment manufacturers.

The facility consists of several functionally similar test stands that are defined by the nominal size of their respective delivery piping. These range from 2-inch through 36-inch, capable of processing flows from very low gpm levels to as high as 45,000 gpm. Figure 5 is an aerial photo of the UV Center. The facility employs several large tanks that are used to prepare source water for challenge testing, or to accept testing effluent for disposal. As highlighted on Figure 5, Tanks 1 and 2 are used for source water storage, with a total capacity of approximately 2 million gallons, and Tanks 3 and 4 for disposal of used water, also with a total capacity of approximately 2 million gallons. Pumps are installed in both Tanks 3 and 4 to transfer the water back to the wastewater treatment facility for final disposal. A battery of 8 diesel centrifugal pumps is used to transfer the test water from the source tanks to the waste tanks through the various test stands available on site.

The test channel location is shown on the schematic of the UV center test facility in Figure 6. It was installed on the 24-inch test stand, fed by up to 2 of the centrifugal diesel pumps. A 24-inch Advanced Flow electromagnetic flow meter is installed, with straight-runs of pipe before and after the meter to assure accurate performance.

A 150-kVA diesel-fired generator was used exclusively for the LPVHO UV system, conditioned as needed. During all testing, the main power was recorded with a three-phase power data logger. All ancillary electrical requirements were provided through local plant feeds.

The bioassay flow-tests were conducted on a mixture of potable water or granular filtered effluent, modified by the addition of lignin sulfonate (LSA) to adjust the UV transmittance, and the direct injection of the MS2 bacteriophage stock to reach a targeted density. The injection point was located approximately 6 feet upstream of the high-efficiency vortex mixer shown on Figure 6. The UV transmittance adjustment of the water was done either on a batch basis by mixing with the tank contents directly, or "on-the-fly" as the feed water was being pumped to the test channel. Transmittance measurements were conducted in 1-cm quartz cuvettes

