PART I

UV Disinfection

Designing an effective system that works on various water sources and applications

Designing UV reactors to be used in a water or wastewater applications is rather complicated. Mathematical or theoretical dose rates can be calculated, but final product evaluation needs to be confirmed, tested and verified by laboratories. Various strains of germs, bacteria and pathogens react differently to UV radiation. Some require strong dose rates for longer periods of time and others only need a short burst of UV to disrupt the proliferation process. An assumed calculated dose rate may be viewed as more than enough to kill certain pathogens, but what happens if the fluence rate is altered by turbidity or other contaminants in the water? What happens if the protective sleeve, whether it is fluoropolymers or quartz, gets scaled and blocks the UV from entering the stream of water? UV systems, just like reverse osmosis (RO) and de-ionization, need to have pretreatment on many water sources. Iron and hardness minerals can cause premature failure of a UV system. All the varying parameters must be analyzed in order to properly design a system that will work effectively on a multitude of water sources and applications, whether the source water is fresh or waste. This month's issue of *Water Quality Products* features Part I of this article, which will focus on fluence rates, design considerations and the effect different fluent rates have on various microorganisms.

By Jeff Roseman

Defining UV Disinfection

First, without trying to be redundant, what is Ultraviolet Light?

UV is the invisible wavelength of the light spectrum that falls between the 100-400 nanometer (nm) range. These can be broken down further into sub-ranges with the first being Vacuum Ultraviolet (VUV) at 100-200 nm, the next three ranges are as follows: UVC (200-280 nm), UVB (280-315 nm) and UVA (315-400 nm). The UVA range causes the change in the skin that leads to sun tanning. The UVB range can cause sunburning and is known to eventually induce cancer. The UVC range is known as the germicidal range and extremely dangerous since it is absorbed by proteins RNA and DNA, and can cause cell mutations and/or cell death. The UVC range is very effective in inactivating bacteria and viruses. The VUV range is absorbed by almost all substances (including water and air) and can only be transmitted in a vacuum.

The UVC or germicidal range is used in UV disinfection equipment design. The range is 200-280 nm, but 254 nm is the peak effective wavelength. The UV energy is absorbed by the DNA of the microorganism and is inactivated or destroyed, thus the reproduction of the organism eliminated.

Fluence Rate

Fluence rate is the preferred term over "UV Dose," because the meaning of the term Dose is used to imply total absorbed energy, for example, the UV Dose to induce sunburn on the skin. Only a small fraction of the radiant energy is absorbed (about 1%), but the fluence rate represents the radiant energy induced on the micro-organisms. This term is expressed in mWs/cm^2 or the preferred unit of mJ/cm^2. UV reactors are measured and the fluence rates are determined and tested at levels that kill germs at different rates. NSF Standards rate units in several classes that protect the consumer and ensure proper water quality. A Class B certification requires a dose rate of 16 mJ/cm^2 and a Class A certification would require a 40 mJ/cm^2 dose or fluence rate. The Fluence Rate (UV Dose) = Intensity of the UV Bulb x (% transmission of protective cover) x Contact Time.

Design Considerations

Proper designs will inactivate organisms to render them from photoreactivation. If the DNA is not completely disrupted, these organisms can reactivate or repair themselves and start to proliferate. Fluence rates must be high enough to keep all organisms that the reactor is designed to control from replicating downstream. Because UV does not add anything to the water these issues must be considered when designing a system.

Scaling issues of the protective sleeve must be addressed. Water sources have contaminants that can cause degradation of the UV intensity because the sleeves become fouled with debris and reduce UV radiance. These same contaminants can cause shadowing of the microorganisms, which prevent proper fluence rates from entering the stream for effective inactivation. Pretreatment is always recommended on water with high hardness, iron or turbidity, or other contaminants that can cause premature failure. Softened water or even RO should be used prior to the UV system to ensure lower maintenance costs and longer run times.

UV sensors should be incorporated in order to alert the user that the system is not producing the effective amount of UV. These units should not just be light-out-type sensors, but sensors that measure UV intensity. This would warn the consumer that their system was compromised and should be serviced. The reactor should use a bulb that can produce at least a 30mJ/cm^2 fluence rate after one year of continuous use. Another consideration is warm up time. If a unit is designed to have the bulb shut off when not in use, the bulb should be allowed ample warm up to become effective. Some bulbs are not as effective at lower temperatures.

Flow rates are always a consideration in the design process. Too fast of a velocity through the UV reactor can render the system ineffective. Pressures and pipe size play a factor in this parameter. Be sure that the proper flow rate is calculated and measured in order to deliver the desired fluence rate to the water stream.

