UV VALIDATION FOR WASTEWATER APPLICATIONS: IS A UNIFORM PROTOCOL POSSIBLE?

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ABSTRACT

With the release of the USEPA Ultraviolet Disinfection Guidance Manual (USEPA, November 2006), the protocols for UV reactor performance validation reached a new level of standardization and acceptance. This paper addresses the concept of a uniform protocol for wastewater applications, including reuse, secondary effluents and low grade wet-weather flows, modeled after the UVDGM and encompassing existing wastewater protocols published by NWRI and the USEPA ETV program. The suggested approach would allow for validation over a prescribed operating range (flow, UVT, power, etc.) as defined by the manufacturer, rather than assign a specific application. The protocol would introduce flexibility with respect to surrogate selection, include the use of chemical actinometry with dyed microspheres, and emphasize the operating strategy of the system (intensity setpoint and calculated dose control). Credit for validated performance would address experimental variability and the accuracy of key system and experimental measurement components. The overall intent of this effort, which is underway, is to provide a modern, updated protocol that can be used universally and be accepted in the owner, design and regulatory communities.

Key Words: UV disinfection, treated wastewaters, reuse, validation protocols, surrogates

A number of verification and validation protocols exist that address the performance of UV systems designed for disinfection of drinking waters and treated wastewaters. An effort is underway that will attempt to unify these protocols, first focusing on those that deal with treated wastewater application, using the recently released UVGDM as a model template.

CURRENT VERIFICATION PROTOCOLS

First, let us briefly review the status of current protocols.

1. USEPA UV Disinfection Guidance Manual (UVDGM) (November 2006)

The UVDGM had been in development for nearly 5 years, and was released in final form in November 2006. Formal drafts were released for comment in June 2003 and January 2005, and updates were given limited distribution in December 2005 and April 2006 – these drafts were used for validations of systems for the past several years. This document is expected to become the primary validation protocol reference for drinking water applications. It is less prescriptive than the European protocols, and provides for flexibility in testing, while establishing QA goals that have to be met for acceptance of test results, and which can affect the RED accreditation for the targeted pathogens. Additionally, it offers alternative testing and analysis approaches for different operating/dose-control strategies, and suggests a multivariate regression analysis to establish the variability/uncertainty associated with a test program. There is global interest in the UVDGM, with national agencies citing the document and its validation requirements within their regulatory framework.

Regulators are expecting to require UVDGM validation on systems offered within their jurisdiction. Such testing has been underway at both validation centers in the United States (Portland OR and Johnstown NY) since 2003, generally for dose-control systems; the validation reports attempt to meet current UVDGM data analysis requirements, or, at minimum, report field data that will allow for credited RED or log inactivation analysis under the final UVDGM. New validations will necessarily follow the UVDGM protocols in order to attain inactivation credits for the targeted pathogen.

Although directed to drinking water validations, the UVDGM validation protocol has raised the standard for the concept itself – it is comprehensive and flexible, has undergone substantial peer review and regulatory input, essentially becoming the industry standard for validation. We strongly believe that it serves as the

basis, in format, methods and data analysis techniques, for a uniform protocol across all water/wastewater applications.

2. NWRI/AwwaRF UV Design Guidance for Reuse and Drinking Waters (2003)

This protocol (along with the ETV protocols discussed below), remain the only formally recognized test methods for wastewater-related applications. Since development of the first protocol, a new NWRI/AwwaRF edition has been published (2003) and there is some indication that this will undergo a second revision in the near future. We are seeing interpretations of verification reports (non-ETV) that suggest that the NWRI/AwwaRF guidance is leaning more to the approaches found in the UVDGM. Specifically, these include limits to the degree of replication needed, and the use of multiple linear regression modeling to assess the data, determine dose-delivery as a function of operating variables and establish uncertainty factors based on the MLR analysis. Scaling is accepted, and commissioning validated systems is addressed by hydraulic checks. New work suggests alternate approaches to commissioning a system, verifying expectations from the validation tests.

