Ultraviolet Water Disinfection: *It's All About the Dose*

By Rick Andrew

Mercury lamps have a very strong ultraviolet (UV) emission at the 254 nanometer (nm) wavelength. Energy at this wavelength is very effective at disrupting ribonucleic acid recombination in microorganisms, which renders them unable to reproduce. When these microorganisms are unable to reproduce, they are effectively prevented from causing illness to those who may inadvertently consume them—the microorganisms are inactivated.

Class A UV systems as defined by NSF/ANSI Standard 55 deliver a high enough UV dose at 254 nm (40 mJ/cm^2) to inactivate the pathogenic microorganisms that could be responsible for causing disease through contamination of our drinking water. It is only natural to think that it must take a very powerful UV source to deliver a UV dose this high.

However, UV dose is also a function of the contact time between the water being treated and the UV source:

UV Dose = UV Source Irradiance Intensity x Contact Time

Given this equation, you can see that it is possible for a relatively weak UV source to deliver a sufficient UV dose, as long as the contact time is significant. Because of this relationship between the UV source irradiance intensity and contact time, Standard 55 testing is structured to determine the actual UV dose delivered by the UV system, as opposed to measuring the irradiance intensity of the UV source.

How a typical UV system works

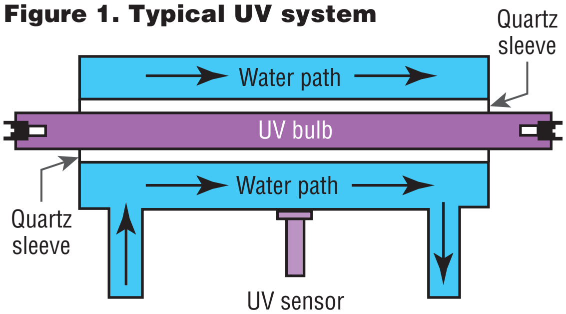
A typical UV system provides a flow path surrounding a mercury lamp, structured to provide close proximity of the water flow along the length of the mercury lamp (see Figure 1). Because turbidity or particulate matter in the water can occlude the UV source and absorb the UV energy, many system manufacturers recommend the use of prefilters to reduce turbidity and particulate matter prior to the system.

UV may not be effective against all forms of protozoan cysts. Studies have demonstrated the effectiveness of UV against *Cryptosproridium* and *Giardia*, but there have not been studies to demonstrate effectiveness of UV against *Toxoplasma* or *Entamoeba*. For these reasons, Standard 55 requires the use of a cyst rated prefilter for UV devices used to disinfect untreated surface water sources.

Also, please note that all Class A UV systems must have an alarm to warn the user when sufficient dose is not being delivered by the system. Insufficient dose can result from a burned out UV source, from turbid water or from fouling of the device.

Given the structure of a typical UV system, one might wonder how the UV dose can actually be measured. It is obviously a function of many factors: the irradiance intensity of the UV source, the proximity of the water being treated to the source, the contact time of the water with the source and whether any water is occluded or hidden from the source as it passes through the system.

Figure 1. Typical UV system



The solution to this complex measurement problem is to use the dose-response method of establishing UV dose.

The dose-response curve

The basic concept of dose-response is fairly simple: subject a known microorganism to the UV treatment system and see how well it is inactivated by the system. Then compare the level of inactivation achieved by the system back to the known susceptibility of the organism when subjected to a measured UV dosage.

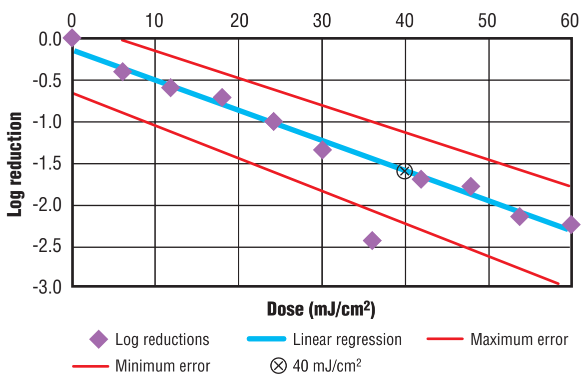
Essentially, this is how the UV dose of the test system is determined according to Standard 55, with one wrinkle. The wrinkle is that every time a *batch* of microorganisms is cultured, its true strength or susceptibility is not really known. Microorganisms are a bit like any other living thing—when well nourished and given a proper growth environment, they are very healthy and strong. If their nourishment is poorer, or their environment is not ideal, they tend to be weaker and more susceptible to inactivation by UV irradiance.

