Frequently Asked Questions about

Ultraviolet Disinfection

from Ecology's Water Quality Program

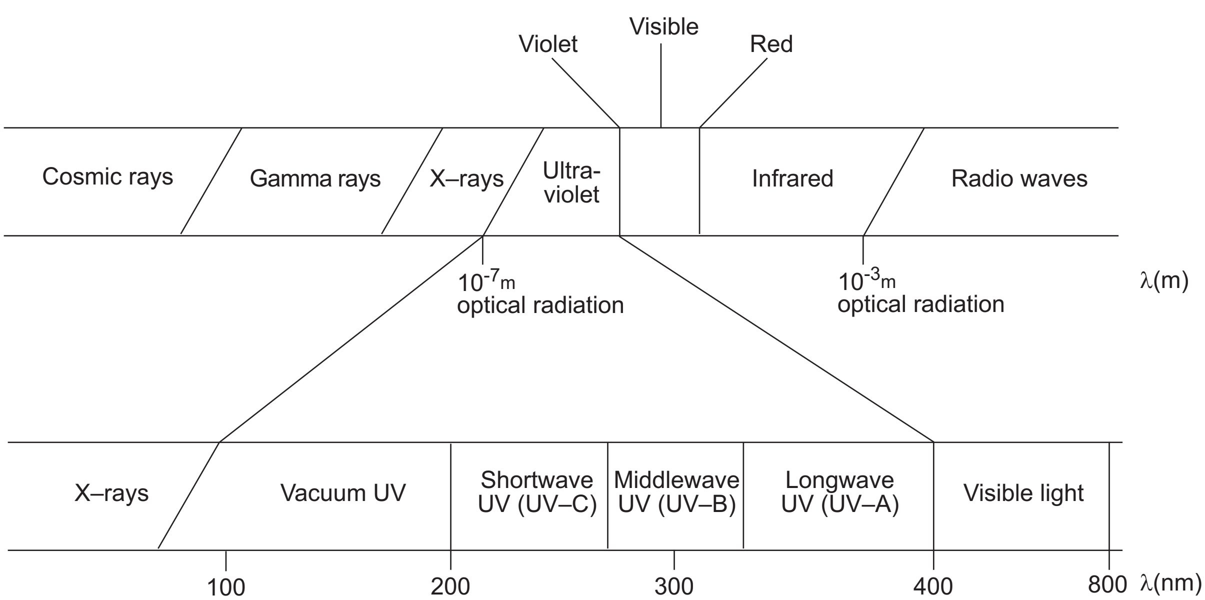
Q: What is ultraviolet light?

A: The term ultraviolet light (UV) describes a range of electromagnetic radiation wavelengths emitted from the region of the light spectrum between visible light (beyond the color violet) and X-rays. As shown in Figure 1, the upper wavelength limit is 400 nanometers (nm) (1 nm = 10-9 meter), and the lower wavelength limit is 100 nm. Below 100 nm, radiation ionizes virtually all molecules.

Scientists usually divide the ultraviolet region into three regions based on wavelength.

- UV-A or longwave UV radiation ranges from 320 to 400 nm.
- UV-B or middlewave UV ranges from 290 to 320 nm.
- UV-C or shortwave UV ranges from 200 to 290 nm.

UV light produced by the sun causes the human skin to tan or burn. Solar-UV radiation (UV radiation present in sunlight at the surface of the earth at noon in clear weather) includes both the longwave UV-A and middlewave UV-B regions. Solar radiation in the UV-B range is most likely to cause sunburn or certain skin cancers. The more harmful effects of the sun that cause skin cancer and eye cataracts, for example, are caused by UV-C shortwaves. Most UV-C is absorbed by ozone within the stratosphere.



Q: How does ultraviolet disinfection work?

A: UV disinfection is a physical form of disinfection transferring electromagnetic energy from a mercury arc lamp to the most important molecules of living cells, the genetic material (DNA and RNA). When UV radiation penetrates the cell wall of an organism, it destroys the cell's ability to reproduce.

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The following sequence of events must occur to achieve the photochemical reactions:

- The molecule must absorb the radiation.
- The molecule must possess a chemical bond that is of importance to the function of the organism.
- A sufficient amount of the excitation energy of the absorbed UV photon must reach this vulnerable bond to alter it.
- After the chemical change, the new configuration must endure.

The genetic nucleotide bases of DNA and RNA (adenine, guanine, thymine, and cytosine) differ in their ability to absorb UV light and undergo a permanent chemical change. The pyrimidines (thymine and cytosine) are 10 times more sensitive to UV light than the purines (adenine and guanine).