3. USEPA Environmental Technology Verification Program (ETV)

The UV-related verifications within the ETV program are administered through NSF International, Ann Arbor MI. Within the ETV program, there are four verification protocols:

A. ETV: UV Disinfection of Reuse Waters

This verification protocol is designed to mimic very closely the NWRI/AwwaRF protocols for drinking waters and reuse waters (NWRI/AwwaRF, 2000). The second edition of the NWRI/AwwaRF (2nd Edition) was released in 2003; the only validation modification addressed the size of the system to be tested – the new version allows testing of one reactor instead of a minimum of two reactors in series. It contains the basic approach to validate dose-delivery performance at alternate transmittance levels, representing varying levels of treatment prior to UV (granular filtration, membrane filtration and RO), and adds separate protocols for verifying specific system design and operational claims, including lamp aging and fouling attenuation factors, and velocity profiles.

B. ETV: UV Disinfection of Secondary Effluents

This is very similar to the Reuse ETV, except that it requires incorporating tracer analyses to verify hydraulic characteristics, and establishes different default attenuation factors than suggested by the Reuse ETV. Strictly followed, these differences mean additional testing (and expense) to yield data that are still within the operating range of the Reuse ETV. The differences are more an artifact of existing practice (and past tests) than due to any technical justification. Additionally, the secondary protocols rely on MS2 testing, which is now considered inappropriate for such "low-dose" applications.

C. UV Disinfection of Wet Weather Flows

This was written after extensive stakeholder input and review, and subsequent modifications once vendors committed to conducting such tests. It requires testing in three phases, addressing dose-delivery under specific UVT conditions in a non-particle matrix, then in a primary effluent matrix, and, finally, verification of the units' cleaning mechanism. These are similar to the Reuse/Secondary effluent protocols, except that the testing phases are required in combination and are not separated as independent optional ETVs.

D. UV Disinfection of Drinking Waters

Different than NSFI's Standards, such as Standard 55, for small POU/POE UV units, the ETV program has a verification protocol for application to drinking waters. These are generally intended for systems larger than the POU/POE units covered under Standard 55. The first versions were limited in scope, generally verifying delivery of a targeted single dose at rated design conditions. It is our understanding that NSF International, at its 2003 stakeholders meeting, decided to craft a new protocol that is based on the

USEPA's UV Disinfection Guidance Manual (UVDGM). This is not in place, possibly because the UVDGM has been in draft form and has itself undergone significant modifications. The final UVDGM is now available (USEPA, November 2006).

3. Other Validation Protocols

Other widely recognized protocols exist that influence the industry:

A. DVGW (Germany)

This protocol was recently updated in 2003. It is very prescriptive, and is directed only to verification of intensity setpoints for system dose control. Because of its limited nature, it has not been used extensively outside of Germany. Testing by this protocol is generally done at a facility in Germany

B. ONORM (Austria)

Similar to the German protocol, this is protocol finds limited use outside of Europe, with testing done at a facility in Austria.

UNIFIED PROTOCOL

There have been legitimate concerns regarding dissimilarities between protocols and their expense. With the release of the final EPA Guidance Manual for drinking waters, the evolution of the validation concept has reached a point where we believe we can reach some unity in the approach that validation protocols can use, leaving the details of their implementation with a well-designed test plan and QA guidance. This unified protocol could eventually be applicable to both wastewater and drinking water. At this point we suggest that we focus on the wastewater protocols, since the UVDGM will essentially be the standard for drinking water, even from a regulatory standpoint. To this end, we are suggesting that a generic Wastewater UV Disinfection protocol be developed, based primarily on the NWRI/AwwaRF, ETV and UVDGM protocols, and structured in a fashion similar to that of the UVDGM.

The approach we are taking is to:

- First review and summarize the protocols in the context of the UVDGM.
- Draft an extended outline for new wastewater protocol, based on the comparisons to the UVDGM, and on testing methods that reflect current approaches to validation.
- Subject the draft outline to critical review within the industry.
- Reflecting comments/editing suggested by reviewers, complete first draft will for critical review.
- Once this first draft has been reviewed and a second draft prepared, the second draft will be distributed to a broader stakeholder group.

The final protocol is expected to be completed by the the fall of 2007.