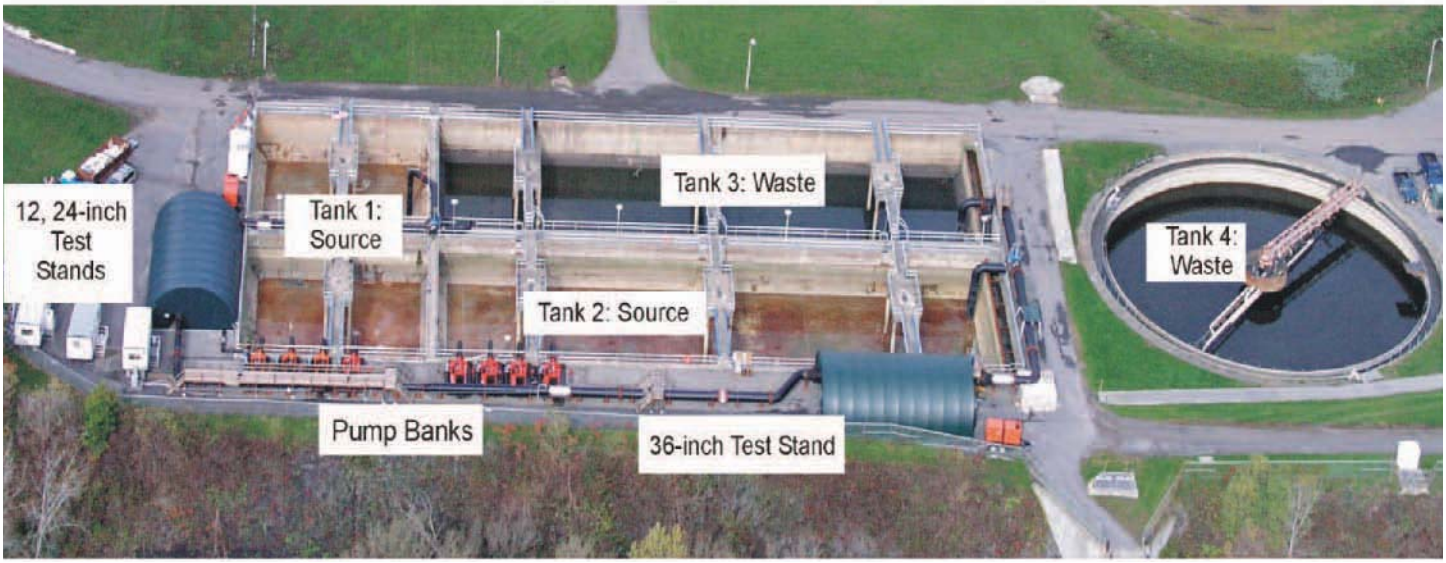

Figure 5. *Aerial view of the UV center test facility.*

with the same cuvette filled with DI water as a reference. All transmittance measurements were conducted at 254 nm with a properly calibrated Gen-Tech Model 1901 double-beam UV/Vis spectrophotometer.

For the flow tests conducted during this validation, Tank 1 was used for staging the challenge water. Before testing, the tank was drained and cleaned. For those tests that were applicable to granular-media filtered (refer to as GMF hereafter) effluents, the tank was charged with cloth-filtered secondary effluent. A potable water supply was used for those tests associated with membrane-filtered (refer to as MF hereafter) effluent applications. In all cases, the water was mixed and dechlorinated with sodium sulfite. After preparing the tank, the water was checked for total chlorine to assure that the concentration was non-detectable at the 0.05 mg/L level.

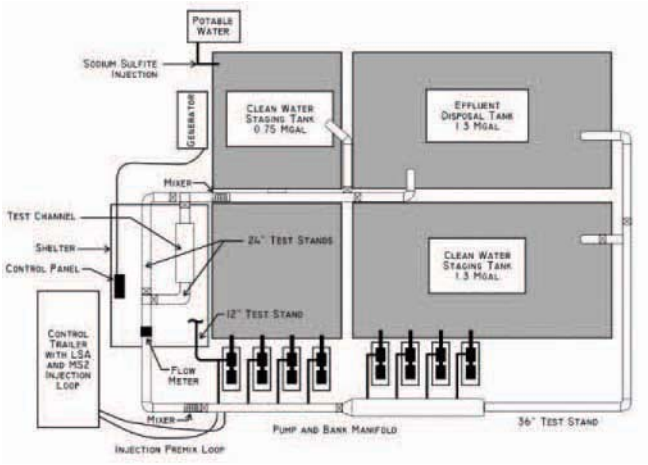

Figure 6. *Schematic of the test facility test stands.*

Grab samples were collected in sterile, 120 mL single-use specimen cups. Influent samples were collected at a valve approximately 20 feet upstream of the channel inlet. Effluent samples were collected at a valve installed on the channel, at the effluent side of the adjustable weir. The valves were allowed to flush freely before samples were collected. Both influent and effluent samples were collected simultaneously and in triplicate, resulting in six samples for each flow test. The samples were placed on ice in a closed (dark) cooler and transported to the lab. Samples were analyzed within 24-hours of collection.

During the test series, large batch solutions of MS2 bacteriophage were prepared with a titer of approximately 1 to 4 x10^{11} pfu/mL. The MS2 was ATCC 15597-B1 and the host *E. coli* strain was ATCC 23631. The propagation procedure was based on an ISO method (ISO, 1995), which was refined to produce the large volumes used in bioassay tests. The enumeration of viable MS2 from samples was based on ISO method 10705-1 (ISO, 1995). The same enumeration process was used for the development of the dose-response curves and for the biodosimetric flow tests to minimize any bias.

or each type of test wastewater (GMF and MF) the LPVHO UV system was validated at four flows per train of 2, 4, 8 and 12 mgd with a "train" defined as a 1-reactor wide channel. For each test flow condition the lamp "effective" output (EO) was set at three different target levels. The lamp EO is defined as the product of the lamp-aging factor (F_P), the quartz sleeve fouling factor (F_t), and the lamp output dimming factor (D_i). Due to the effect of temperature on lamp output, the product of these factors is also adjusted by a temperature factor (TF).

