UV as Green Alternative for Public Health Protection

Editor's note: *In light of WQA's sustainability efforts being recognized with recent ANSI accreditation, this article is being reprinted for its insightful projection of UV technology as a sustainable water treatment option.*

By Paul Overbeck

While man harnessed the controlled use of ultraviolet light for disinfection of drinking water almost 100 years ago, it is only in the last decade that we are seeing its global acceptance in expanded application for public health protection. UV (now referred to by researchers and investment advisors as an 'advanced technology') has become common in applications including municipal drinking water, wastewater disinfection and advanced oxidation applications (AOP).

Figure 1. Electromagnetic spectrum

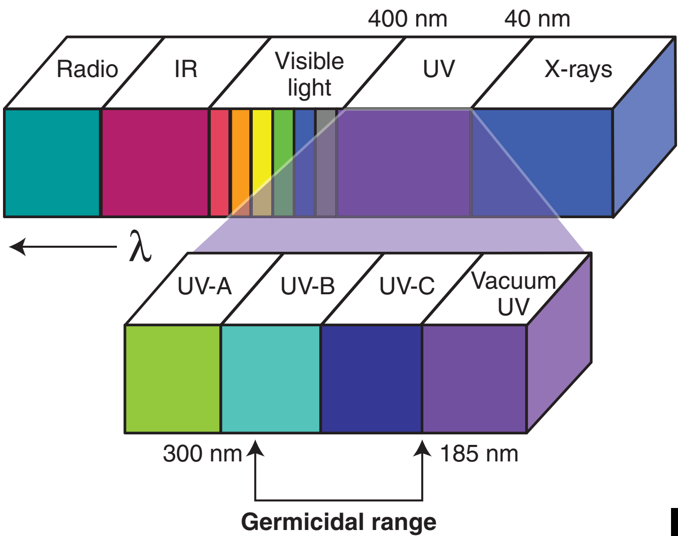
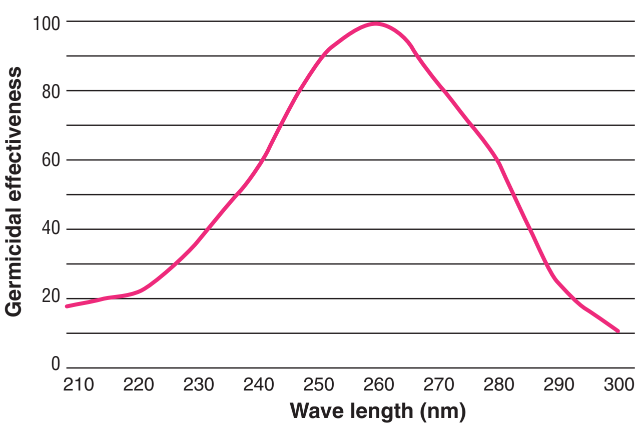
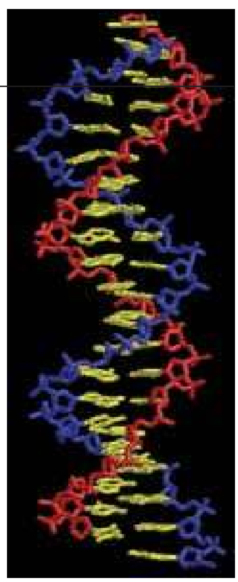


Figure 2. Absorption spectrum of cellular DNA



Courtesy of Trojan UV



UV is often used in combination with hydrogen peroxide (H_2O_2) and/or ozone for preoxidation of surface water taste and odor compounds. It is also used to reduce micropollutants in drinking water and wastewater.

The November *2008 Water Market USA* report published by Global Water Intelligence (www.globalwaterintel.com) stated: "The fastest growing water technology markets over the period between 2008 and 2016 will be ultrafiltration and microfiltration membranes (+280 percent), ozone disinfection systems (+233 percent), UV disinfection (+227 percent), membrane bioreactors (+180 percent) and reverse osmosis membrane systems (+165 percent). Capital expenditure on water reuse will top $10 billion (USD) between 2009 and 2016."

An advisory to investors from Goldman Sachs recommended, "focus on the high-tech end of the world's $425 billion (USD) water industry." That advisory specifically cited ultraviolet disinfection and its role in water reuse.

This is not surprising, as one shinning example of how UV and UV-based AOP technology can benefit reuse is the Orange County Water District's (OCWD) reclamation and replenishment facility. This facility recently won the US EPA's 2008 Clean Water State Revolving Fund *Pisces Award*, recognizing projects that advance clean and safe water through exceptional planning, management and financing.