At this point, based on our knowledge and understanding of the ETV, NWRI and UVDGM protocols, we anticipate reconsideration and adjustment of the following elements in developing the generic, uniform protocol for wastewater validation:

1. Use the UVDGM format (contents and context, outline and checklists) as the format for the proposed protocol.
2. Eliminate Directed UV Protocol specific to UV application (reuse, secondary, wet weather, etc.). The individual test plans written for a validation can address meeting specific requirements (e.g., Title 22); the protocol itself should focus on the procedures – and accommodate the wide range of water quality (as expressed by the UVT) expected for wastewater applications (e.g., 20 to 80% UVT). The manufacturer will determine the application and the operating range for its specific system.
3. Separate the protocols dealing with dose performance (the primary focus of this effort) lamp output attenuation, fouling attenuation and cleaning device efficacy. .This is not the case in the ETV wet-weather protocol. Additionally, these ancillary protocols should be updated – this is not currently the focus of this effort, but can be after it is completed. In particular, work and documents that have been under development by others should be reviewed and brought into these updates.
4. Particle impacts can be studied separately and specific to an application. The ETV for wet-weather flows requires testing in a primary effluent matrix to assess the impact of particles. This is influenced by the characteristics of the wastewater used for the tests, which limits its application as a generic verification. We propose eliminating this from the validation protocol. Rather, a protocol can be written (as a separate option) to develop dose-response relationships in the laboratory for a particular site application, addressing the effect of particle size (by fractionation, or serial filtration) on performance.
5. By making the different tasks independent, a manufacturer can choose one or more in the conduct of a validation. From a practical standpoint, the dose performance validation would be done separately (inclusive of technical testing that normally accompanies such a validation) because it generally requires larger systems and the testing can be done in a matter of weeks. The other validations require different setups and timeframes and can be done on a smaller scale.
6. Additionally, the test matrix should encompass an expanded operational envelope for dose-delivery testing, reduce the degree of replication and support a

valid multivariate regression analysis. The verification should allow for flexibility in developing the test matrix – a manufacturer may choose to verify performance in a targeted UVT range, instead of the specific targets (e.g., 40% for wet weather or 65% for secondary) suggested in the current protocol. These steps bring this protocol closer to the "unified" goal, allow for more cost-effective validations, and give the manufacturer flexibility in setting the design operating range for verification.

7. Remove replication of dosimetry runs as a requirement, leaving the requirement to collect a minimum of three influent and three effluent samples with each test event (an "event" being defined as the collection of the inf/eff samples at a prescribed set of unit operating and water quality conditions – flow, power, number of lamps, UVT, etc.). This allows for a broader spectrum of operating conditions, instead of expending budget on test repetitions. At the user's discretion, replication can be added to the test program, with the benefit of reducing the uncertainty of the regression analysis. California has allowed this, conditioned on the collection of quality, low-variability test data. Data across a wider, or more varied, test matrix, will support the MLR approach, and gives the vendor a more "marketable" verification report.

8. Incorporate the reactor operating strategy into the design of the test plan for a specific reactor. This would follow the UVDGM approach, which specifically discusses test matrices for sensor-setpoint and dose-algorithm strategies. As such, smaller systems would typically be evaluated in the simpler setpoint approach, while larger systems that have dose-control (or are required to have dose control and readout) would be tested over a broad operating envelope. Such flexibility recognizes the diversity of commercial systems.

9. Adopt the UVDGM dose-response collimated beam protocol as a standard through all test ranges. This simply updates all protocols to the latest standard – it is more rigorous, and has specific methods for analyzing the data generated by the collimated beam test. It would also assure that there is uniformity across all applications and among laboratories.

10. Quality control limits for the dose-response curves should be updated. NWRI and the UVDGM show such limits for MS2; the UVDGM for B. subtilis. New surrogates that are in use should also have data developed to support such an assessment. T1 and QB are examples.

11. Unify the attenuation factors. Default factors can be adopted for the different lamp technologies, with the flexibility to adopt factors that have been demonstrated through a documented alternative study. Derivation and application of these factors would be made consistent throughout all applications (this is not the case, for example, when comparing the reuse and secondary ETV protocols). Validations typically combine the two to a single attenuation factor, defined by the vendor. This typically becomes important when the setpoint approach is used. It is not necessarily an issue when evaluating the dose-control strategy, except to assess the sensor intensity as a function of power and/or UVT.