[1] $$EO = F_P \cdot F_T \cdot D_i \cdot TF$$

Within the framework of this validation, the three target EO levels were defined, referenced to a water temperature of 20°C or a TF_{20} of 1.0. The first represents new lamps, clean sleeves, and 100% power input (4.5A lamp current).

[2] $$EO(target) = 1.0 \times 1.0 \times 1.0 \times 1.0 = 1.0$$

Similarly, the second represents aged lamps, fouled sleeves and power dimming to 62% of nominal (2.8A lamp current), hereto at 20°C.

[3] $$EO(target) = 0.85 \times 0.80 \times 0.62 \times 1.0 = 0.42$$

The third level is between the previous two, representing aged lamps, fouled sleeves and 100% power input (4.5A lamp current), normalized to 20°C. This is the more likely design-operating EO for a commissioned LPVHO UV system.

[4] $$EO(target) = 0.85 \times 0.8 \times 1.0 \times 1.0 = 0.68$$

For purposes of this validation, the impact of aged lamps and fouled sleeves were simulated by adjustment of the test water transmittance. The TF_{20} factor was included in this adjustment of transmittance. Before the start of a biodosimetry test run, the test water transmittance is adjusted downward from the nominal UV transmittance as defined by the granular or membrane filtration objectives with Lignin Sulfonate (LSA) until the test EO at a water temperature of T is equivalent to the target EO for a water temperature of 20°C. The following set of equations can be written

[5] $$EO(test) \cdot \frac{I_{avg(UVT)}}{I_{avg(UVT55 or UVT65)}} = EO(target)$$

Where $I_{avg(UVT55\ or\ UVT65)}$ is the average fluence rate (irradiance) in the system at the nominal UV transmittances of 55% (GMF) or 65% (MF). I_{avg} is the average fluence rate calculated at the equivalent attenuation factor. Since the bioassay testing is actually conducted with new lamps and clean sleeves the equation above can be written as follows.

[6] $$1.0 \cdot 1.0 \cdot Di \cdot TF20 \cdot \frac{I_{avg(UVT)}}{I_{avg(UVT55\ or\ UVT65)}} = EO(target)$$

Finally, the required attenuation can be calculated as follows.

[7] $$\frac{I_{avg(UVT)}}{I_{avg(UVT55orUVT65)}} = \frac{EO(target)}{D_i \,.\, TF_{20}} = \frac{F_P \,.\, F_t}{TF_{20}}$$

The UV transmittance reduction from the nominal values of 55% and 65% can be calculated to adjust the reactor nominal average intensity $I^{avg(UVT55or65)}$ by the targeted attenuation: (Fp * Ft) / TF_{20}. The results shown in Table I below are an example of this calculation for Fp = 0.85, Ft = 0.80 and a water temperature T of 12°C. The resulting attenuation is 0.763. A line-source integration software (Janex, 2002) is used to calculate the average fluence rate of the LPVHO reactor for various water UV transmittance.

Table I. *Example of UV transmittance adjustment.*

Transmittance (%T/cm)	I_{avg} (mW/cm²)	I_{avg}x0.763 (mW/cm²)
55	8.465	6.459
46	6.459	
65	11.543	8.804
56	8.804	

Based on these calculations, verification testing was performed at adjusted transmittances. For a water temperature of 12oC and 65% nominal transmittance condition, which simulates MF water per NWRI/AwwaRF guidance, the actual operating transmittance during testing was 56%. For the 55% nominal transmittance, which simulates GMF water, the actual operating transmittance was 46%.

RESULTS AND DISCUSSION

UV Intensity Sensor Characterization

The UV intensity sensor readings obtained from the LPVHO UV reactors were recorded as percentage of full scale 20 madc for different water UV transmittance levels. Figure 7 illustrates the sensor reading as a function of UV transmittance. A power function was observed to provide a good model fit of the results.

