Ultraviolet Radiation:

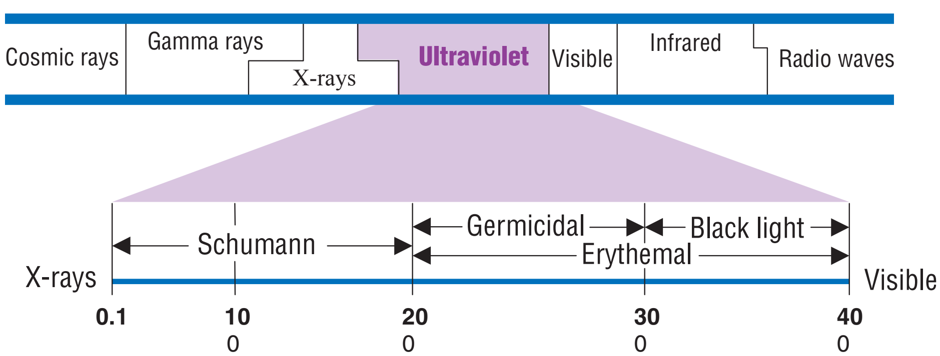
Knowing All the Facts for Effective Water Treatment

By Salman Siddiqui

Summary: *The number of possible applications for ultraviolet (UV) light is growing by leaps and bounds as the industry has learned more about it over the years. Here follows a discussion of some of the dosage requirements for UV for proper disinfection as well as the technology's strong and weak points.*

It's long been known that ultraviolet (UV) radiation has germicidal properties. Its use can be traced back to 1910 when a solar UV disinfection system was installed in a municipal water facility in Marseilles, France. While UV radiation was among the earliest recognized methods of disinfection, its use was reduced around this same period because of the advent of chlorination and ozonation. Recent scientific research showing the hazardous side effects of chemical water treatments has sparked renewed interest in UV radiation as the equipment and methods for its effective utilization have greatly improved.

Figure 1. Electromagnetic spectrum



UV light is electromagnetic radiation traveling in wavelengths in straight lines and in all directions from its emitting source. Light is characterized by its color or wavelength. Visible light covers the range from 400 nanometers (nm)—violet—to 700 nm—red. Light with wavelengths longer than 700 nm is in the infrared and radio emission ranges. Light with wavelengths shorter than 400 nm is in the UV range (see *Figure 1*). Light with wavelengths below 200 nm is absorbed by water and air and can only be transmitted in a vacuum, hence it's called "vacuum ultraviolet."

The ultraviolet range is further subdivided into three distinct groups. These three ranges have divergent properties and effects (see *Figure 2*). Although some oxidative/disinfection properties are also available at the 185-nm wavelength due to co-production of ozone, the most potent UV frequency is 254 nm, as far as its disinfection or germicidal efficacy is concerned (see *Figure 3*).

Figure 4 depicts the energy distribution behavior of UV light. This pattern shows a number of small spikes at different wavelengths, but these are too small to have any germicidal effect. The optimum wavelength in this range where the intensity is capable enough to noticeably affect the microorganism is at 254 nm.

Table 1. Ultraviolet range break-up (1 nm = 10 $^{-9}$ m)

UV-A	320-400 nm	"Black light" or long wave ultraviolet—Responsible for sun tanning
UV-B	280-320 nm	"Middle ultraviolet"—Sun burning and dangers of skin cancers
UV-C	200-280 nm	"Far ultraviolet" or "short wave"—Absorbed by DNA causing genetic damage; often called "germicidal" radiation

UV has a unique mode of action. It doesn't necessarily kill the target organisms—instead, UV light absorbed by microorganisms shifts electrons and breaks bonds (see *Figure 4*) in their deoxyribonucleic acid (DNA). This prevents them from reproducing, thereby minimizing spread of disease. UV is produced artificially by various sources including UV lamps, suntan lamps, germicidal lamps, carbon arcs, welding and cutting torches, furnaces, and laboratory tests and equipment.

Types of UV lamps

The most common lamps used are mercury vapor lamps. These can either be low or medium pressure. In low-pressure mercury lamps, the energy is emitted primarily at 253.7 nm, commonly given as 254 nm. In medium-pressure lamps, the emission is more widely distributed across the 200-to-600 nm range and the power density is much higher. Dosage is defined as UV intensity × time. This is represented as milliJoules per square centimeter (mJ/cm^2), which is equal to milliWatt-seconds per square centimeter (mW-sec/cm^2) or 1,000 microWatt seconds per square centimeter (µW-sec/cm^2). We'll use the last for the purposes of this article.

