Ultraviolet germicidal irradiation

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A low pressure mercury vapor discharge tube floods the inside of a hood with shortwave UV light when not in use, sterilizing microbiological contaminants from irradiated surfaces.

Ultraviolet germicidal irradiation (**UVGI**) is a disinfection method that uses ultraviolet (UV) light at sufficiently short wavelength to kill microorganisms.[1] It is used in a variety of applications, such as food, air and water purification. UV has been a known mutagen at the cellular level for more than one-hundred years. The 1903 Nobel Prize for Medicine was awarded to Niels Finsen for his use of UV against tuberculosis.[2] Application of UV irradiation to purify water was a technique invented by Ashok Gadgil.[3]

UVGI utilises short-wavelength ultraviolet radiation (UV-C) that is harmful to microorganisms. It is effective in destroying the nucleic acids in these organisms so that their DNA is disrupted by the UV radiation. This removes their reproductive capabilities and kills them.

The wavelength of UV that causes this effect is rare on Earth as its atmosphere blocks it.[4] Using a UVGI device in certain environments like circulating air or water systems creates a deadly effect on micro-organisms such as pathogens, viruses and molds that are in these environments. Coupled with a filtration system, UVGI can remove harmful micro-organisms from these environments.

The application of UVGI to disinfection has been an accepted practice since the mid-20th century. It has been used primarily in medical sanitation and sterile work facilities. Increasingly it was employed to sterilize drinking and wastewater, as the holding facilities were enclosed and could be circulated to ensure a higher exposure to the UV. In recent years UVGI has found renewed application in air sanitization.

How UVGI Works

Ultraviolet light is electromagnetic radiation with wavelengths shorter than visible light. UV can be separated into various ranges, with short range UV (UVC) considered “germicidal UV.” At certain wavelengths UV is mutagenic to bacteria, viruses and other micro-organisms. At a wavelength of 2,537 Angstroms (254 nm)[5] UV will break the molecular bonds within micro-organismal DNA, producing thymine dimers in their DNA thereby destroying them, rendering them harmless or prohibiting growth and reproduction. It is a process similar to the UV effect of longer wavelengths (UVB) on humans, such as sunburn or sun glare. Micro-organisms have less protection from UV and cannot survive prolonged exposure to it.

A UVGI system is designed to expose environments such as water tanks, sealed rooms and forced air systems to germicidal UV. Exposure comes from germicidal lamps that emit germicidal UV electromagnetic radiation at the correct wavelength, thus irradiating the environment. The forced flow of air or water through this environment ensures the exposure.

Effectiveness

UVGI is a highly effective method of destroying microorganisms. When concentrated in a closed environment such as a water holding tank or duct system it is lethal over time to all micro-organisms.

The effectiveness of germicidal UV in such an environment depends on a number of factors: the length of time a micro-organism is exposed to UV, power fluctuations of the UV source that impact the EM wavelength, the

presence of particles that can protect the micro-organisms from UV, and a micro-organism's ability to withstand UV during its exposure.

In many systems redundancy in exposing micro-organisms to UV is achieved by circulating the air or water repeatedly. This ensures multiple passes so that the UV is effective against the highest number of micro-organisms and will irradiate resistant micro-organisms more than once to break them down.

The effectiveness of this form of sterilization is also dependent on line-of-sight exposure of the micro-organisms to the UV light. Environments where design creates obstacles that block the UV light are not as effective. In such an environment the effectiveness is then reliant on the placement of the UVGI system so that line-of-sight is optimum for sterilization.

Sterilization is often misquoted as being achievable. While it is theoretically possible in a controlled environment, it is very difficult to prove and the term 'disinfection' is used by companies offering this service as to avoid legal reprimand. Specialist companies will often advertise a certain log reduction i.e. 99.9999% effective, instead of sterilization. This takes into consideration a phenomenon known as light and dark repair (photoreactivation and excision (BER) respectively) in which the DNA in the bacterium will fix itself after being damaged by UV light.[6]

A separate problem that will affect UVGI is dust or other film coating the bulb, which can lower UV output. Therefore bulbs require annual replacement and scheduled cleaning to ensure effectiveness. The lifetime of germicidal UV bulbs varies depending on design. Also the material that the bulb is made of can absorb some of the germicidal rays.

Lamp cooling under airflow can also lower UV output, thus care should be taken to shield lamps from direct airflow via parabolic reflector. Or add additional lamps to compensate for the cooling effect.

Increases in effectiveness and UV intensity can be achieved by using reflection. Aluminum has the highest reflectivity rate versus other metals and is recommended when using UV.