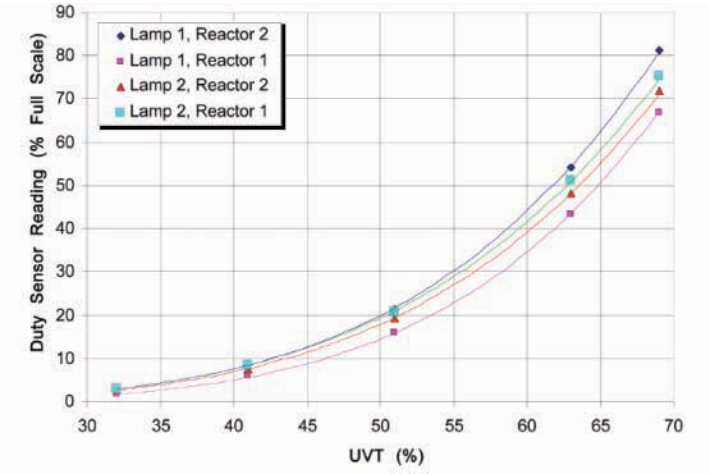

Figure 7. *UV intensity sensor reading as a function of UV transmittance.*

The UV intensity sensor readings at two fixed UV transmittances with different lamp arc current settings are plotted in Figure 8. The normalized sensor readings are expressed as the percentage of the sensor reading at the nominal lamp current of 4.5 A. Readings were fitted using quadratic equations and the fitting parameters were used to determine the lamp dimming factor (D_i), which is used to calculate the lamp "effective" output factor EO.

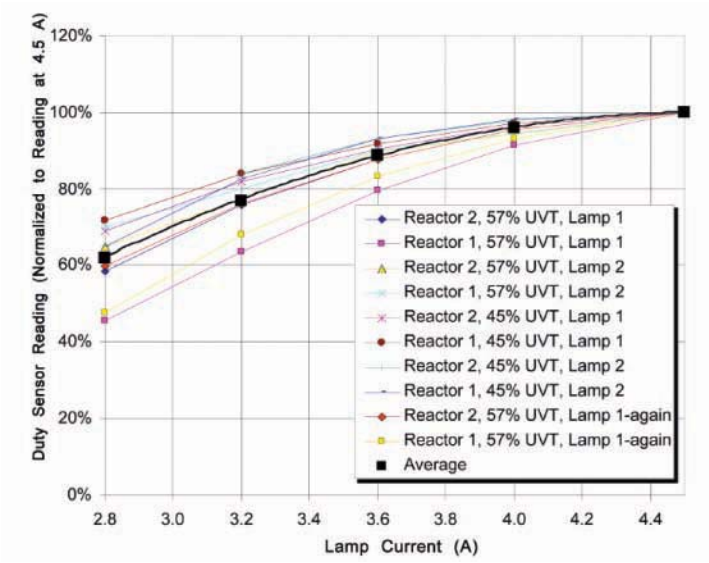

Figure 8. *Normalized UV intensity sensor readings versus lamp current.*

The UV intensity readings obtained from the duty sensors of the LPVHO UV reactors and an IL 1700 SUD 240 (with a 254 filter) reference detector were compared, based on their respective values normalized to their maximum readings. Figure 9 presents this comparison demonstrating the excellent linear agreement observed between the two detectors, suggesting that the UV intensity sensor, which equips the LPVHO UV reactors provides an accurate measure of intensity, and is linearly responsive across their operating range.

