Ultraviolet Light in TOC Reduction

By James Dallan

Summary: *While activated carbon, RO and DI are frequently used for TOC reduction, UV is frequently employed as a final step in ultrapure water applications.*

Ultraviolet (UV) light is a section within the energy band known as the Electromagnetic Spectrum. This includes electromagnetic waves such as cosmic rays, gamma rays, X-rays, UV, visible light, infrared light and radio waves—which are all parts of the energy band containing UV.

UV irradiation has been in use for many years in water disinfection. It destroys germs by causing a molecular change in their DNA make up and, in strong enough exposures, can even kill a microorganism outright. This prevents germs from multiplying and destroys their ability to spread disease. When germs cannot multiply, they are considered dead or inactivated. At a wavelength of 254 nanometer (nm), UV reaches its near peak germicidal effectiveness against most microorganisms.

In addition to its use in water disinfection, UV is used in several other applications, including examination of some structural materials, speeding up aging of some material surfaces, curing or drying of inks, creating ozone, destroying ozone, and in total organic carbon (TOC) reduction in ultrapure water treatment applications.

TOC reduction

Total organic carbons often represent a problem in using ultrapure water in rinsing electronic components during manufacturing. These trace TOC compounds could cause serious defects in semiconductors, where even the most minute of contaminants can affect performance, and could advance the spread of microorganisms that feed on these organic impurities.

Some TOC reduction can be achieved by using activated carbon filters and reverse osmosis (RO) or deionization (DI) systems; however, in order to achieve very high levels of TOC reduction, it's customary to use UV as a last step in TOC water treatment. It's simple and very effective.

Unlike the 254-nm UV wavelength used in disinfecting water, TOC reduction requires the use of a higher UV energy level created at the 185-nm wave band. This higher energy causes a photochemical reaction(s) that breaks up the organic molecules in water and generates hydroxyl (OH^- or $OH\bullet$) free radicals that oxidize most organics into carbon dioxide (CO_2) and water (H_2O), as per the following:

$$\text{TOC} + \text{UV185-nm} \rightarrow CO_2 + H_2O$$

Reductions in the order of < 1-2 parts per billion can be achieved with a properly designed treatment system, depending on characteristics and the types of organics to be treated. TOC reduction and microbial destruction occurs with the use of 185-nm lamps. Since carbon dioxide is a natural by-product of TOC reduction, it should be noted that a certain drop in water resistivity will occur after UV. This is caused by an "ionizing charge" some organic elements hold after receiving UV energy. Using a final RO or DI step will restore the water resistivity and will reduce further the level of these remaining organic elements.

Dosages in TOC reduction

The amount of energy produced by 185-nm TOC reduction UV systems is much greater than that produced by regular 254-nm disinfection UV systems. This is achieved by using higher energy 185-nm lamps, and by designing TOC UV reduction systems to operate at much higher dosage levels than in regular water disinfection.

By definition, dosage is the intensity of UV light per surface area multiplied by time and is represented by the following formula:

Dosage = Intensity x Time
= (microWatts per square centimeter) x (seconds)
= μW-sec/cm^2

The intensity is the amount of UV energy that a UV lamp produces at a certain distance from its surface per square centimeter of the lamp surface area. The time is the period it actually takes water to travel inside the UV chamber.

While much lower dosages have proven effective in recent years at inactivating a variety of microorganisms and protozoa than previously thought, dosages in the magnitude of 90,000

Chart 1. Limitations of UV

UV light can only be effective if it hits its target. If UV light is prevented from reaching its mark due to suspended solids or other impurities in water, for example, it won't be as effective as it can be. Following are key obstacles that reduce UV disinfection effectiveness:

- **Suspended solids**—These will act as an umbrella, protecting or "shadowing" germs from UV light. Suspended solids should be physically removed from water by pre-filtration before a UV unit.
- **Iron/manganese**—These will cause discoloration on the quartz sleeve that surrounds the UV lamp and reduce transmission of UV light. They also absorb UV energy. They should be removed from water by pretreatment or at least reduced to no more than 0.3 ppm for iron and no more than 0.05 ppm for manganese.
- **Hardness**—When water is hard, scale will eventually build up on the quartz sleeve around the UV lamp and will stop the UV light from passing. A water softener should be used before a UV unit if the water is hard.
- **Dissolved substances**—Other organic and inorganic dissolved substances can also reduce the germicidal effectiveness of UV light and should be pre-treated before a UV unit.

Chart 2. Advantages of UV

UV has many advantages over other disinfection processes:

- UV is effective and quick. No need for holding tanks and reaction times. No need for storing chemicals.
- UV does not alter the taste of water, which makes it ideal for use in bottling plants and food processing applications.
- UV is safe. No need to add or handle hazardous chemicals or risk polluting the environment.
- UV is compatible with all other water treatment processes. No need for de-chlorination if using RO systems. In fact, UV enhances the use of other water treatment systems by keeping them free from germs.
- UV is economical. Almost always, the cost of UV disinfection units is much less than the cost of chemical treatment systems. The cost of service and maintenance of UV units is very low. The electrical running cost of a UV unit in a house is about that of a regular light bulb.
- More effective against viruses than chlorine.
- Easy installation. UV units are very easy to install and require very little space.

SOURCE: Dallan, James, "Ultraviolet Water Disinfection," Ground Water Canada Magazine, April 1998

μW-sec/cm^2 and much higher (even over 200,000 or 300,000 μWsec/cm^2) are at times used in TOC reduction.

Standard TOC reduction systems are usually rated to operate at about 120,000 μW-sec/cm^2. Higher dosages (or lower dosages) can easily be achieved by resetting the service water flow rates of TOC UV systems to produce the desired dosages as per the dosage formula shown above.

Factors affecting UV

One shouldn't forget that, as in every water treatment technology, there are certain conditions that can influence the efficacy of that technology if not addressed. For UV, those include absorption characteristics of various contaminants, turbidity that could create a shadowing effect and fouling or aging of the quartz sleeve or lamp (see *Chart 1*). Still, the many advantages of UV (see *Chart 2*) far outweigh these limitations, which generally can be accounted for through system design, operation and maintenance, as well as pretreatment measures.

Conclusion

Ultrapure water by definition is very pure. It's normal for UV light to penetrate pure water easily resulting in a "high" UV transmission factor in TOC applications. It should be mentioned, however, that—in general UV use—absorption, turbidity and fouling play an important role in reducing UV systems effectiveness. Systems usually can be configured to reduce the impact of these and other factors affecting optimal UV system performance, as has been detailed in previous *WC&P* articles (see *Archives* at www.wcponline.com).

About the author

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