Application Note
Dosing with UV Light

UV Dosing for Sustained Purification and Decontamination of Water Systems

Systems that incorporate water storage, generation or transfer continue to proliferate in both residential and commercial settings. These systems include humidifiers, HVAC systems, potable water storage, coffee machines, and more. In virtually all cases, people ultimately come into contact with the water or a vaporized water, either of which has the potential to carry and contain dangerous bacteria, viruses, and mold spores. The effect of contact can range from allergic reaction to serious, even deadly, illness. While many systems may incorporate some type of filtering, many rely on users following care and cleaning instructions. Yet even following these instructions does not provide a level of purification that is likely desired.

Ultraviolet light in the 250nm to 280nm wavelength (UV-C) has been proven germicidal and has, for over 100 years, been utilized for disinfection and sterilization. The primary source of UV-C light has been mercury lamps. These lamps, in addition to containing mercury, tend to be large, fragile, and short-lived. Combined with their unit and maintenance costs, the life-cycle costs of a mercury lamp system are quite high and have limited the technology's implementation.

Advancements in the light emitting diode (LED) sector over the last 15 years have resulted in UV-C LEDs that generate effective, germicidal UV light output from a much smaller form factor with longer lifetimes and significantly reduced power requirements. They contain no toxic materials thereby eliminating contamination and environmental concerns. Further, UV-C LEDs are "instant on-off" devices. This feature allows the intermittent operation of the UV-C LED, something that is not possible with the conventional mercury lamp, and which can extend the lifetime of the UV-C LED up to twelve times longer than constant use, and further reduces life-cycle costs.

Dosing with UV-C LEDs

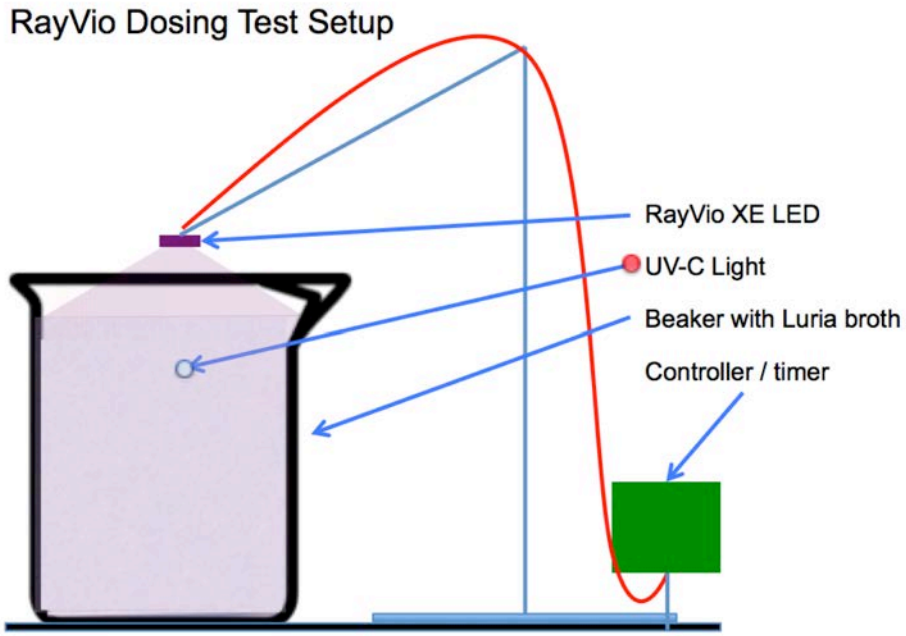
UV-C LEDs can be operated at regular intervals for short periods of time and deliver the desired germicidal results. Simply treating the area for minutes each hour, germs can be virtually eliminated and mold spore growth stopped. Stopping the growth of mold spores can be extremely important in HVAC systems where condensation provides a constant environment for growth and air flow can distribute spores, and germs, to inhabited spaces. In personal systems, like a humidifier or water tank that sit idle for days and weeks, dosing for a few minutes each hour means minimal energy consumption and continued protection from germs over time.

Proving the Case for Dosing

RayVio conducted two simple experiments with its XE Series LEDs to demonstrate the effectiveness of UV-C dosing. The first experiment was a side-

by-side test of clean water, one untreated and the second treated with UV-C via a single XE Series LED. The experiment was designed to show that ongoing intermittent treatment with UV-C light would keep the water clean.

The second experiment started with water that was heavily contaminated with bacteria. With a setup similar in design to the first experiment, one sample was left untreated and the other received regular treatment with UV-C light from an XE Series LED.



In both cases, the dosing of UV-C light for five minutes each hour was proven to be effective; it prevented the growth of bacteria in clean water, and it eliminated bacteria in the contaminated water.

RayVio electronics setup for both experiments

External controller
timer function and
on/off control signal

for RayVio constant
constant current
LED driver board

RayVio
XE Series LED

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Keeping clean water clean.