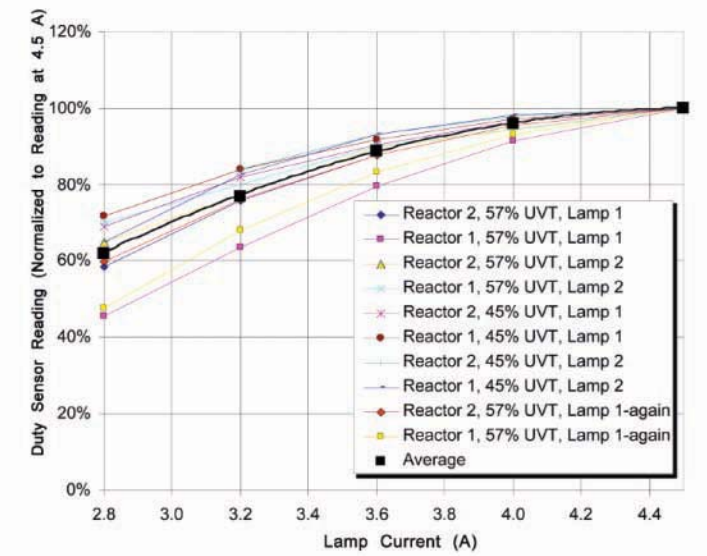

Figure 9. ***IL1700 SUD sensor versus the LPVHO UV intensity sensor.***

Head Loss

Head loss through a UV disinfection system should exist at any non-negligible flow rate, because of the hydraulic resistance due to viscous flow and the presence of obstacles such as lamps, baffles and mounting frame. Head loss measurements were made by attaching staff gages to the inside of the reactor channel wall, approximately 30 cm up- and downstream of the two reactors, and between the reactors. The channel was leveled within 0.5 cm before the start of test. The water level was measured at the three positions for each flow rate, and the head loss estimated as the calculated differences in water level among these three locations. Zero-readings were obtained with no flow through the channel, but with the channel filled with stationary water.

The results are depicted on Figure 10 along with the head loss obtained from CFD modeling to show that the modeled head loss is in agreement with the experimental values.

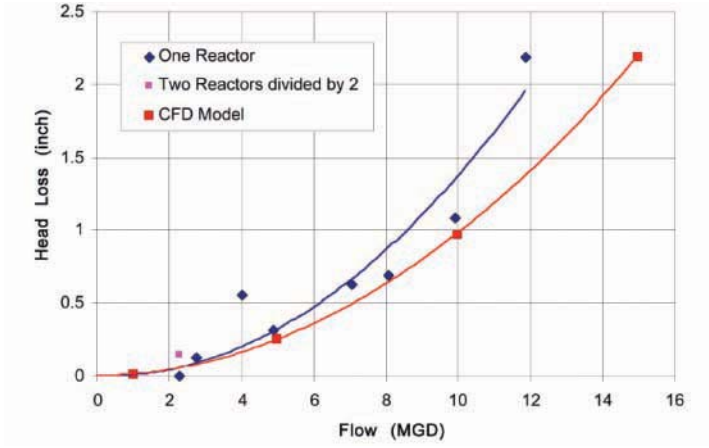

Figure 10. ***Reactor modeled & experimental head loss vs. flow.***

Velocity Profile

The NWRI/AwwaRF guidance mentions that commissioned system should have velocity profiles that are equivalent or better than demonstrated by the validation test unit. A 6 x 13 measurement matrix was designed for the cross-section of the LPVHO UV test channel. These measurements were conducted at flow rates 2, 4, 8 and 12 mgd, upstream of the lead reactor, downstream of the lag reactor and in between the two reactors. A specifically designed frame was used to position the velocity meter at desired location inside the channel. At each location, three readings of flow velocity were recorded. The velocity meter was a Marsh-Mc Birney. Each reading was an integrated average recorded by the meter over a period of 7 seconds.

A general observation is that the velocity profiles were variable and not within a +/- 20% band about the theoretical velocity (flow/area) at all points. As a brief demonstration of the velocity profiling data, Figure 11 is presented showing the average of the horizontal measurements for each depth location with the floor as the zero datum (INF is upstream of UV Reactor 2, EFF is downstream of UV Reactor 1) for flows of 2 and 12 mgd. The average profiles for the three measurement locations are shown, as is the mean theoretical velocity and the +/- 20% band about the theoretical velocity. The non-ideal behavior at the influent to the first reactor is obvious, an artifact of the shortened approach channel length. Even with the baffle in place, the velocity gradients created by the 24-inch inlet pipe to the channel are significantly variable. The most stable profile was evident at the location between reactors, but appeared to become less stable at the effluent location, possibly because of the upflow pattern caused by the level control weir.