12. Incorporate intensity-power-UVT tests into the protocol. This serves as very useful design and operating data for validated RED estimates. From these, one can estimate the level to which lamps and or fouling can deteriorate before RED performance goals are affected.

13. Sensors are critical elements of any reactor design, especially for drinking water reactor applications. The UVDGM approach for evaluating UV sensors is suggested – making this consistent through all applications. Design guidance, outside of the validation protocols, will set standards with respect to the number of sensors that should be installed in a reactor – the validation protocol should only assess the responsiveness of these sensors and their variability relative to reference sensors. QA limits, as incorporated in the UVDGM, would be used across all applications.

14. Eliminate the hydraulic tracer analysis requirements found with the current secondary effluent ETV protocol. Its use is outdated.

15. Add the multiple linear regression (MLR) approach to the protocols for analysis of the biodosimetric test data developed in the field. This is an important feature of the current version of the UVDGM and is a preferred approach with reuse applications. This technique allows one to design the test matrix rationally, and provides a correlation of the RED as a function of the unit operating parameters, such as UVT, power, banks/modules, flow, etc. Examination of the uncertainty of the correlation (developed on the basis of the variability of the observed data about the regression line) can establish the lower confidence levels, and the credited RED. This approach can use a manufacturer's dose algorithm; the verification would simply establish the variability of the observed data about the predictive relationship.

16. Low-dose alternative challenge microbes should be readily allowed. MS2 validations are effective for RED levels greater than about 30 mJ/cm2. This has led to issues when validating at lower doses. The UVDGM addresses this with application of an RED bias, which accounts for differences that might occur in a hydraulically inefficient reactor when the targeted microbes (such as Crypto, E. coli, Giardia, fecal coliforms) are more sensitive to UV than the challenge microbe. As described in the UVDGM, if there is no independent, direct measurement of dose-distribution in a reactor, one can apply the "RED bias" as an uncertainty factor. Alternately, use a test surrogate that is

closer in sensitivity to the targeted pathogen or pathogenic indicator (e.g., use T1 for low dose secondary effluents). This should be addressed across all protocols, and should provide for using a more sensitive organism than MS2, or demonstrate independently the actual dose-distribution within the reactor.

17. Establish the same QA goals as the UVDGM across all applications. These specifically relate to flow meter calibrations; sensor variability relative to references; variability of the collimated-bean, dose-response data; radiometer calibrations; and spectrophotometer calibrations. Additionally, there are normal field and lab QA/QC analyses relating to field, trip and lab blanks, and variability among influent and effluent sample sets.
18. Flexibility for Challenge Microbe Selection. This should be allowed across all applications. There is considerable new work that has been done on different challenge microbes, including investigations into high dose surrogates. Although choices will likely focus on current favorites, such as MS2, T1 and Q-beta coliphage, the protocols should allow the flexibility to respond to new, acceptable organisms.
19. Incorporate dose-distribution measurement by dyed microspheres. This method is relatively new and can be considered demonstrated (Blatchley, et.al., 2006a and 2006b, Shen and Scheible, 2007). It uses fluorescent actinometry to determine the dose delivered to individual particles injected into the feedstream. By measuring thousands of such particles, one can determine the dose-distribution within a reactor. This is a critical parameter that is specific to a reactor's hydraulic behavior and intensity field. Applying dose-response kinetics determined from collimated beam measurements allows one to estimate the delivered dose for any targeted organism. Establishing a protocol for the dyed microspheres approach would advance the technology, and provide a potentially cost-effective method for validating a system.

Additional elements can be identified and discussed. The objective, however, is to introduce and incorporate a commonality to the protocols. Eventually, this will result in a testing protocol that simply addresses the operating range for a particular UV reactor design. From this validated operating range, one can decide the application on a site-specific basis. For example, if a vendor designs a system that is meant to operate in a UVT range of 40 to 65%, it may have applications relating to wet weather flows (stormwaters), secondary effluents or reuse waters. Using the format of the UVDGM will allow for a better understanding of the protocols and encourage a greater uniformity as we move forward. We also anticipate that this protocol would be adopted under the ETV program as an option to the manufacturer.

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