Pathogen Specific UV System Sizing for Wastewater and Reuse – "Best Fit" Design Without the Pilot

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ABSTRACT

Extensive validation testing, which considers a large validation envelope, and which is in line with existing guidelines, now offers the utility and design engineers an economical and accurate design approach.

Research findings have illustrated that pathogens differ significantly in their dose response curve to UV (UV sensitivity (DL)). Accordingly, challenge microorganisms used during validation testing should display inactivation profiles similar to the actual target pathogen(s). For highest precision and a "best fit" design, a collimated beam test (CBT) can be run with the site specific wastewater to establish a dose response curve, DL, and log inactivation for a site-specific target pathogen. Site specific, precise dose delivery can then be calculated by entering these values into a sophisticated validation formula using the DL approach.

No matter whether wastewater reuse or discharge, with a UV system design based on the DL approach, a best fit design can be achieved saving capital as well as operational costs without risking permit violation and public health.

1. INTRODUCTION

Ultraviolet (UV) radiation is a proven disinfectant and is the preferred method of disinfection of potable and reuse water. While accepted for wastewater disinfection, early open channel UV system designs were generally based on a calculated dose approach. This approach assumes ideal flow and UV intensity distributions, and does not reflect actual real system performance, risking permit non-compliance. On the other hand, assuming a set of conservative design parameters, while ensuring adequate performance for permit compliance, often resulted in an overdesigned system.

Qualified extensive validation testing in line with existing guidelines that applies a set of operational parameters spanning a validation envelope including a minimum of 2 different surrogates now offers the utility and design engineers an economical and accurate design approach: The so called DL approach for UV system validation and project specific design.

MATERIALS AND METHODS

As demonstrated in Figure 1 UV sensitivities are highly variable by species and the site specific wastewater conditions. This actually impacts the UV dosage requirements per log of pathogen inactivation.