This variability in organism culture hardiness necessitates the development of a dose-response curve for each batch of microorganisms cultured. Once the batch of microorganisms has been cultured, samples of them are subjected to a known

UV source under very controlled conditions, with increasing dosage. This dosage is established by contact time under the known UV source. Standard 55 requires response to be measured at dosages of 0, 6, 12, 18, 24, 30, 36, 42, 48, 54 and 60 mJ/cm^2 for Class A testing. In practice, this is achieved by exposing plates of the microorganisms to a highly calibrated and controlled UV source for increasing lengths of time—for example, 0, 6, 12, 18, 24, 30, 36, 42, 48, 54 and 60 seconds.

The specific microorganism used in Standard 55 for establishing the UV dose

Figure 2. Typical Standard 55 UV dose response curve



for a Class A system is MS-2 Coliphage (ATCC #15597B). MS-2 Coliphage shows very linear, measurable response over the dosage range required for the dose-response curve. It is also widely available, can be cultured relatively easily and has a good analytical method that allows it to be enumerated without too many interferences from other organisms.

A typical dose-response curve is shown in Figure 2. Note that at the 40 mJ/cm^2 dosage, about 1.6 logs of MS-2 are inactivated. NSF has seen inactivation of various cultures or batches of MS-2 range from about 1.5 logs to about 1.9 logs over the years. This is a relatively narrow range, but nonetheless the variability in cultures is evident. If dose-response curves were not established for each batch, the true strength of the organisms would not really be known. To simply require a 1.9 log reduction of MS-2 in order to pass the test might understate the performance of many systems.

The test itself

Once the strength of the culture of organisms has been established through dose-response, the actual UV device can be tested. Component filters or other media that may interfere with the test are removed from the UV devices to be tested. Two devices are used and they are plumbed on the test stand in parallel. These devices are conditioned according to manufacturers instructions prior to testing. Test water with the following characteristics is prepared:

- 17.5-22.5º C
- <1.0 NTU turbidity
- 200-500 mg/L total dissolved solids (TDS)
- >96 percent UV transmittance (before addition of PHBA)

The test is performed at or above the maximum flow rate obtained through the devices with their integral flow control devices installed. The test water is further adjusted to reduce the UV transmittance with parahydroxybenzoic acid (PHBA). PHBA is added to reach 70 percent UV transmittance. If the alarm is operating, the test is ready to begin. If the alarm is not operating, additional PHBA is added until the alarm activates. This level of UV transmittance is maintained throughout the test. By testing at 70 percent UV transmittance or the device alarm point, the device is demonstrated to provide the required UV dosage necessary for disinfection even when the UV transmittance is significantly reduced to the point of alarm activation.

The devices are operated over a period of seven days, with samples repeatedly collected both at initial device start-up after sitting stagnant and when the devices are operating at steady state conditions, to cover a variety of usage patterns. The overall dosage is determined by comparing a geometric mean of organism counts in the influent samples to a geometric mean of organism counts in the effluent samples of each of two test devices. The overall log reduction calculated for each device must be equal to or greater than the log reduction of the dose-response curve at 40 mJ/cm^2 (1.6 log reduction in the example of Figure 2).

So that's how it's done!

You may have examined UV devices and wondered how their effectiveness is measured. You may have seen some relatively small UV devices designed for point of use (POU) applications and wondered how a system that small could possibly be effective. Now that you know it's all about the dose, and how that dose is measured, you can understand that small UV devices can deliver high dosages if their flow rates are low enough. And now that you are aware of how the dosage is tested according to NSF/ANSI Standard 55, you can have confidence that Certified UV systems do perform as advertised when operated and maintained according to the manufacturer's instructions.

About the author

♦ *Rick Andrew has been with NSF International for six years, working with certification of residential drinking water products. He has been the Technical Manager of the Drinking Water Treatment Units Program for three years. His previous experience was in the area of analytical and environmental chemistry consulting. Andrew has a bachelor's degree in chemistry and an MBA from the University of Michigan. He can be reached at 1-800-NSF-MARK or email: Andrew@nsf.org.*