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TECHNOLOGIES

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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 RO (reverse osmosis) and DI (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.

Defining Ultraviolet Disinfection

First off, 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 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), 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 (deoxyribonucleic acid) of the microorganism and is inactivated or destroyed, thus the reproduction of the organism eliminated.

The Fluence Rate

Fluence Rate is the preferred term over "UV Dose", since 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 microorganisms. 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 insure 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. Since UV does not add anything to the water these issues must be considered in 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 (reverse osmosis) should be used prior to the UV system to insure 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 30-mJ/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 is 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

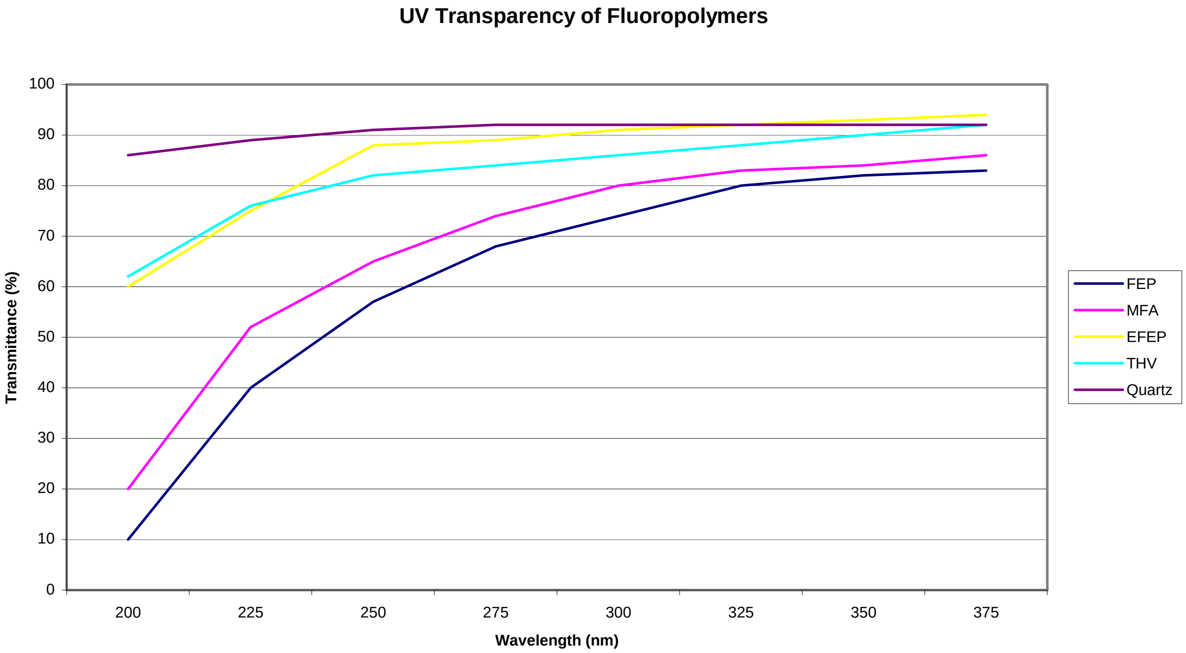
By looking at the table and seeing how the different fluence rates affect various bacteria, molds, protozoa, viruses, and yeasts, one can understand how vigorous testing must be conducted to properly bring a UV system to market. Calculated fluence rates can be a basis for design, but testing is the only 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.

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		0
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

Theoretical Calculations



The above graph reveals the transmission rates of various fluoropolymers and quartz. These polymers and quartz materials are used to protect the UV bulb from the liquid being treated. There are several styles of fluoropolymers. These vary from straight tubes like the quartz sleeve to coiled protection devices that offer longer contact times. They also have varying degrees of clarity that affect UV transmission. Several of the polymers have a low rate of UV transmission, but when coiled, they offer increased fluence rates and turbulence, which enhances their ability to inactivate microorganisms. Quartz offers a 90% transmission rate, but by studying the chart below, one can see how the increased contact times offer very