Of the pyrimidines, thymine undergoes change the most readily, and the chemical changes are very stable. UV light reacts with two adjacent thymine molecules to produce a thymine dimer. If the thymine dimers are in vital areas of the DNA, the organism cannot reproduce.

Q: How effective is UV disinfection?

A: The U.S. EPA considers UV disinfection an effective method of disinfection for secondary treated or higher quality wastewater effluent. Bacteria, protozoa, and viruses are susceptible to UV-C radiation, particularly at wavelengths around 254 nm. Approximately 90 percent of the ultraviolet light produced for wastewater disinfection is at the 254 nm wavelength.

One study (Chang et al. 1985) showed that "the viruses, the bacterial spores and the amoebic cysts required about 3 to 4 times, 9 times and 15 times, respectively, the [UV] dose required for [inactivation of] E. coli."

A recent pilot-scale study (Thompson, SS et. al, 2003) investigated the use of low-pressure, high-intensity UV radiation for disinfection of urban wastewater. A dose of approximately 170 mW-s/cm2 was required to achieve 99.99 percent inactivation. Another virus inactivation kinetics study (Enriquez, J. et. al., 2003) showed doses of UV required to achieve 99 percent inactivation of adenovirus 40, coliphage MS-2, and feline calicivirus were 109, 55, and 16 mJ/cm2, respectively.

UV doses of 140,000 W.sec/cm2 ((mJ/cm2) or greater are applied to tertiary coagulated and filtered effluents to produce Class A reclaimed water. See Chapter E1-4 for more information about reclaimed water disinfection requirements.

Q: Will the microorganisms repair the UV-damaged DNA?

A: The ability of a cell to repair itself is vital to the normal functioning of all organisms. Microorganisms use two principal types of repair mechanisms for UV-damaged DNA — enzymatic photoreactivation and excision repair. The rate of cellular DNA repair depends on many factors, including the cell type, the age of the cell, and the extracellular environment.

A standard test for determining the maximum degree of photoreactivation has not been developed but the following is a generally accepted method. During a pilot UV study, samples from the UV unit should be placed in a transparent and opaque bottle and left in natural sunlight for 1 hour. The difference between the control in the opaque bottle and the transparent bottle is due to photoreactivation.

Studies have shown great variations in the degree of photoreactivation but a general rule is that it may increase the count of the fecal or total coliforms by one logarithm at UV doses normally used in wastewater treatment plants. The photoreactivation observed in the study will be the maximum obtainable and may not be indicative of what occurs in the environment.

Photoreactivation of coliforms may take up to nine hours for maximum recovery rates. Photoreactivation can be important if the effluent is subjected to visible light for any period of time before it is sampled or enters the receiving body of water. This could be an open wetwell, a long open channel, or an unused chlorine contact chamber. A study by Whitby, et al. (1993) showed that photoreactivation was not significant in a receiving body of water. The ability of E. coli to photoreactivate may fall off sharply at salinities approaching 70-80 percent of seawater.

As the applied UV dose increases, photoreactivation decreases. A cell that has accumulated a large amount of DNA damage may no longer effectively repair the damage and at high doses of UV light, photoreactivation may be insignificant. Photoreactivation of coliform organisms in wastewater effluent is generally considered a concern at UV doses less than 30 mW-s/cm2. At higher doses the genetic structure has been altered too many times for the microorganism to reverse the action.

Q: What is enzymatic photoreactivation?

A: Photoreactivation has been observed in almost all microorganisms and involves the illumination of the cell with visible blue light. It requires a specific enzyme that binds to the defective site on the DNA. Illumination results in the absorption of light energy by the enzyme. The absorbed energy promotes cleavage of chemical bonds at the defect in a single DNA strand. The most common photoreactivation process is the cleavage of the thymine dimer to yield two free thymine residues. In this way, visible light can repair DNA damaged by UV light.

Q: What is excision repair?

A: Excision repair is a “dark” repair process - independent of light. The repair requires the sequential action of four enzyme activities in a “cut, patch, cut, and seal” process. If the defect is a thymine dimer, a DNA polymerase enzyme patrolling the cell detects it. The polymerase enzyme also makes an incision on one side of the defect and replaces the defective section with the correct nucleotide bases. The enzyme then removes the other end of the defective segment. Finally, a DNA ligase attaches the new segment to the old DNA.

References and other related articles:

Chan Y and E G Killick, 1995. The Effect of Salinity, Light and Temperature in a Disposal Environment on the Recovery of E. coli Following Exposure to Ultraviolet Radiation. *Wat. Res Vol. 29 No.5*, pp. 1373-1377.

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