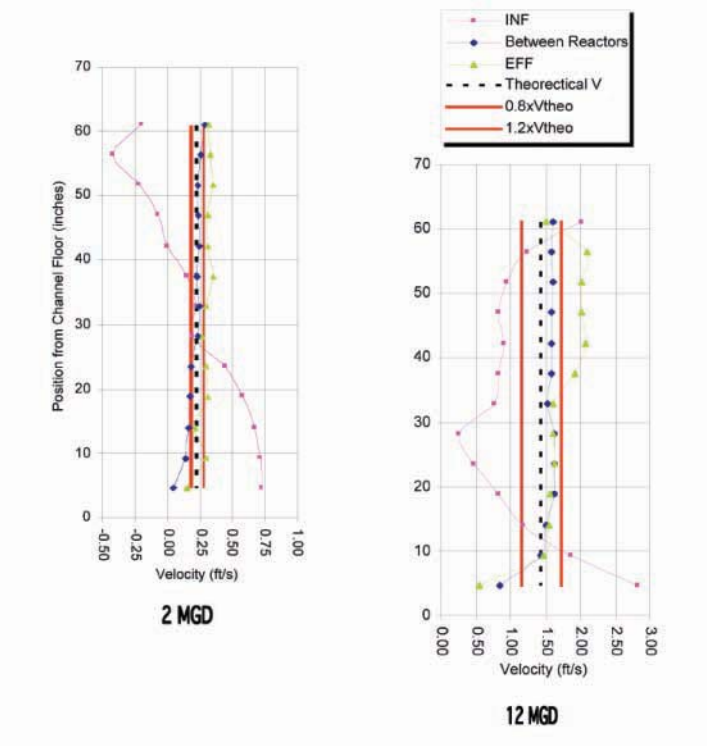

Figure 11. *Flow velocity profile for the LPVHO test channel.*

A key observation that can be made from these data is that the hydraulic conditions represent a 'worse' case when compared to minimum full-scale commissioning requirements. As such, the biodosimetry performance data of the LPVHO UV system tested can be considered conservative.

It is the philosophy of the NWRI/AwwaRF testing program upon which this wastewater reuse verification was designed to simulate worst-case scenario in terms of lamp fouling, lamp intensity, and transmittance for each application. Accordingly, no attempt to idealize the influent hydraulics was made.

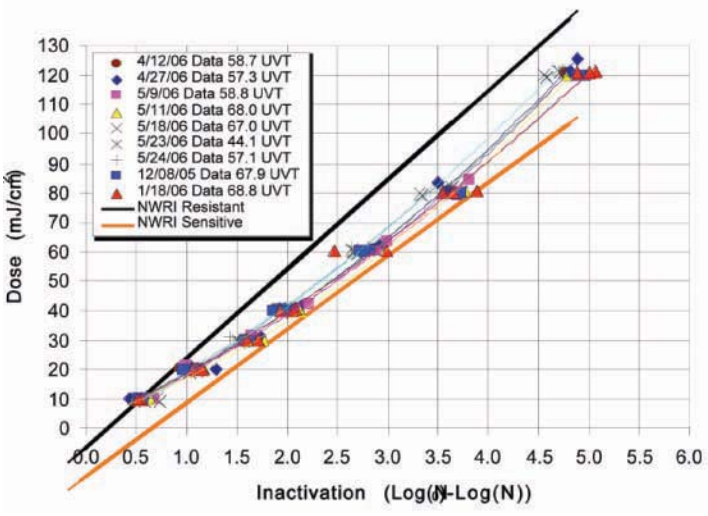

Figure 12. *Summary of dose-response curves and regressions.*

Biodosimetry

Biodosimetric testing for the LPVHO UV system was carried out on seven different dates in the period December 2005 through May 2006. A seeded influent sample from each day was used to develop the dose-response relationship for samples collected that day. These dose-response data are summarized in Figure 12.

Figure 12 shows that 93.4% of the data points lay within the boundary limits referenced in the NWRI/AwwaRF guidance. This is well above the minimum requirement of 80%. In some instances the inactivation ratios at a given dose vary up to 0.5-log. This variability is typical for such microbiological analyses. It highlights the need for several dose-response data sets to enhance the statistical confidence of the dose-response calibration curve.