effective calculated fluence rates of the coiled tubes, as compared to the quartz. Coil performance has been calculated for three contact times in each of the coil groups having effective transmission rates of 60, 70, and 80%. The different percentages represent the variation in fluoropolymer materials and wall thickness. There is only one contact time for the 90% rate, which represents the quartz sleeve. The coils offer a longer contact time, because the length of the coil is approximately 80 inches as compared to around 10 inches when the same bulb is used in a reactor. Keep in mind these are calculated and theoretical fluence rates and once a UV system is designed and built, it should be tested for actual performance. All rates are mWs/cm^2. The graph depicts a visual representation of how well the coils can perform as compared to quartz. A 6,000-mWs/cm^2 value in each of the transmission rates was used in the graph for simplicity.

Bulb Intensity	%Transmission	Contact Time	Calculated Rate
6,000	60%	5 seconds	18,000
6,000	60%	10 seconds	36,000
6,000	60%	15 seconds	54,000
6,000	70%	5 seconds	21,000
6,000	70%	10 seconds	42,000
6,000	70%	15 seconds	63,000
6,000	80%	5 seconds	24,000
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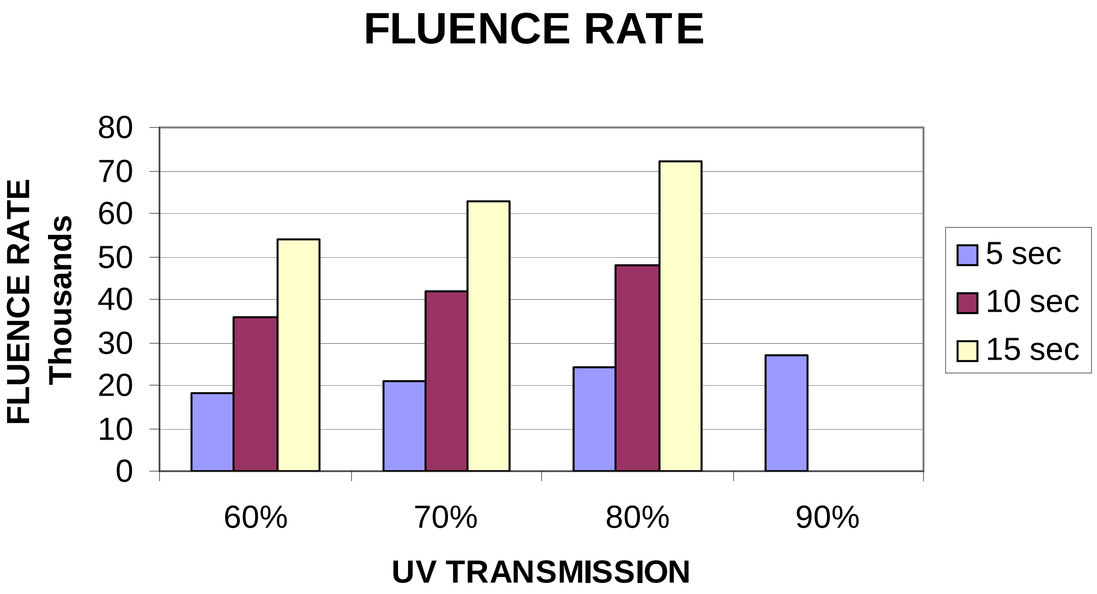
6,000	80%	15 seconds	72,000
6,000	90%	5 seconds	27,000



A collimated beam apparatus is the best method to define the fluence rate of a UV reactor. There are several variances that must be considered when collimating the beam of UV light to be sure the readings are accurate and definitive. Corrections must be made because water will absorb UV in low-pressure mercury bulbs and if medium pressure bulbs are used, a sensor correction must be accounted for in the calibration. These fluence rate calculations can become very complex, because of inefficiencies in fluence distribution to the microorganisms depending on trajectories. Computerized Fluid Dynamics (CFD) can be used to model the behavior of a real UV reactor.