Inactivation of microorganisms

The degree of inactivation by ultraviolet radiation is directly related to the UV dose applied to the water. The dosage, a product of UV light intensity and exposure time, is measured in microwatts per second per square centimeter, or unambiguously as microwatt seconds per square centimeter ($\mu W \cdot s/cm^2$). Dosages for a 90% kill of most bacteria and virus range from 2,000 to 8,000 $\mu W \cdot s/cm^2$. Dosage for larger parasites like *Cryptosporidium* require a lower dose for inactivation. As a result, the US EPA has accepted UV disinfection as a method for drinking water plants to obtain *Cryptosporidium*, *Giardia* or virus inactivation credits. For example, for one-decimal-logarithm reduction of *Cryptosporidium*, a minimum dose of 2,500 $\mu W \cdot s/cm^2$ is required based on the US EPA UV Guidance Manual published in 2006.[7]:1-7

Creating UVGI

A 9 W germicidal lamp in a compact fluorescent lamp form factor
Main article: Germicidal lamp

Germicidal UV is delivered by a mercury-vapor lamp that emits UV at the germicidal wavelength. Mercury vapour emits at 254 nm. Many germicidal UV bulbs use special transformers to ensure even electrical flow to the bulbs so the correct wavelength is maintained. Since germicidal UV has a narrow bandwidth, power fluctuations will render intended irradiating environments ineffective. In some cases, UVGI electrodeless lamps can be energised with microwaves, giving very long stable life and other advantages. This is known as 'Microwave UV.'

There are several different types of germicidal lamps: - Low-pressure UV lamps offer high efficiencies (approx 35% UVC) but lower power, typically 1 W/cm³ power density. - Amalgam UV lamps are a high-power version of low-pressure lamps. They operate at higher temperatures and have a lifetime of up to 16,000 hours. Their efficiency is slightly lower than that of traditional low-pressure lamps (approx 33% UVC output) and power density is approx 2-3 W/cm³. - Medium-pressure UV lamps have a broad and pronounced peak-line spectrum and a high radiation output but lower UVC efficiency of 10% or less. Typical power density is 30 W/cm³ or greater.

Depending on the quartz glass used for the lamp body, low-pressure and amalgam UV lamps emit light at 254 nm and 185 nm (for oxidation).

185 nm light is used to generate ozone.

Weaknesses and strengths

Advantages

For more details on this topic, see Disinfectant.

UV water treatment devices can be used for well water and surface water disinfection. UV treatment compares favorably with other water disinfection systems in terms of cost, labor and the need for technically trained personnel for operation: deep tube wells fitted with hand pumps, while perhaps the simplest to operate, require expensive drilling rigs, are immobile sources, and often produce hard water that is found distasteful. Chlorine disinfection treats larger organisms and offers residual disinfection, but these systems are expensive because they need a special operator training and a steady supply of a potentially hazardous material. Finally, boiling water over a biomass cook stove is the most reliable treatment method but it demands labor, and imposes a high economic cost. UV treatment is rapid and, in terms of primary energy use, approximately 20,000 times more efficient than boiling.[*discuss*]

Drawbacks

UV disinfection is most effective for treating a high clarity purified reverse osmosis distilled water. Suspended particles are a problem because microorganisms buried within particles are shielded from the UV light and pass through the unit unaffected. However, UV systems can be coupled with a pre-filter to remove those larger organisms that would otherwise pass through the UV system unaffected. The pre-filter also clarifies the water to improve light transmittance and therefore UV dose throughout the entire water column. Another key factor of UV water treatment is the flow rate: if the flow is too high, water will pass through without enough UV exposure. If the flow is too low, heat may build up and damage the UV lamp.[8]

Potential dangers

At certain wavelengths (including UVC) UV is harmful to humans and other forms of life. In most UVGI systems the lamps are shielded or are in environments that limit exposure, such as a closed water tank or closed

air circulation system, often with interlocks that automatically shut off the UV lamps if the system is opened for access by human beings.

In human beings, skin exposure to germicidal wavelengths of UV light can produce sunburn and (in some cases) skin cancer. Exposure of the eyes to this UV radiation can produce extremely painful inflammation of the cornea and temporary or permanent vision impairment, up to and including blindness in some cases. UV can damage the retina of the eye.

Another potential danger is the UV production of ozone. UVC light from the sun is partly responsible for the earth's ozone layer in the stratosphere, but ozone in the troposphere can be harmful to a person's health. The United States Environmental Protection Agency designated 0.05 parts per million (ppm) of ozone to be a safe level. Lamps designed to release UVC and higher frequencies are doped so that any UV light below 254 nm will not be released, thus ozone is not produced. A full spectrum lamp will release all UV wavelengths and will produce ozone as well as UVC, UVB, and UVA. (The ozone is produced when UVC hits oxygen (O_2) molecules, and so is only produced when oxygen is present.)