This is just one of many recent awards the OCWD has garnered. Others include the *2008 Stockholm Industry Water Award* from the Stockholm International Water Institute, US EPA's *2008 Water Efficiency Leader Award*, *Water Agency of the Year* from International Desalination Association and *Water Agency of the Year* from WateReuse Association.

The need for improved disinfection practice is global. A recent Frost & Sullivan report featured a section titled, *Resurgent European Disinfection Market: Improved techniques of UV & ozone continue to enhance their position against conventional chemical disinfectants.*

UV and how it works

In physics, the term *light* refers to electromagnetic radiation of any wavelength, whether visible or invisible to the human eye. Light can exhibit properties of both waves and particles called photons.

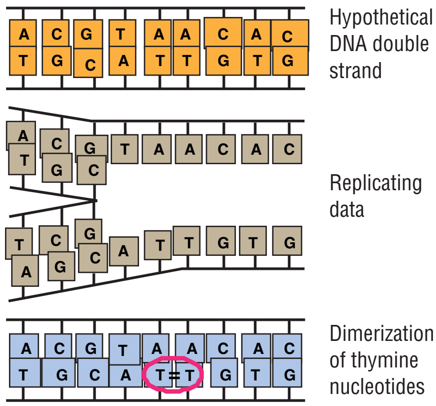
The ultraviolet portion of the electromagnetic spectrum is between 400 and 10 nm wavelength. UV systems for disinfection and combined advanced oxidation applications are designed for operation in the 185 to 300 nm range. (Figure 1)

UV disinfection performance is tied to the *First Law of Photochemistry* where only the light (photon) that is absorbed by a molecule can be effective at producing photochemical change in the molecule. If photons are not absorbed as they pass through a medium, nothing can happen and no photochemical reaction can be induced.

In order to inactivate microorganisms, UV energy must somehow be absorbed and cellular DNA and RNA absorb light in the UVC range (Figure 2). UV light efficacy for microbial disinfection peaks between 245 and 275 nm. Outside these wavelengths, there is a drop off in effectiveness, although wavelengths are still absorbed by the DNA.

DNA and RNA deliver the instructions for cell replication. When UV is absorbed by organisms, it causes damage to these nucleic acids and prevents cell replication by dimerization of thymine nucleotides. A thymine dimer is the covalent bonding of two adjacent thymine residues within a DNA molecule. (See Figure 3).

Figure 3. DNA replication and dimerization—stuck zipper



Dimerization causes replication instructions to catch like a 'sticky zipper' (Figure 3). The cell is not 'killed'; it is alive, but because the instructions stop and the cell cannot split or reproduce, it cannot achieve pathogenic infectivity dose levels (Figure 4).

Figure 4. Typical pathogen infectious dose versus typical raw sewage levels

Organism	Infectious dose	Conc. in raw sewage* (# / 110 mL)
Salmonella typhi	$10^4 – 10^7$	$10^2 – 10^4$
Shigella fexneri 2A	180	$1 – 10^3$
Clostridium perringens	10^{10}	$10^3 – 10^5$
Giardia	1 – 10	$10 – 10^4$
Cryptosporidium	1 – 10	$10 – 10^3$
Viruses	1 – 10	$10^2 – 10^4$

Depends on the prevalence of infected individuals in the community; may be considered greater than indicated in the table.

UV dose

UV technologists and regulators often refer to UV inactivation dose in a similar fashion as those who would use oxidizing biocides like chlorine or ozone. This creates a Ct value (residual concentration multiplied by exposure time) to control pathogens.

Specifically, UV dose equals UV intensity multiplied by the time the organism is exposed (UV dose = intensity x time). In past years, North Americans used dose units of mW·sec/cm². The more globally accepted terms for UV dose are J/m², commonly used in US drinking water treatment units as mJ/cm².

- 10 J/m² = 1 mW·sec/cm² = 1 mJ/cm²
- 400 J/m² is the same as 40 mJ/cm²

Target pathogen inactivation dosages have been well researched and recognized by global public health agencies. The identified UV dose for a four-log (99.99 percent) inactivation for various organisms are:

- *Escherichia coli* 0 157:H7 = 5.6 mJ/cm²
- *Cryptosporidium parvum* oocysts = 5.7 mJ/cm²
- *Giardia lamblia* cysts = 1.7 mJ/cm²
- Poliovirus Virus Type 1 = 21.5 - 30 mJ/cm²

The UV dose response with protozoan cysts such as *Giardia* and *Cryptosporidium* is a major driver for incorporating UV as a primary disinfectant in water treatment systems with post-chlorination for residual disinfection in distribution systems. The UV dose for parasite inactivation has been shown to be surprisingly low in comparison to the dose needed for oxidizing biocides.