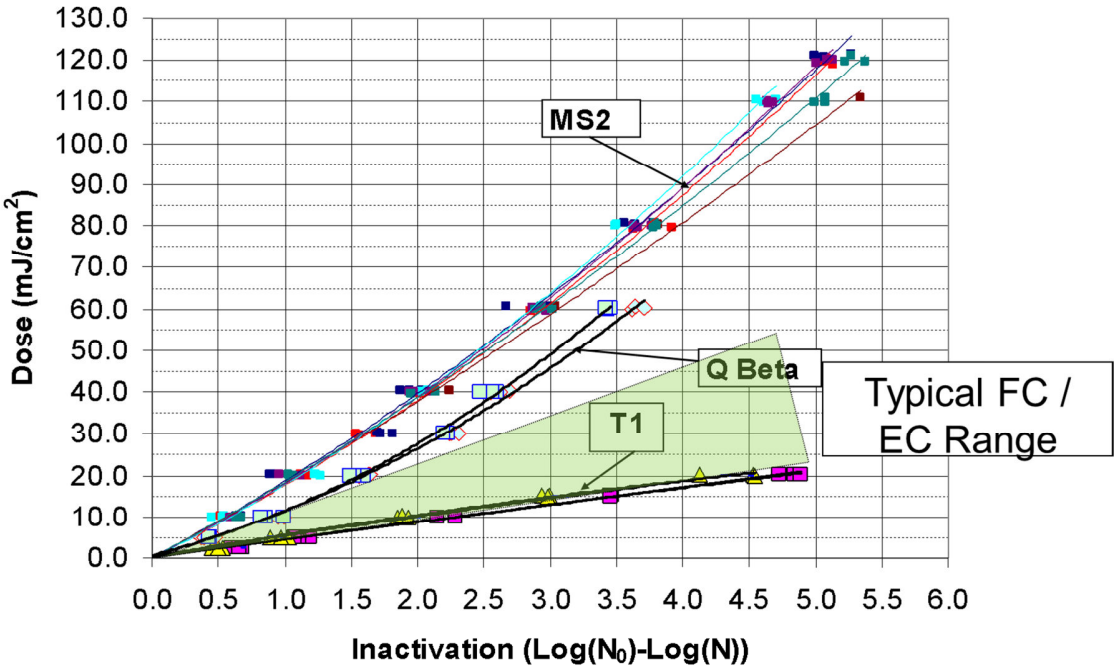

Figure 1: Range of UV sensitivities by type of surrogate

The original thought that testing with a more resistant organism (e.g. the well established MS2 phages) would represent a conservative design, has proven wrong due to non-ideal dose distributions of real life UV systems. In fact, the opposite is the case causing the risk of overestimation of UV system performance when the challenge organism is more resistant to UV light than the target pathogen.

Following the above reasoning, the UV Disinfection Guidance Manual (UVDGM, 2006) defines the “RED bias” as a correction factor that accounts for the difference between the UV sensitivity of the target pathogen and the one of the challenge organism [1].

To account for such differences, Xylem Water Solutions under the 3rd party oversight of Carollo Engineers validated their latest new open channel UV wastewater product Duron using a particular large validation envelope that included four different surrogates, a wide range of UVTs and flow rates as well as performance data assessment of 1 - 4 UV banks in series. Validation data was analysed according to different established validation protocols including the latest NWRI Ultraviolet Disinfection Guidelines for Drinking Water and Water Reuse (2012) and the most comprehensive and demanding US EPA's UV Disinfection Guidance Manual (2006).

Figure 2: Wedeco Duron UV validation system

RESULTS AND DISCUSSION

Following the data analysis of the validation test, a validation formula was developed of the following structure:

Equation 1:

$$RED = 10^{A} \times UVA^{B \times UVA} \times \left(\frac{S/S_0}{Q \times D_L} \right)^{C+D \times UVA + E \times UVA^2} \times Modules^{F+G \times UVA + H \times UVA^2} \times D_L$$

where:

RED is the reduction equivalent dose (mJ/cm²),
UVA is the UV absorbance (%),
S is the UV intensity as measured by the UV sensor (mW/cm²),
So is the UV intensity for a ballast power setting of 100 percent (mW/cm²),
Q is the flow rate per lamp (gpm),
Modules is the quantity of banks in sequence
D_L is the microbial UV sensitivity (mJ/cm2 per log inactivation),
A- H are coefficients

It is critical to this formula that the microbial UV sensitivity (D_L) is an input parameter to the RED formula as well as the actual measured UV intensity (S), for the following reasons:

Integration of microbial UV sensitivity (D_L): As illustrated above, UV sensitivities in treated wastewater do not only vary by species, but also by treatment plant specifics. For highest precision and a "best fit" design, a collimated beam test can be run to establish a dose response

curve for a site-specific target pathogen. This establishes the site and target pathogen specific D_L, which can then be integrated into the above validation formula. Consequently, this procedure allows for designing the UV system specifically to the dose requirements of the targeted pathogen and its site specific UV sensitivity – thereby reducing potential over sizing and wasted power whilst retaining confidence in the disinfection being delivered.

Integration of measured intensity (S): Only by collecting UV sensor data during validation testing which is in full scale system operation used for performance monitoring and UV system control, performance compliance to validation conditions can be assured.

In order to allow for a comparison to a UV system not applying the D_L approach, equivalent performance can be assured by comparing the corresponding validated dose. As the validated dose is defined as

Equation 2: $$D_{val} = RED / VF$$

where:

RED is the reduction equivalent dose (mJ/cm²),
Dval is the validated dose (mJ/cm²), and
VF is the validation factor, which is a function of the RED bias factor and the uncertainty of validation

With the D_L approach, the RED bias can be set to 1, consequently making the validation factor only a function of the quality of validation data and prediction fit. The below example illustrates, how this will reduce the required UV system design for a typical wastewater disinfection scenario targeting at a disinfection level below 216 cfu/100 ml FC, with an UV inlet FC count of 100.000, consequently, a reduction of 2.67 log. Via a CBT, which was run on a water sample from the site, the D_L was assessed as 4 mJ/cm²/log. Consequently the required validated dose would come to 10.7 mJ/cm².