UV-C radiation is able to break down chemical bonds. This leads to rapid ageing of plastics (insulations, gasket) and other materials. Note that plastics sold to be "UV-resistant" are tested only for UV-B, as UV-C doesn't normally reach the surface of the Earth. When UV is used near plastic, rubber, or insulations care should be taken to shield said components; metal tape or aluminum foil will suffice.

History

Using ultraviolet (UV) light for drinking water disinfection dates back to 1916 in the U.S. Over the years, UV costs have declined as researchers develop and use new UV methods to disinfect water and wastewater. Currently, several states have developed regulations that allow systems to disinfect their drinking water supplies with UV light.

The largest UV disinfection system, the New York City Catskill/Delaware Facility, is currently being constructed. A total of 56 energy-efficient UV reactors will be installed to treat 2.2 billion US gallons (8,300,000 m^3) a day to serve New York City.[9][10]

Uses for UVGI

Air Disinfection

UVGI can be used to disinfect air with prolonged exposure. Disinfection is a function of UV concentration and time, CT. For this reason, it is not as effective on moving air, when the lamp is perpendicular to the flow, as exposure times are dramatically reduced. Air purification UVGI systems can be freestanding units with shielded UV lamps that use a fan to force air past the UV light. Other systems are installed in forced air systems so that the circulation for the premises moves micro-organisms past the lamps. Key to this form of sterilization is placement of the UV lamps and a good filtration system to remove the dead micro-organisms.[11] For example, forced air systems by design impede line-of-sight, thus creating areas of the environment that will be shaded from the UV light. However, a UV lamp placed at the coils and drainpan of cooling system will keep micro-organisms from forming in these naturally damp places.

ASHRAE covers UVGI and its applications in IAQ and building maintenance in its 2008 Handbook, HVAC Systems and Equipment in Chapter 16 titled Ultraviolet Lamp Systems. ASHRAE's 2011 Handbook, HVAC Applications, covers ULTRAVIOLET AIR AND SURFACE TREATMENT in Chapter 60.

Water sterilization

For more details on this topic, see Ultraviolet.

Ultraviolet disinfection of water consists of a purely physical, chemical-free process. UV-C radiation in particular, with a wavelength in the 240 nm to 280 nanometers range, attacks the vital DNA of the bacteria directly. The radiation initiates a photochemical reaction that destroys the genetic information contained in the DNA. The bacteria lose their reproductive capability and are destroyed. Even parasites such as *Cryptosporidia* or *Giardia*, which are extremely resistant to chemical disinfectants, are efficiently reduced. UV can also be used to remove chlorine and chloramine species from water ; this process is called photolysis, and requires a higher dose than normal disinfection. The sterilized microorganisms are not removed from the water. UV disinfection does not remove dissolved organics, inorganic compounds or particles in the water.[12] However, UV-oxidation processes can be used to simultaneously destroy trace chemical contaminants and provide high-level disinfection, such as the world's largest indirect potable reuse plant in Orange County, California.[13]

UV disinfection leaves no taint, chemicals or residues in the treated water. Disinfection using UV light is quick and clean.

Technology

The UV units for water treatment consist of a specialized low pressure mercury vapor lamp that produces ultraviolet radiation at 254 nm, or medium pressure UV lamps that produce a polychromatic output from 200 nm to visible and infrared energy. The optimal wavelengths for disinfection are close to 260 nm.[7]:2-6 Medium pressure lamps are approximately 12% efficient, whilst amalgam low pressure lamps can be up to 40% efficient. The UV lamp never contacts the water, it is either housed in a quartz glass sleeve inside the water chamber or mounted external to the water which flows through the transparent UV tube. It is mounted so that water can pass through a flow chamber, and UV rays are admitted and absorbed into the stream.[14]

Sizing of a UV system is affected by three variables: flow rate, lamp power and UV transmittance in the water. UV manufacturers typically developed sophisticated Computational Fluid Dynamics (CFD) models as optimize UV system performance. However, the true performance of the UV reactor should always be validated through a bioassay. This typically involves testing the UV reactor's disinfection performance with either MS2 or T1 bacteriophages at various flow rates, UV transmittance and power levels in order to develop a regression model for system sizing. For example, this is a requirement for all drinking water systems in the United States per the US EPA UV Guidance Manual.[7]:5-2

The flow profile is produced from the chamber geometry, flow rate and particular turbulence model selected. The radiation profile is developed from inputs such as water quality, lamp type (power, germicidal efficiency, spectral output, arc length) and the transmittance and dimension of the quartz sleeve. Proprietary CFD software simulates both the flow and radiation profiles. Once the 3-D model of the chamber is built, it's populated with a grid or mesh that comprises thousands of small cubes.