This can create regulated disinfection byproducts such as trihalomethanes (THMs) and haloacetic acids. The use of two disinfection technologies constitutes an increasingly popular 'multibarrier' approach to potable water safety (Figure 5).

Typically, standard UV systems are designed and rated to deliver 40-mJ/cm² dose at the end of one-year operation, greatly exceeding the dose requirement for a four-log inactivation of most organisms (Figure 6). In the residential POU/POE market, NSF International has developed two equipment standards for UV units depending on the source water.

NSF 55 requires a minimum 40-mJ/cm² dose capability for waters that are not known to be microbially safe and *NSF 55 B* requires a minimum 16-mJ/cm² dose for operation on water supplies that are already treated or known to be microbially safe.

UV in the *NSF 55 B* case provides security against upset conditions that may allow pathogen access to the distribution. This occurred in 1993 with the *Cryptosporidium* outbreak in Milwaukee, WI.

UV transmittance (UVT)

In order for UV photons to be absorbed, they must first reach the organism. If the water to be treated has other materials present that compete for photons, the intensity of the UV may be significantly lowered to the point of being ineffective.

Natural organic matter (NOM) will absorb UV in the germicidal wavelengths. Particles/turbidity can cause light scattering and shielding of organisms from UV exposure. Fouling of the quartz sleeve between the lamp and the flowing water can also reduce transmittance and UV performance. Minerals such as calcium, magnesium, iron and manganese that accumulate on quartz sleeves can cause fouling.

Figure 5. Inactivation comparison

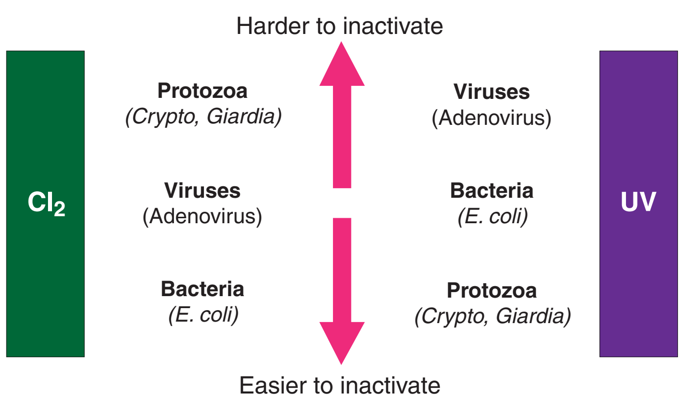
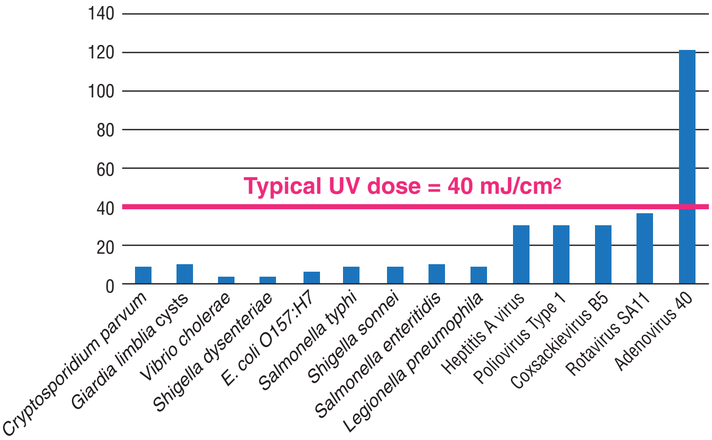
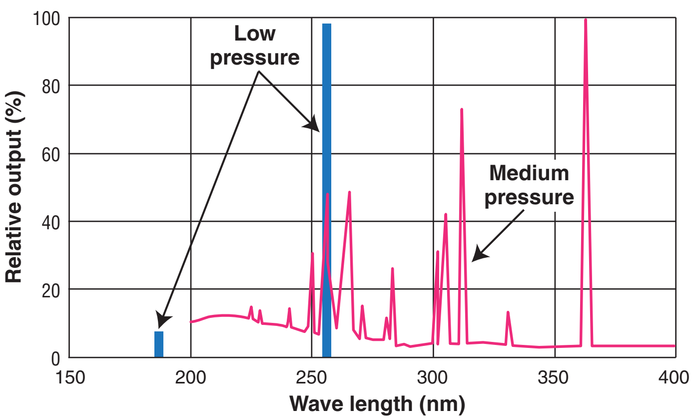


Figure 6. UV dose for four-log inactivation of various organisms



Hard water and problem water sources may require softening before the UV unit to minimize maintenance and maximize disinfection. Cleaning frequency is also directly impacted by the type of lamp used, as lamp operating temperatures vary widely.