Many systems start with clean water, a humidifier, coffee maker, drinking water dispenser, etc. To demonstrate the effectiveness periodic doses of UV-C light on clean water, RayVio started with two containers each with one-litre of 0.1% Luria broth in deionized water. The Luria broth feeds microbes that fall into the solution from the ambient environment. The containers were placed in an unoccupied cubicle in an open office environment with normal traffic and at 'room' temperature, approximately 22C degrees. No bacteria was intentionally introduced into either solution.

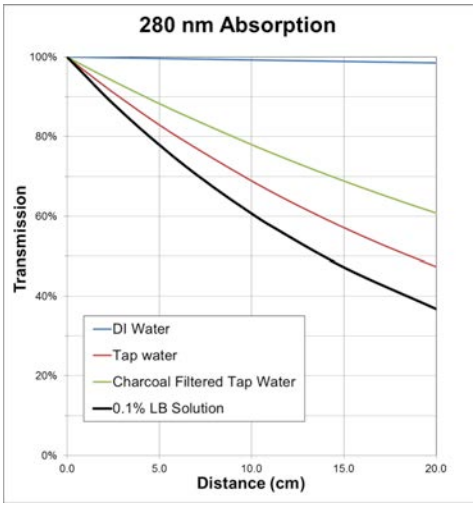


Figure 1. Optical Transmission in 0.1% Luria Broth Solution

The control sample was not treated with any applied UV-C light. The test sample had a single XE Series LED placed 5cm above the surface of the water. The 280nm XE LED was operated at 3mW of power for 5 minutes every hour.

As shown in Figure 1, the Luria broth allows less optical transmission than common tap water. Because effectiveness is directly related to the light being absorbed through the entire liter of solution, this is considered a more difficult use case that would be typical.
Both the control and test samples were measured to have 0 CFU/ml at Time 0 as shown in Figure 2.

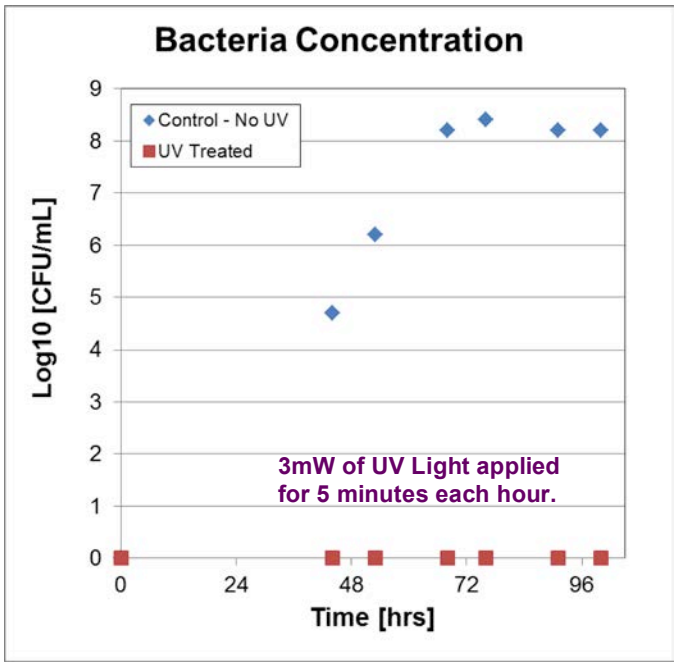


Figure 2: Bacteria concentration in Luria broth samples.

Results:
The control sample achieved a microbial concentration of 1e8 CFU/ml after approximately 70 hours. This represents a potentially infection level of contamination depending on the germs.

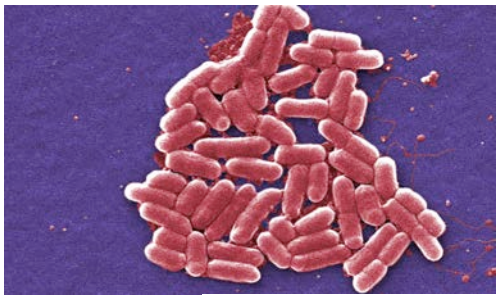
The test sample that was treated with periodic doses of UV-C light from a single XE Series LED had no detectable microbes after 100 hours of exposure.

"3mW of UV-C light from a RayVio XE Series LED applied hourly for 5 minutes can keep stored water 'clean' indefinitely."

It is clear that periodic dosing of a clean water system like a humidifier, coffee maker, steam cleaner, or drinking water container can eliminate the growth of germs and prevent contamination over extended periods of time.

Eliminating Contamination in Water

RayVio's second experiment was designed to demonstrate the effect of UV-C dosing on highly contaminated solutions.



e. coli Photo by Janice Haney Carr, CDC

The setup for the contaminated water consisted of two plastic beakers of solution. The test sample had a single XE Series LED at the mouth of the beaker and was treated with 6mW of 280nm UV-C power for five minutes every hour. The test solution consisted of 1.0% Luria broth in deionized water with a starting e. coli concentration of 3e6 CFU/ml. To speed microbial growth, both the control and test sample were incubated at 34C.