Points of interest—such as at a bend, on the quartz sleeve surface, or around the wiper mechanism—use a higher resolution mesh, whilst other areas within the reactor use a coarse mesh. Once the mesh is produced, hundreds of thousands of virtual particles are "fired" through the chamber. Each particle has several variables of interest associated with it, and the particles are "harvested" after the reactor. Discrete phase modeling produces delivered dose, headless and other chamber specific parameters.

When the modeling phase is complete, selected systems are validated using a professional third party to provide oversight and to determine how closely the model is able to predict the reality of system performance. System validation uses non-pathogenic surrogates to determine the Reduction Equivalent Dose (RED) ability of the reactors. Most systems are validated to deliver 40 mJ/[cm.sup.2] within an envelope of flow and transmittance.

To validate effectiveness in drinking water systems, the methods described in the US EPA UV Guidance Manual is typically used by the U.S. Environmental Protection Agency, whilst Europe has adopted Germany's DVGW 294 standard. For wastewater systems, the NWRI/AwwaRF Ultraviolet Disinfection Guidelines for Drinking Water and Water Reuse protocols are typically used, especially in wastewater reuse applications.[15]

UVGI, also termed "ultraviolet disinfection", is commonly used for water sterilization in a variety of applications. Its use in wastewater treatment is replacing chlorination due to the chemical's toxic by-products. A disadvantage of the technique is that water treated by chlorination is resistant to reinfection, where UVGI water must be transported and delivered in such a way as to avoid contamination. Individual wastestreams to be treated by UVGI must be tested to ensure that the method will be effective due to potential interferences such as suspended solids, dyes or other substances that may block or absorb the UV radiation.
"UV units to treat small batches (1 to several liters) or low flows (1 to several liters per minute) of water at the community level are estimated to have costs of 0.02 US$ per 1000 liters of water, including the cost of electricity and consumables and the annualized capital cost of the unit." (WHO) [16]

Large scale urban UV wastewater treatment is performed in cities such as Edmonton, Alberta. The use of Ultraviolet (UV) light has now become standard practice in most municipal wastewater treatment processes. Effluent is now starting to be recognised as a valuable resource, not a problem that needs to be dumped. Many wastewater facilities are being renamed as water reclamation facilities, and whether the waste water is being discharged into a river, being used to irrigate crops, or injected into an aquifer for later recovery. Ultraviolet light is now being used to ensure water is free from harmful organisms.

UV systems destined for drinking water applications are validated using a third party test house to demonstrate system capability, and usually a non pathogenic surrogate such as MS 2 phage or Bacillus Subtilis is used to verify actual system performance. UV manufacturers have verified the performance of a number of reactors, in each case iteratively improving the predictive models.

Lamp technology is based around either Amalgam or Medium Pressure lamps. Both lamp types are used by the leading companies, and each type has specific strengths and weaknesses.

Aquarium and pond

Ultraviolet sterilizers are often used in aquaria and ponds to help control unwanted microorganisms in the water. Continuous sterilization of the water neutralizes single-cell algae and thereby increases water clarity. UV radiation also ensures that exposed pathogens cannot reproduce, thus decreasing the likelihood of a disease outbreak in an aquarium.

Aquarium and pond sterilizers are typically small, with fittings for tubing that allows the water to flow through the sterilizer on its way to or from a separate external filter. Within the sterilizer, water flows near to the ultraviolet light source, usually through a baffle system that lengthens the time during which the water is exposed to the radiation.

Laboratory hygiene

UVGI is often used to disinfect equipment such as safety goggles, instruments, pipettors, and other devices. Lab personnel also disinfects glassware and plasticware this way. Microbiology laboratories use UVGI to disinfect surfaces inside biological safety cabinets ("hoods") between uses.

Food and beverage protection

Since the FDA issued a rule in 2001 requiring that virtually all fruit and vegetable juice producers follow HACCP controls, and mandating a 5-log reduction in pathogens, UVGI has seen some use in sterilization of fresh juices such as fresh-pressed apple cider.

