Ultraviolet Light: An Alternative Disinfectant

By Kelly A. Reynolds, MSPH, Ph.D.

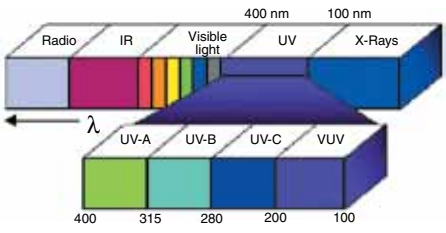
According to the Centers for Disease Control and Prevention, disinfection of public water supplies is recognized as one of the greatest achievements in public health during the 20th century. The most commonly used disinfectant in the United States is free chlorine. Unfortunately, chlorine efficacy is highly dependent on water quality parameters. In addition, chlorine combines with natural organics and manmade contaminants in some source waters to form potentially harmful disinfection byproducts (DBPs). Perhaps most daunting is the known resistance of certain human pathogenic microbes to conventional chlorine treatment, especially protozoa, i.e., *Cryptosporidium* and *Giardia* (see "On Tap," *WC&P*, April 2002).

Over the last decade, the emergence of *Cryptosporidium* as a major waterborne pathogen has refocused attention on the need for alternative disinfectants. Cryptosporidia have an environmentally resistant oocyst stage and are highly robust. Conventional methods of water treatment frequently fail to remove or inactivate oocysts from source waters. Their small size and low infectious dose have added to the challenge that these organisms pose to water utilities and consumers.

Issues of emerging waterborne pathogens are disconcerting to consumers and the water treatment industry alike. Advances in treatment technologies, however, continue to develop that minimize the impact of newly identified pathogens. Although ultraviolet (UV) light irradiation isn't a new technology, it's being considered for increased application in the water treatment industry. The advantage of UV over other disinfectants is it can inactivate hard to control organisms without chemical additions to the final product that can alter taste and without producing harmful DBPs.

Figure 1. UV ranges measured in electromagnetic waves

Range name	Wavelength range (nm)
UVA	315-400
UVB	280-315
UVC	200-280
Vacuum UV (VUV)	100-200



SOURCE: International Ultraviolet Association; www.iuva.org/Public Area/index.htm

How does it work?

UV light falls in the range of electromagnetic waves between 100 and 400 nanometers (nm) long, which are sandwiched between X-rays and the visible light spectrum (see *Figure 1*). The UV range is divided into four categories: Vacuum UV (100-200 nm); UV-A (315-400 nm), associated with sun tanning; UV-B (280-315 nm), associated with sun burning; and UV-C (200-280 nm), the range best absorbed by DNA and that's associated with cancer, mutations and inactivation of microbes. In terms of maximum disinfection ability, the optimum UV range is between 245 nm and 285 nm.

UV irradiation is typically produced by electrically powered quartz lamps following electron flow through mercury gas in the lamps. UV light is distributed by low-pressure lamps emitting at wavelengths of approximately 254 nm; medium pressure lamps emitting at wavelengths from 180 nm to 1,370 nm; or lamps that emit at other wavelengths in a high intensity pulsed manner. To increase dosage—usually defined as UV intensity × time over a specified area—additional lamps are used or exposure times increased. This dosage measure translates to milliWatt seconds per square centimeter (mW-sec/cm^2), equal to milliJoules per square centimeter (mJ/cm^2). You may also see microWatt-seconds per square centimeter (μW-sec/cm^2)—1 mJ/cm^2 equals 1,000 μW-sec/cm^2. In a pulsed UV reactor, capacitors build up and deliver electricity in pulses to xenon flash tubes in the center of a 2-inch diameter flash chamber through which the water flows. High intensity UV irradiation (75 mW/cm^2) is emitted and can be adjusted by altering the frequency of pulsing.[3] Multiple UV reactor designs, including flow-through systems, appear to be effective for protozoa disinfection and applicable to drinking water treat-

ment operations.[5]

The germicidal effect of UV light is due to the photochemical damage to the DNA or RNA of the organism. Following UV irradiation, thymine dimers occur, hooking nucleic acid strands together and preventing reproduction of the organism. It's the nature of UV irradiation to inactivate a constant fraction of the microbial population during each progressive increment of time. Therefore, there's a direct and proportional relationship between the UV dose and microbial response. As such, high intensity UV energy applied for shorter periods of time is equally as effective as low intensity UV energy applied for longer periods of time.

Viability vs. infectivity

Published literature in peer review journals on the efficacy of UV irradiation on *Cryptosporidium* appears conflicting and controversial, primarily because researchers used a variety of experimental protocols. Initially, UV light wasn't considered effective against *Cryptosporidium*. Earlier studies determined that for effective inactivation, 150 minutes of exposure to UV light was needed, an impractical approach for routine, in-line water treatment.[6] More recent studies using medium pressure UV light (19 mJ/cm^2) and animal infectivity assays indicate UV can achieve a 3.9-log reduction in *Cryptosporidium*.[2] Others have found medium and low-pressure UV systems are equally effective at low doses (3 mJ/cm^2), achieving a 3.4 and 3.0-log reduction, respectively.[4] Following UV irradiation, drastically different results are found when comparing estimates of *Cryptospridium* viability using excystation and vital dye staining vs. animal infectivity. Infectivity studies typically show a far greater log reduction of the protozoa at lower UV doses.