Figure 7. Low-pressure lamp spectral output at 185 and 253.7 nm with medium-pressure output over 200-to 400-nm wavelength



Fouling will occur on almost any water source with slower fouling rates on water less than 100 mg/L total hardness. Iron is a big problem and should be limited to less than 0.5 mg/L to avoid frequent cleaning.

Design of an effective UV disinfection system must take UVT into account. The UV system employed will require additional lamps and/or higher energy output to offset losses in transmittance.

From a typical clean source water, it is greater than 90 percent UVT, while wastewaters are often 30 to 50 percent. In the industrial process, it could be greater than 99 percent (ultrapure) to be essentially zero for meat brines in the food processing industry. These metrics can vary seasonally for surface waters, but can be assumed to be very stable for ground waters not under the influence of surface water.

The same is true for operation under variable turbidity conditions. Gross filtration, however, can make a significant difference in performance and will be economically practical in many applications.

UV lamps/power supplies

There are three distinct types of UV lamps commercially available and applied in the industry today. Each UV system manufacturer will match the lamp with a specific power supply to optimize performance of their system.

Commercial UV lamps are characterized by the mercury vapor pressure inside the lamp and the relative UV energy they produce.

- Low-pressure, low-output (LPLO) used in small systems; limited UV energy per lamp requires many lamp/ballasts for larger flow rates.
- Low-pressure, high-output (LPHO) high output allows greater doses from compact systems; this category includes amalgam lamps.
- Medium-pressure, high-output (MPHO) extremely high UV output over a broad spectrum; capable of treating significant flow volumes and lower quality water and for use in advanced oxidation processes.

The DNA UV absorption curve (Figure 2) should be remembered when looking at both low- and medium-pressure lamp wavelength output (Figure 7). Medium-pressure lamp output provides photons for absorption with many peaks over the DNA absorption curve.

Though less efficient, medium-pressure lamps emit significantly more UV energy. This allows for very compact treatment systems capable of treating large flows.

Relative UV output is affected by changing mercury vapor pressure and the applied wattage. UV pressure within the lamp increases as the mercury vapor plasma comes up to temperature.

In most systems, there is a delay between start-up and achieving design operating temperature/pressure and resulting UV dose. The output of various commercial lamp types can be compared (Figure 8).

Figure 8. Indicates approximate lamp power output, efficiency, warm-up temperature and operating life.
Please note that there may be considerable variation among manufacturers.

	LPLO	LPHO	MPHO
Power/lamp	40-80 W	165-500 W	1-25 kW
Efficiency	25-35%	30-40%	5-15%
Warm-up	2 min.	5 min.	15 min.
Temperature	40°C	200°C	800°C
Life	10,000 hrs. (14 mo.)	10,000 hrs. (14 mo.)	5,000 hrs. (7 mo.)

UV regulation and validation

The recognized advantages of UV technology are many and have become evident globally. Several government agencies have developed standard protocols for validation of UV disinfection systems to assure the safe and effective use of UV in disinfection practice. Additional details are available from the following sources:

- The German Association for Gas and Water (*DVGW 2006*)
- US EPA *LT2ESWTR UV Guidance Manual*
- NWRI/AWWA (National Water Research Institute)
  - The Austrian Standards Institute (*ÖNORM M 5873-1*; low-pressure systems, 2001 and *ÖNORM M 5873-2*, medium-pressure systems, 2003),
  - *NSF 55* (National Sanitation Foundation, International)

The use of advanced treatment processes, including UV and advanced oxidation, will see significantly higher growth in the decades ahead. This will help meet a tightening regulatory environment, consumer safety concerns and water reuse necessities in many international regions.

About the author and organization

Paul Overbeck is Executive Director of the International Ultraviolet Association and the International Ozone Association-PAG. IUVA is a not-for-profit educational association focused on safe and effective use of ultraviolet and advanced oxidation technologies in water, wastewater, air and commercial-industrial applications. For additional information on the associations, publications, technical events and membership, visit www.iuva.org.

Global research on UV dose response was presented in an excellent paper titled, "UV Dose Required to Achieve Incremental Log Inactivation of Bacteria, Protozoa and Viruses" in UV News magazine, Volume 8 Issue 1. A copy is available by contacting IUVA.

IUVA will be delivering educational programs around the world in 2009 with workshops, conferences and World Congresses (see list above). IUVA recently completed UV Advanced Oxidation and UV New Applications workshops in Long Beach, CA and a half-day commercial-industrial workshop at WQA Aquatech in Chicago, IL.