Ultraviolet germicidal irradiation

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 sterilization method that uses ultraviolet (UV) light at sufficiently short wavelength to break down micro-organisms. 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 100 years. The 1903 Nobel Prize for Medicine was awarded to Niels Finsen for his use of UV against tuberculosis.

UVGI utilises the short wavelength of UV that is harmful to forms of life at the micro-organic level. 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. 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 moulds that are in these environments. Coupled with a filtration system, UVGI can remove harmful micro-organisms from these environments.

The application of UVGI to sterilization 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 sanitisation.

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) 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. Since the Earth’s atmosphere absorbs most of the UV from the sun, germicidal UV is very rare in all circumstances. 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 sterilisation.

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.

Creating UVGI

A 9 W germicidal lamp in a modern compact fluorescent lamp form factor

Germicidal UV is delivered by a mercury-vapor lamp that emits UV at the germicidal wavelength. Mercury vapour emits at 254nm. 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 efficicncy 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.

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. Limited exposure mitigates the risk of danger.

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 at the atmospheric level can be harmful to a person's health. The United States Environmental Protection Agency designated .05 parts per million (ppm) of ozone to be a safe level.

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.

Uses for UVGI

Air purification

UVGI can be used to sterilize air that passes UV lamps via forced air. 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. 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 drain pan of cooling system will keep micro-organisms from forming in these naturally damp places. The most effective method for treating the air rather than the coils is in-line duct systems, these systems are placed in the center of the duct and parallel to the air flow

Water purification

Water purification via UVGI is used in most water sterilization processes, such as purification, detoxification and disinfection. Its use in wastewater treatment is replacing chlorination due to that chemical's toxic by-products. A disadvantage 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 waste streams 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)

Laboratory hygiene

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