It's important to note that the concentration of e. coli in this test case is significantly higher that the contamination of untreated sewage water which is typically 1e4 to 1e5 CFU/ml of e. coli.[1]

As shown in Figure 3, the Luria broth solution represents a significant optical challenge as approximately 90% of the UV-C light is absorbed before reaching the bottom of the beakers.

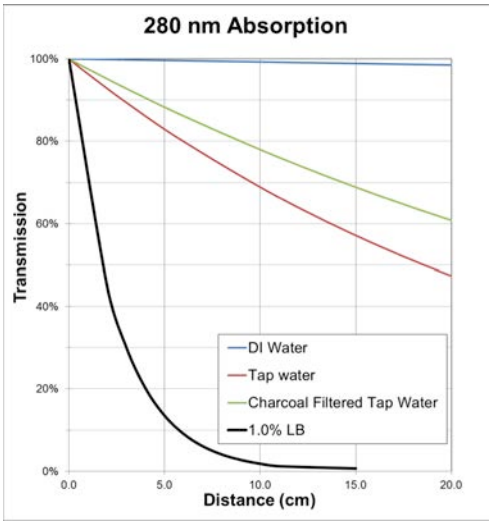


Figure 3. Optical Transmission of 1.0% Luria broth solution.

[1] Environmental Engineering IV A. Pawlowski pg. 524 CRC press. Waterborne Pathogens, 2nd edition (m48), pg. 24, AWWA

Results:
Over the first six hours of testing, the concentration of e. coli in the control sample increased from 3e6 CFU/ml to 3e7 CFU/ml.
In the test sample, effectiveness of UV-C dosing can be seen in minutes. Following the first UV-C dose from the XE Series LED, there was a 2log10 reduction in contamination (Figure 4). After four hours (four 5-minute doses) efficacy of the UV-C doses is increasing. This increase in efficacy corresponds with the increased growth phase in the control sample. Continued reduction in contamination was measured through 22 hours during which 5-minute doses were applied each hour. After five, 5-minute doses spread out over 6 hours, no live e. coli was detected and the solution was considered disinfected and safe for human consumption.

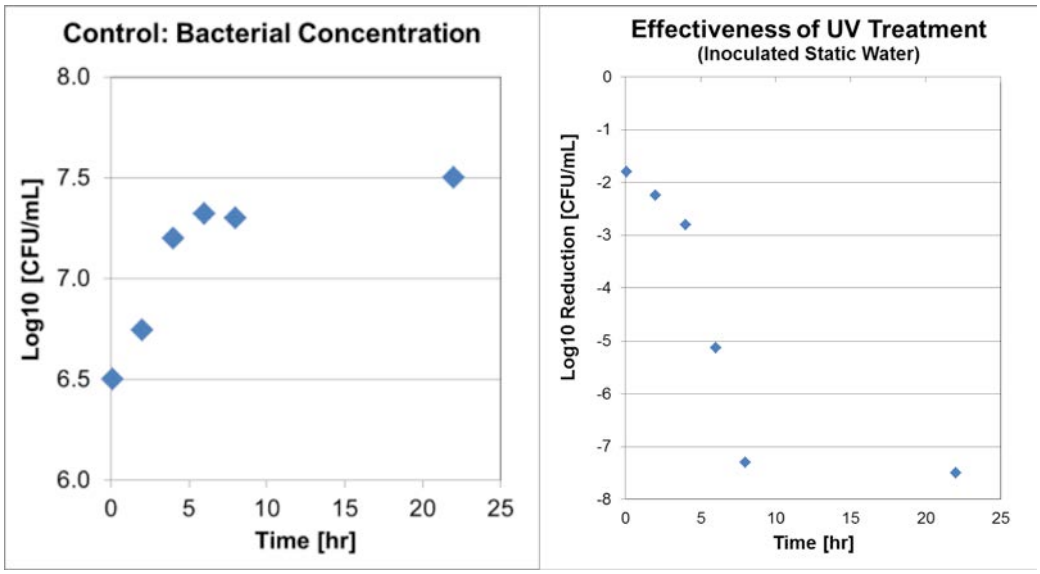


Figure 4. Effectiveness of UV-C Dosing with XE Series LED.

Conclusion

In both of RayVio's dosing demonstrations it is clear that clean water can be kept clean and that contaminated water can be disinfected. For consumer products, like humidifiers and coffee makers, the ability to keep stored water clean over extended periods of time offers consumers increased confidence and protection from potential illnesses. In cases of industrial water use or where the water source may not be known, such as in an HVAC system, it's clear that even contaminated or standing water can be cleaned.

By implementing periodic dosing, manufacturers can significantly increase the UV-C LED's lifetime, reduce engineering and heat-sink costs, reduce energy needs and battery consumption, and optimize life-cycle costs. This can all be accomplished without sacrificing the germicidal benefits of RayVio's UV-C light.