ANSI/NSF Standard 55—Ultraviolet Microbiological Water Treatment Systems covers point-of-use/point-of-entry (POU/POE) UV systems intended to be used under two specific water conditions. Class A systems—40,000 µw-sec/cm^2—are designed to disinfect and/or remove microorganisms from contaminated water, including bacteria and viruses, to a safe level. Class B systems (16,000 µw-sec/cm^2) are designed for supplemental bactericidal treatment of treated and disinfected public drinking water or other drinking water, which has been tested and deemed acceptable for human consumption by state or lo-

Figure 2. Germicidal effectiveness related to wavelengths

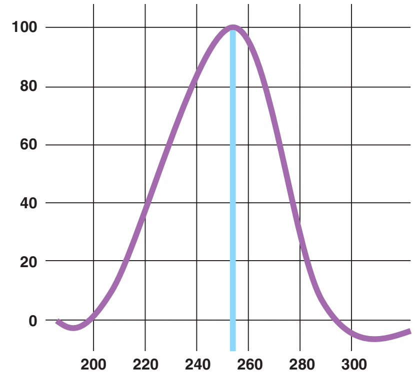


Figure 3. Typical relative spectral energy distribution

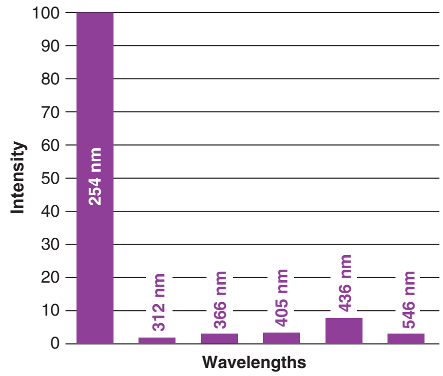
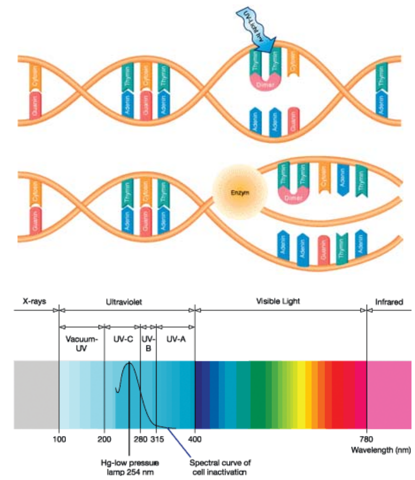


Figure 4. Mode of action of ultraviolet light



cal authorities. These latter systems are designed to reduce normally occurring non-pathogenic or nuisance microorganisms only.[1]

Dosage requirement

Examples of the UV dosage required to control different species of microorganisms is given in Table 1. As early as 1998, UV has proven effective against cysts and oocysts as well. It's expected more detailed information on this will be available in the Long Term 2 Enhanced Surface Water Treatment Rule and Stage 2 Disinfection By-Products Rule being finalized by the U.S. Environmental Protection Agency (USEPA), but studies from 2000 to 2002 indicated a 3-log (99.9 percent) reduction with UV doses as low as 6,000 µW-sec/cm^2. Still, if their presence is suspected, it's recommended some other method of reduction also be employed as an additional barrier.

Criteria for UV disinfection

The USEPA has spelled out some basic criteria "for the acceptability of an ultraviolet disinfection unit on municipal supply." These include:

a. UV radiation at a level of 253.7 nm must be applied at a minimum dosage of 16,000 mw-sec/cm^2 at all points throughout the water disinfection chamber.

b. Maximum water depth in the chamber, measured from the tube surface to the chamber wall, shall not exceed three inches.

c. The UV tubes shall be jacketed so that a proper operating tube temperature of about 105° F is maintained, and of quartz or high silica glass with similar optical characteristics.

d. A flow or time delay mechanism shall be provided to permit a two-minute warm-up period before water flows from the unit.

e. The unit shall be designed to permit frequent mechanical cleaning of the water contact surface of the jacket without disassembly of the unit.

f. An automatic flow control valve, accurate within the expected pressure range, shall be installed to restrict flow

FYI: Applications & Limitations

UV Applications

There are a variety of uses to which ultraviolet light can be put. Among those are:

Potable water—For utilization in domestic, commercial, industrial and municipal sectors.

Food preparation—Bacteria-free water to be incorporated in food products.

Beverage industry—Water serves as the base for this industry. The main utilization includes syrup mix water for soft drinks.

Fermentation products—Disinfection of the process water protects desirable bacteria from unwanted side effects, thereby providing purer fermentation products.

Rinse water—Bacteria-free rinse water provides a greater degree of cleanliness in sanitary areas.

Wash water—To guard against bacteria-activated spoilage where fruits, vegetables, meat, fish and other products are processed for packaging.

Cosmetics—Bacteria-free water is increasing in demand for a number of cosmetic products.

Pharmaceuticals—Bacteria-free water is an absolute must for the pharmaceutical industry.