Biodosimetric tests were conducted for the two types of challenge waters: granular-media filtered (GMF) effluents and membrane-filtered (MF) effluents over the range of flows from 2 to 12 mgd. Three EO target values were tested for each type of challenge water, with duplicates for each testing condition at EO of 0.42 and 1.0, and with triplicates for each testing condition at EO of 0.68. All testing conditions are summarized in Table II.

Table II. *Summary of bioassay flow test matrix.*

Test water	Target EO	Test flow Rates (mgd) 2.0	4.0	8.0	12.0
Granular- Media Filter (GMF)	0.44	GM1-042-2 GM2-042-2	GM1-042-4 GM2-042-4	GM1-042-8 GM2-042-8	GM1-042-12 GM2-042-12
	0.68	GM1-068-2 GM2-068-2 GM3-068-2	GM1-068-4 GM2-068-4 GM3-068-4	GM1-068-8 GM2-068-8 GM3-068-8	GM1-068-12 GM2-068-12 GM3-068-12
	1.0	GM1-10-2 GM2-10-2	GM1-10-4 GM2-10-4	GM1-10-8 GM2-10-8	GM1-10-12 GM2-10-12
Membrane Filter (MF)	0.44	M1-042-2 M2-042-2	M1-042-4 M2-042-4	M1-042-8 M2-042-8	M1-042-12 M2-042-12
	0.68	M1-068-2 M2-068-2 M3-068-2	M1-068-4 M2-068-4 M3-068-4	M1-068-8 M2-068-8 M3-068-8	M1-068-12 M2-068-12 M3-068-12
	1.0	M1-10-2 M2-10-2	M1-10-4 M2-10-4	M1-10-8 M2-10-8	M1-10-12 M2-10-12

A multiple linear regression analysis was developed to correlate the validation RED with the flow rate and the EO value. The resulting dose algorithm equation will be used to size and operate the LPVHO UV system in the field. The data analysis of the validation data was based upon the lower 75% confidence interval result for each flow condition (e.g., flow rate, %UVT), and all subsequent discussion is based upon the 75% confidence interval as well. The dose algorithm equation used to estimate the RED per reactor is expressed as follows:

$$[8] \qquad RED_{per\text{-}reactor} = \frac{1}{2} \cdot 10^{A} \cdot (Flowrate)^{B} \cdot (EO)^{C}$$

With A, B and C the regression coefficients.

Validation REDs are plotted against the regression fit model as illustrated in Figure 13 for MF water. The residuals between the predicted REDs and the validation

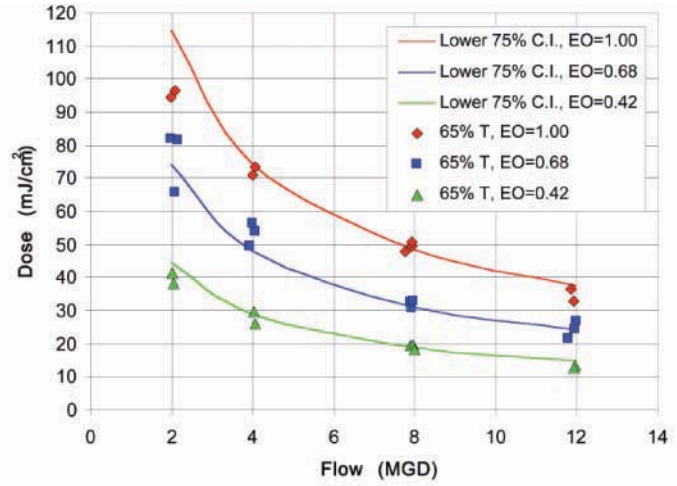

Figure 13. *RED versus flow rates for MF effluent versus model prediction.*

REDs for both GMF and MF effluents are scattered around zero and show no significant trend with either of the three variables supporting the validity of the regression fit model.