In the evaluation of previous studies and for future studies, it's important to distinguish between viability and infectivity and realize the public health implications of each. More research is needed to look at rapid methods of protozoa infectivity detection for increased monitoring of water quality and disinfection efficacy. For example, cell culture assays are reported as being equivalent to the animal assays, and an appropriate alternative, for determining the infectivity of *Cryptosporidium parvum*[6] and molecular methods, used in conjunction with cultural methods, promise to enhance detection speed.

Advantages & disadvantages

Currently the U.S. Environmental Protection Agency (USEPA) is considering how UV light irradiation, as a component of a multiple barrier treatment system, might enable systems to comply with existing disinfection requirements of the Surface Water Treatment Rule while also complying with the Stage 2 Disinfectants/Disinfection By-Products (D/DBP) Rule.[11] A key advantage (and disadvantage) of UV light disinfection is that no residual is produced. While this means no DBPs are produced following UV treatment of water, unlike chlorine and other alternative disinfectants, it also means there's no post-treatment protection while the water passes through the distribution system. Use of UV irradiation would greatly simplify the complex trade off between risk of microbial pathogens in water and DBP production. Being a physical rather than a chemical treatment, UV doesn't add anything to, and thus doesn't alter the taste or physiochemical composition of, the finished water. In addition, unlike conventional disinfectants, chemical water quality parameters, i.e., pH, temperature, alkalinity and total inorganic carbon don't impact UV irradiation efficacy. Treatment is completed in seconds in flow-through systems, eliminating the need for holding tanks and long contact times. Operating costs are relatively low compared to other conventional and alternative treatments.

There are some potential disadvantages, though, as well. UV irradiation isn't only absorbed by DNA but also by proteins. This characteristic can cause variable results with UV disinfection efficacy among different organism. For example, single-strand RNA viruses (i.e., poliovirus) are much more susceptible to UV irradiation than double-strand DNA viruses (i.e., enteric adenoviruses). In addition, certain microbial agents, especially bacteria, and possibly adenoviruses, are capable of directly or indirectly repairing the damage caused by irradiation and reverting back to a viable state.[1,8] This phenomenon, known as photoreactivation, usually occurs following exposure to sunlight. The extent of reactivation varies among microbes but appears to be minimized by shielding the treated water from sunlight until a time that the DNA damage is irreversible. Although photoreactivation has been shown not to affect infectivity of UV irradiated *Cryptosporidium*, more studies are needed to evaluate a wide range of pathogens and the effect that varying UV dose has on a variety of microbes and time limits required after which photoreactivation can no longer occur.

A number of factors can alter the rate of UV absorption and decrease the efficacy of the disinfectant. These factors are often site specific and thus calculations of time and intensity required for treatment aren't applicable to sites with different water quality parameters. The presence of dissolved or suspended matter, including chemical and dissolved organics or inorganics, can protect microbes from UV irradiation. Likewise, turbidity, color, or clumping of microbes can all affect UV disinfection efficiency. In addition, poor flow conditions in UV reactors can create dead spaces where inadequate disinfection occurs. Finally, operational considerations for optimum UV efficacy must include monitoring of diminished output over time due to either aging of the lamp—average life of low pressure UV lamps is 8,800 hours—or fouling of the lamp surface due to scaling or biofilm. Proper maintenance and lamp cleaning can easily remedy these potential problems.

With the absence of residual disinfectant in UV treated water, the water is subject to recontamination via the distribution system, prior to consumption. In addition, biofilm formation and coliform regrowth may occur. To address this problem, a secondary chemical disinfectant could be used to maintain a residual during distribution. Although recent epidemiological studies suggest a significant level of endemic waterborne gastrointestinal illness could be due to intrusions in the distribution system, residual chlorine was determined to have little impact on protozoan and viral pathogens reintroduced in the distribution system.[9]

A promising future

While chlorine remains the disinfectant of choice for large water treatment systems (serving >10,000 people) UV light irradiation promises to provide an alternative to chlorine disinfection and may change the status of water treatment as we currently know it. Consider that a UV dose of up to 15 mW-/cm^2 can inactivate 4-logs of hepatitis A virus[10] and that even lower doses appear to achieve the same inactivation with *Cryptospo-ridium* (see Hargy, Tom, "Status of UV Disinfection of Municipal Drinking Water Systems in North America," this issue).

Conclusion

In summary, there are many advantages to UV light disinfection of water and most disadvantages of the method can be overcome by maintenance control policies. Additional standardized research is needed to evaluate the efficacy of UV disinfection on numerous waterborne pathogens, including protozoa from a variety of sources (human and

animals) and stock oocysts of varying age. Research continues in these areas and some of these issues will be discussed at the next workshop hosted by the International Ultraviolet Association, June 4, 2002, in Albany, N.Y. Visit the IUVA website (www.iuva.org) for more information.

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