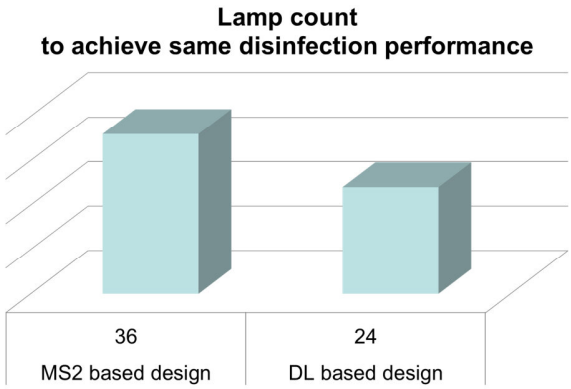

Figure 3: Lamp count requirement by design approach

Assuming that a UV system has only been tested with MS2 with an UV sensitivity between 18 – 20 mJ/cm², a RED bias of 2.65 would need to be applied at a design UVT of 65%, following the

UVDGM. Under the assumption that the quality of validation has been equivalent, for comparison purposes the uncertainty of validation will be set in both cases to 1. Then, a UV system being designed on MS2 would need to deliver a RED of 28.3 mJ/cm², whereas it would only need to deliver a RED of 10.7 mJ/cm² using the DL approach. In case of the Wedeco Duron the design reduction in this example would come to lamp count savings of 50% when applying the D_L approach instead of a "standard" MS2 based design!

CONCLUSIONS

Clearly, validating a UV system for the full range of operating conditions and treatment goals is a difficult task, requiring a large number of tests. However, the benefits to the water and wastewater treatment community are immense. A system validated under the use of the D_L approach spanning a wide range of operational conditions enables design engineers to match the local water matrix and treatment goals (regulatory requirements and target pathogen) specifically to a validated UV system design. Such a validation and design approach can thus save substantial time and money by preventing overdesign, providing the "best fit" to treat the specific target organism at a specific water quality.

So, what should the design engineer look for in a UV validation report for wastewater disinfection?

- Third party oversight: To ensure that validation test results are reliable, a qualified third party should provide oversight of the testing protocols and verify the validation results.
- Certified laboratory: Sampling must be done under strict protocols and bioassay testing must be done by a laboratory certified for UV disinfection validation
- Validation performed in compliance with appropriate and official protocols (e.g. the latest
- A validation envelope that encompasses the full range of operating conditions in terms of flow rates, UV transmittances (UVTs), and test organisms: To avoid having to apply a RED bias factor, multiple challenge organisms bracketing the sensitivities of the target pathogen is required to give greatest design precision, and allow to apply a site-specific UV sensitivity, which can be integrated into a D_L based validation formula.
- UV system control including online UV intensity data: Primarily to ensure operational performance compliance, but also to optimize power consumption and prolong lamp life, validation testing should include UV intensity data collection over the full range of validated conditions.

The Duron system's large validation envelope ensures the design professional and the utility manager that the Duron UV system will perform over the full range of operating requirements. UV intensity and power consumption data incorporated into the OptiDose control protocol ensure permit compliance with energy savings and enhanced lamp life throughout the life of the

UV system. The WEDECO Duron system's validation combines "best fit" for an optimally sized system, saving capital costs, with control protocols for operational savings that are unmatched by other UV systems.

REFERENCES

[1] US Environmental Protection Agency, 2006: UV Disinfection Guidance Manual

[2] National Water Research Institute, 2003: Ultraviolet Disinfection – Guidelines for Drinking Water and Water Reuse, 2nd edition

[3] National Water Research Institute, 2012: Ultraviolet Disinfection – Guidelines for Drinking Water and Water Reuse, 3rd edition