Biodosimetry is the most reliable method available to measure fluence rates in a UV reactor. A harmless microorganism can be introduced in the water upstream of the reactor. Samples of the influent and effluent are taken and the log reduction of the inactivated microorganisms can be calculated. A dose response curve can be determined using a collimated beam apparatus and a dose rate can be obtained by using the corresponding log inactivation found in the UV reactor.

The coils have proven to be very effective and several products have been designed using these components. Further developments in fluoropolymers that have better clarity and UV resistance are being introduced. Thinner wall thicknesses, in applications with low pressure, are proving to be very satisfactory in system designs and microorganism control. Overall, the fluoropolymers have a place in water and wastewater treatment when applied properly.

Costs

Cost effectiveness in comparing the two bulb protection materials must be considered when designing UV reactors. Replacement and maintenance costs, whether a straight tube is utilized or a coil, help the designer choose components. Reactors must be made to provide economical run times and proper UV protection

for the consumer. The average wholesale cost of a 10-inch quartz sleeve is around $20.00, depending on quality and market area. The cost of a coiled fluoropolymer tube is less than the quartz and the length of the bulb can be reduced, thus lowering the cost of the overall system. Coil costs vary with wall thickness and number of loops. Low-pressure systems benefit from the use of very thin wall tubing, which cost less, and higher UV transmission rates can be obtained because of the thinner wall. The fluoropolymers offer more flexibility in design, smaller system size, easier maintenance, and are safer to handle. They are very useful and suitable in many applications, but do have limitations, because they are restricted to lower flow rates and lower pressures, however, they provide the industry an exceptional twist for UV applications.

Applications

There are several applications that can use UV to help reduce and control microorganisms. The fluoropolymers offer flexibility. Various venues have been explored with successful products being introduced in wastewater and fresh water. The limitations of using these coiled or straight tubes are only confined by the imagination. Using these components to protect the UV bulb in the reactor can help reduce the footprint of building a tabletop model water treatment system. Space requirements for a wastewater system utilized these coils in order to meet their specification and sizing parameters.

Some ideas for use would be water coolers or as post treatment on RO (reverse osmosis) systems as a precautionary measure. The water quality would be superior and not be compromised with hardness, iron, or other contaminants that would scale the protective coil or sleeve. This water would also not need high fluence rates to remove bacteria, but insure bacterial control. Pretreatment of water prior to UV is always recommended and this would be an example of a good application.

Fish tanks and aquaculture would also be very good applications, especially for the straight tubing since it can be cleaned and reused. Scale from nitrates and other debris found in this type of water needs to be wiped off to keep the UV dose high enough to control bacteria. Wastewater systems that require regular maintenance because of contaminants are uses that could benefit from these components.

Apple cider disinfection is another new possible use. The FDA has recently accepted UV as a method of disinfection for apple cider. A five-log reduction must be achieved, but if these systems can be proven and used, the FDA accepts the use of the food grade fluoropolymers. Pasteurization alters the taste of cider and since UV does not add anything to the cider this method will become acceptable within the industry, because consumers want the natural taste of apple cider.

Ozone destruct systems could also be another possible use. The 254 nm range is very good at destructing ozone and in low flow environments the tubing could be very instrumental in product design, by keeping the systems small, portable, and within sizing parameters.

In Conclusion

Fluoropolymer tubing, whether it is coiled or straight, offer very good bulb protection in UV system design. Even though the transmission levels are lower, the increased contact time and turbulence offer effective fluence rate ability, smaller footprint sizing parameters, and cost effective design considerations. Although not traditional and widely used as the quartz comparison, the fluoropolymers are emerging as an alternative and will continue to win acceptance in many applications. These plastics, by far, are not the answer or cure all for every application, but they should be considered and trusted as a good alternative to using quartz. Their cost and safety issues are very appealing and the effectiveness have been proven in several applications and new innovative methods are being considered for future use. Some of the above uses are only a small sampling of where these plastic tubes can be used. The limitations, again stated, are only confined by the imagination.

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3. **Roseman, Jeff, "Changing the Face of Ultraviolet," Water Quality Products, December 2003**

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