UV Dosing

One method for gauging UV effectiveness is to compute uv dose. The U.S. EPA publishes UV dosage guidelines [17]
Dosage involves the following parameters:

- flow rate (reflecting contact time)
- transmittance (reflects light reaching the target)
- turbidity ("cloudiness")
- lamp age (reflects reduction in UV intensity)
- lamp fouling
- % active lamps (reflects lamp outages in each lamp bank)

Other uses

EPROM erasers

UVGI lamps are used to erase the stored information held in EPROMS (erasable programmable read only memory) in less than a minute. Longer wavelength UV-B or UV-A lamps can also be used, but the erase time is considerably greater.

See also

- SODIS
- Sanitation
- Disinfectant
- Water purification
- Portable water purification
- Sanitation Standard Operating Procedures
- Water treatment

References

1. ^ National Institute for Occupational Safety and Health. (2008, April). NIOSH eNews, 5(12). Retrieved September 10, 2008, from http://www.cdc.gov/niosh/enews/enewsV5N12.html
2. ^ "The Nobel Prize in Physiology or Medicine 1903". *Nobelprize.org*. The Nobel Foundation. http://nobelprize.org/nobel_prizes/medicine/laureates/1903/. Retrieved 2006-09-09.
3. ^ http://www.lbl.gov/Education/ELSI/sustain-main.html
4. ^ Lupu, Alexandra (2006-07-20). "UV Radiation – What UVA, UVB and UVC Rays Are and How They Affect Us". *Seasonal Discomforts*. Softpedia. http://news.softpedia.com/news/UV-Radiation-What-UVA-UVB-and-UVC-Rays-Are-and-How-They-Affect-Us-30345.shtml. Retrieved 2006-09-09.
5. ^ Kowalski W.J.; Bahnfleth W.P.; Witham D.L.; Severin B.F.; Whittam T.S. (October 2000). "Mathematical Modeling of Ultraviolet Germicidal Irradiation for Air Disinfection". *Quantitative Microbiology* (Springer) **2** (3): 249–270. doi:10.1023/A:1013951313398. http://www.ingentaconnect.com/content/klu/quan/2000/00000002/00000003/00390528.
6. ^ "How does UV disinfection work". *R. Franklin*. UVO3.co.uk. http://www.uvo3.co.uk/blog/uv-water/how-does-uv-disinfection-work/. Retrieved 22/06/2011.

7. ^ a b c (PDF) *Ultraviolet Disinfection Guidance Manual for the Final Long Term 2 Enhanced Surface Water Treatment Rule*. Washington, DC: United States Environmental Protection Agency. November 2006. http://www.epa.gov/ogwdw000/disinfection/lt2/pdfs/guide_lt2_uvguidance.pdf. Retrieved 30 January 2011
8. ^ GADGIL,A.,1997, **Field-testing UV Disinfection of Drinking Water**, Water Engineering Development Center, University of Loughborough,UK: LBNL 40360.
9. ^ "Trojan Technologies Wins New York City Drinking Water UV Project" (PDF) (Press release). Trojan UV. 2 November 2005. http://www.trojanuv.com/resources/trojanuv//News/Press/New_York_City_Press_Release.pdf. Retrieved 30 January 2011.
10. ^ "Municipal Drinking Water – Multi-barrier Disinfection Strategy, New York City". Trojan Technologies. http://www.trojanuv.com/uvresources?resource=403. Retrieved 15 November 2011.
11. ^ "Environmental Analysis of Indoor Air Pollution". CaluTech UV Air. http://www.purifier.org/snapcat/iaq.pdf. Retrieved 2006-12-05.
12. ^ HARM, W., 1980, **Biological Effects of Ultraviolet Radiation, International Union of Pure and Applied Biophysics**, Biophysics series, Cambridge University Press.
13. ^ "The Groundwater Replenishment System, Orange County, California". Trojan UV. 2010. http://trojanuv.com/uvresources?resource=44. Retrieved 30 August 2011.
14. ^ WOLFE, R.L., 1990, **Ultraviolet Disinfection of Potable Water**, Env. Sci. and Technology 24(6):768-773
15. ^ (PDF) *Treatment Technology Report for Recycled Water*. State Of California Division of Drinking Water and Environmental Management. January 2007. p.[page needed]. http://www.cdph.ca.gov/certlic/drinkingwater/Documents/DWdocuments/treatmenttechnology.pdf. Retrieved 30 January 2011
16. ^ WHO
17. ^ Chapter 7

External links

- ASHRAE 2008 Handbook - Table of content
- Emission spectra of different germicidal lamp types
- The mercury lamp
- WHO
- Wastewater technology fact sheet: Ultraviolet disinfection
- Lawrence Berkeley National Laboratory, Field-testing UV Disinfection of Drinking Water
- Sanuvox
- UVGI Systems in Malaysia