The dose-flow curves obtained tend to flatten as the flow increases showing improved disinfection efficiency at higher velocities. As flow increases, the axial mixing resulting from the staggered lamp array and side deflectors enhances the number of microorganisms traversing areas of intense UV irradiance

Evaluation of the Additive Nature of Downstream Reactors

Part of the operational philosophy of the LPVHO UV system is based upon the application of a multiple-reactor train to meet the dose delivery requirements of a reuse application. Additional rows of lamps in the train are brought online as disinfection requirements increase due to increased flow rate or to decreased transmittance. Thus, one of the goals of this verification test was to evaluate the dose-additive nature of downstream reactors.

One flow test was conducted with two reactor installed but only the most downstream unit operating. The validation result for this test was compared with those that were tested with two reactors and the same flow conditions, as summarized in Table III. The validated REDs for these tests demonstrated that the dose delivered by the LPVHO UV system is proportional to the number of reactors installed. Additionally, it can be inferred from the results that the non-homogeneous inlet velocity profile did not compromise the performance of the most upstream reactor.

Table III. *Evaluation of dose delivery as a function of # of reactors installed.*

Test Date	Eff. Type	Flow (MGD)	UVT (%)	I_{DR} (amps)	EO (test)	Inactivation log (N_o/N)	# of Reactors	RED (mJ/cm^2)
4/27/2006	MF	2.09	67.9	4.5	0.94	4.049	2	96.62
5/11/2006	MF	1.97	66.4	4.5	0.94	4.102	2	94.53
12/8/2005	GMF	2.00	67.9	4.5	0.90	2.370	1	48.35

CONCLUSIONS

Completion of this verification testing program enabled the determination of the disinfection performance of a full-scale LPVHO UV system in accordance with the *Ultraviolet Disinfection Guidelines for Drinking Water and Water Reuse, 2nd Edition* (NWRI/AwwaRF, May 2003). Use of the NWRI/AwwaRF protocol ensured that the verification testing was carried out in a consistent and objective manner, with appropriate quality control.

The influent velocity profiles measured with the test equipment were non-uniform, however this did not compromise the performance of the most upstream reactor. Accordingly, the verification revealed that the dose delivery is additive with the number of reactors in a train. Based on the verification of dose additivity with the number of downstream reactors, the RED values found during biodosimetry can be converted to a dose delivery per LPVHO UV reactor, and readily used in commercial system sizing.

The LPVHO UV system was tested at full-scale to validate the dose delivery of the commercial units, with the objective of minimizing the need for any scale-up adjustments or considerations. Overall, with the perforated baffling arrangements at the head end of the channel, in lieu of an extended channel length approach, the hydraulic conditions imposed during testing are considered "worse case" when compared to typical commissioned installations. As such, commissioning considerations can center on verifying hydraulic characteristics such as the velocity profiles and head loss, and dose-delivery expectations do not require scaling from the validation tests.

The results from this bioassay validation testing have been submitted to the State of California Department for conditional acceptance of the use of the LPVHO process in reclaimed wastewater disinfection of filtered wastewater for water recycling.

REFERENCES

Asano, T. 2001. "Water From Wastewater – The Dependable Water Resource", Paper presented at the 11th Stockholm Water Symposium, August 12-18, 2001, Stockholm, Sweden.

International Standards Organization (ISO). 1995. *Water Quality-Detection and Enumeration of Bacteriophage. Part I: Enumeration of F-Specific RNA Bacteriophage*. (Switzerland: International Standards Organization, ISO 10705-1).

Janex M.L., Nace A., Do-Quang Z. 2002. "UV Fluence Rate Evaluation in a UV System: Simulating the Impact of Operating and Design Parameters", Paper presented at the 2002 annual AWWA show in New Orleans, USA.

National Water Research Institute (NWRI) and American Waste Water Association Research Foundation (AWWARF), 2nd edition. 2003. *Ultraviolet Disinfection Guidelines for Drinking Water and Water Reuse*. (Fountain Valley, California).

NSFI. 2002. ETV *Verification Protocol for Secondary Effluent and Water Reuse Disinfection Applications*. (Prepared for NSF International and the U.S. Environmental Protection Agency under the Environmental Technology Verification Program).

US EPA Region IX. 1998. "Water recycling and Reuse: The Environmental Benefits". EPA Publication, EPA 909-F-98-001.