Consider Some Germs

Table 1 (page 13) shows how the different fluence rates affect various bacteria, molds, protozoa, viruses and yeasts, therefore, one can understand how vigorous testing must be conducted to properly bring a UV system to market. Calculated fluence rates can be a basis for design, but testing is the only method to reveal real application success for inactivation. Some rates are very high and these microorganisms would never be candidates for a UV application, but for the most part, UV is a very acceptable treatment method.

Part II

Next month, *Water Quality Products* will feature Part II of this article, which will cover theoretical calculations of UV transmission rates based on various fluoropolymers and quarts; evaluating bulb protection materials cost; and applications. *wqp*

Author's Note: For references to this article visit our website at www.wqpmag.com/lm.cfm/wq050502.

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TABLE 1

The following are some fluence rates that can inactivate various microorganisms. These are all measured in mWs/cm^2.

Bacteria	UV Dose	Bacteria	UV Dose
Agrobacterium lumefaciens	8,500	Pseudomonas aeruginosa (Environ.Strain)	10,500
Bacillus anthracis 1,4,5,7,9 (anthrax veg.)	8,700	Pseudomonas aeruginosa (Lab. Strain)	3,900
Bacillus anthracis spores (anthrax spores)	46,200	Pseudomonas fluorescens	6,600
Bacillus megatherium Sp. (veg)	2,500	Rhodospirillum rubrum	6,200
Bacillus megatherium Sp. (spores)	5,200	Salmonella enteritidis	7,600
Bacillus paratyphosus	6,100	Salmonella paratyphi (Enteric Fever)	6,100
Bacillus subtilis	11,000	Salmonella Species	15,200
Bacillus subtilis spores	22,000	Salmonella typhimurium	15,200
Clostridium tetani	23,100	Salmonella typhi (Typhoid Fever)	7,000
Clostridium botulinum	11,200	Salmonella	10,500
Corynebacterium diphtheriae	6,500	Sarcina lutea	26,400
Dysentery bacilli	4,200	Serratia marcescens	6,160
Eberthella typhosa	4,100	Shigella dysenteriae - Dysentery	4,200
Escherichia coli	6,600	Shigella flexneri - Dysentery	3,400
Legionella bozemanii	3,500	Shigella paradysenteriae	3,400
Legionella dumoffill	5,500	Shigella sonnei	7,000
Legionella gormanil	4,900	Spirillum rubrum	6,160
Legionella micdadei	3,100	Staphylococcus albus	5,720
Legionella longbeachae	2,900	Staphylococcus aureus	6,600
Legionella pneumophila (Legionnaire's Disease)	12,300	Staphylococcus epidermidis	5,800
Leptospira canicola-Infectious Jaundice	6,000	Streptococcus faecaila	10,000
Leptospira interrogans	6,000	Streptococcus hemolyticus	5,500
Micrococcus candidus	12,300	Streptococcus lactis	8,800
Micrococcus sphaeroides	15,400	Streptococcus pyrogenes	4,200
Mycobacterium tuberculosis	10,000	Streptococcus salivarius	4,200
Neisseria catarrhalis	8,500	Streptococcus viridans	3,800
Phytomonas tumefaciens	8,500	Vibrio comma (Cholera)	6,500
Proteus vulgaris	6,600	Vibrio cholerae	6,500
Molds	**UV Dose**	**Molds**	**UV Dose**
Aspergillus amstelodami	77,000	Oospora lactis	11,000
Aspergillus flavus	99,000	Penicillium chrysogenum	56,000
Aspergillus glaucus	88,000	Penicillium digitatum	88,000
Aspergillus niger (breed mold)	330,000	Penicillium expansum	22,000
Mucor mucedo	77,000	Penicillium roqueforti	26,400
Mucor racemosus (A & B)	35,200	Rhizopus nigricans (cheese mold)	220,000
Protozoa	**UV Dose**	**Protozoa**	**UV Dose**
Chlorella vulgaris (algae)	22,000	Giardia lamblia (cysts)	100,000
Blue-green Algae	420,000	Nematode Eggs	40,000
E. hystolytica	84,000	Paramecium	200,000
Virus	**UV Dose**	**Virus**	**UV Dose**
Adeno Virus Type III	4,500	Influenza	6,600
Bacteriophage	6,600	Rotavirus	24,000
Coxsackie	6,300	Tobacco Mosaic	440,000
Infectious Hepatitis	8,000	—	
Yeasts	**UV Dose**	**Yeasts**	**UV Dose**
Baker's Yeast	8,800	Saccharomyces cerevisiae	13,200
Brewer's Yeast	6,600	Saccharomyces ellipsoideus	13,200
Common Yeast Cake	13,200	Saccharomyces sp.	17,600