Cooling water—Purification of cooling water for heat exchangers and process machinery to prevent their contamination from waterborne bacteria.

Electronic rinse water—Operates as an integral part of the high purity water system for rinsing of components.

Secondary effluent—An effective means of inactivating coliform bacteria and viruses in secondary effluent discharge from sewage plants.

Photographic processing—Used to prevent microorganism growth in processing fluids, thereby eliminating a source of spotting on photographs.

Cooling towers—An effective means to reduce chemical consumption and biofouling.

Ion exchange resin beds—Used both to protect beds from bacterial contamination and downstream equipment such as spray nozzles.

UV Limitations

The effectiveness of an UV system in eliminating microbiological contamination is directly dependent on the physical qualities of the influent water supply. Among those are:

Suspended solids—These shield the microbes so that they pass through the UV unit without being destroyed.

Iron/manganese—Will cause staining on the lamps or quartz sleeves at levels as low as 0.03 parts per million (ppm) of iron and 0.05 ppm of manganese.

Calcium/magnesium—Hardness will produce scale formation on the lamp or quartz sleeve.

to the maximum design flow of the treatment unit.

g. An accurately calibrated UV intensity meter, properly fitted to restrict its sensitivity to the disinfection spectrum, shall be installed in the wall of the disinfection chamber at the point of greatest water depth from the tube or tubes.

h. A flow diversion valve or automatic shut-off valve shall be installed that will permit flow into the potable water system only when at least the minimum UV dosage is applied. When power isn't being supplied to the unit, the valve should be in a closed position, which prevents the flow of water into the potable water system.

i. An automatic, audible alarm shall be installed to warn of a malfunction or impending shutdown, if considered necessary by the control or regulatory agency.

j. The material of construction shall not impart toxic materials into the water either as a result of presence of toxic constituents in materials of construction, or a result of physical or chemical changes resulting from exposure to UV energy.

k. The unit shall be designed to protect the operator against electrical shock or excessive radiation.

Table 2. Required UV for 3-log microorganism inactivation*

Bacteria	
Aeromonas hydrophila	3,900
Bacillus subtilis (spores)	51,000
B-40 Phage	23,000
Campylobacter jejuni	4,000
Escherichia coli O157:H7	4,100
Escherichia coli	6,400
Legionella pneumophila	6,900
MS-2 Phage	45,000
PRD-1 Phage	24,000
Salmonella anatum	15,000
Salmonella enteritidus	9,000
Salmonella typhi	6,400
Salmonella typhimurium	5,000
Shigella dysenteriae	2,000
Shigella sonnei	6,500
Staphylococcus aureus	6,500
Streptococcus faecalis	8,000
Vibrio cholerae	2,200
X174 Phage	7,300
Yersinia enterocolitica	3,700
Protozoa	
Cryptosporodium parvum	6,000
Giardia lamblia	6,000
Virus	
Adenovirus Type 40	90,000
Adenovirus Type 41	80,000
Coxsackievirus B5	21,000
Hepatitis A HM175	22,000
Hepatitis A	15,000
Poliovirus Type 1	14,000
Rotavirus SA11	23,000

* Ultraviolet energy in microwatt-seconds per square centimeter (μW-sec/cm²)

SOURCE: Adapted from USEPA, UV Disinfection Guidance Manual, Draft Proposal, June 2003, p. A-28.

Devices and applications

A number of devices have been developed for production of UV radiation for specific requirements. These include:

Unsubmerged—Where the process flow stream is routed through transparent tubes placed adjacent to an externally mounted, low-pressure, mercury arc lamp.

In channel submerged systems—Consists of lamps mounted on racks that can be lowered into the flow channel. Each lamp is inserted into a transparent tube and sealed to protect it from exposure to the water. For this type of system, water level variations should be kept to a minimum to avoid short-circuiting.

Enclosed submerged lamp systems—Much like the other submerged systems except that the lamps are fixed in place. This arrangement allows for the possible use of new high intensity lamps for enhanced treatment capabilities.

Advantages of UV include:

1. Does not change taste or odor of water,
2. Inactivates bacteria almost immediately requiring a contact time of as little as 0.5-5 seconds,
3. Compact and easy to use,
4. Low maintenance, and
5. No over-treatment.

On the other hand, disadvantages of UV include:

1. Electricity requirement,
2. No disinfection residual,
3. Requires pre-treatment of cloudy or colored water, and
4. Photoreactivation, whereby some microorganisms that are inactivated—but not "killed"—by the UV dosage repair their DNA, enabling them to reproduce.

Conclusion

The above article is meant to be a primer on various issues related to effective UV disinfection of drinking water. This technology will only continue to grow in popularity as its use is further refined. For additional information, see the references provided below.

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