UV Inactivation of Airborne Bacteria and Viruses in HVAC Systems

By
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Disinfecting air flowing in HVAC systems is critical for protecting the health of individuals in medical environments including, but not limited to, hospitals, clinics, and medical offices, as well as in schools, office buildings and industrial environments. Ultraviolet (UV) light has long been known to be an effective tool for inactivating airborne microbes such as bacteria and viruses that can pose a threat to human health.

To evaluate the various germicidal applications of UV we need to understand characteristics of light and concepts related to irradiation and dosage.

Light is characterized by its frequency or "wavelength". Some wavelengths are visible to the human eye and others are not. In the visible part of the light spectrum, the human eye perceives wavelength as color. Longer wavelengths are perceived as red and shorter wavelengths are perceived as blue. Wavelengths too long to be seen by the human eye are denoted as Infrared (IR) and wavelengths too short to be detected by the human eye are termed Ultraviolet (UV). Certain parts of the UV spectrum are very effective for destroying the ability of bacteria and viruses to live and reproduce.

UV energy of the proper wavelength can be applied to air flowing in HVAC air ducts to inactivate airborne microbes. Two possible approaches are:

1. Simply placing UV sources in an existing HVAC air duct.
2. Installing a specially designed UV air treatment unit into the HVAC system.

These two approaches are compared below. As will be seen, approach #1 of simply installing UV sources in an existing HVAC air duct, while it is the easiest approach, is not very effective. Approach #2, on the other hand, although it is a bit more involved, can provide excellent air disinfection results.

Deactivation of microorganisms requires the application of UV energy of sufficient intensity for a sufficient time. The dose accumulated by a microorganism depends on the power density, which is the UV power per unit area. This is known as the "irradiance". The accumulated dose is the product of the irradiance and the exposure time.

Dose = Irradiance x Time

Irradiance (power density) is typically measured in Watts of UV power divided by the area in square centimeters (mW/cm^2) over which it is applied. Here, mW denotes milli Watts. One mW is 1/1000th of one Watt. The dose is measured in $mW\text{-}s/cm^2$, where s denotes seconds of time. For many typical microbes, the number of viable organisms is reduced by a factor of ten times (90% reduction) by the application of a dose of few $mW\text{-}s/cm^2$ of UV energy of the proper wavelength. A 90% reduction is also termed a 1 log reduction. Higher reduction levels can be achieved by applying higher doses. For example, increasing the dose by a factor of 3 will provide a 3 log (99.9%) reduction. (Each factor of ten reduction is a 1 log reduction.) A reduction of more than 3 – 4 logs is generally considered to be a desirable level of disinfection for protecting against airborne pathogens.

The challenge for deactivating microbes in air flowing in HVAC systems is that the air is usually moving very fast, frequently at speeds of 4-5 feet per second or more. For typical UV sources, this results in exposure times of 1 second or less. This means that high UV irradiance is needed to offset the short exposure time and provide the dose needed for microbe inactivation.

Approach 1: Placing UV sources in an existing HVAC air duct

Figure 1 illustrates the situation for approach #1 where a UV lamp is inserted into an existing airduct. The UV source radiates UV energy in all directions. Some of the energy is directed toward the area of interest, arbitrarily denoted here as point P, but much of the energy is dispersed in other directions.

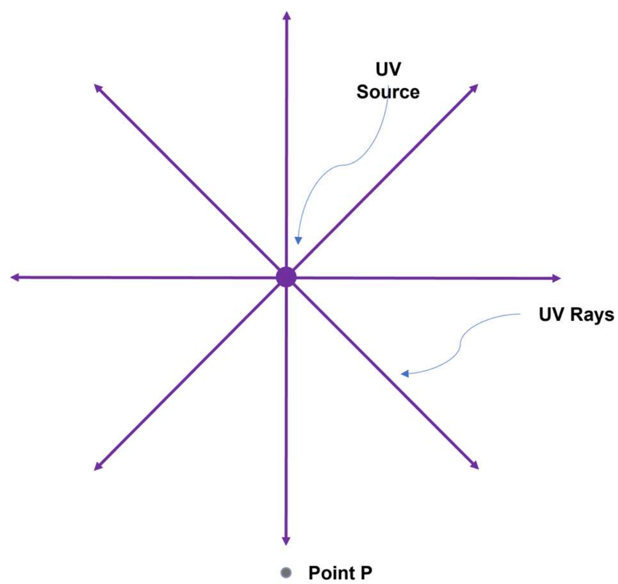

Fig. 1: UV Rays Without Reflections

Unfortunately, the materials used in HVAC air ducts absorb UV energy and reflect very little of it. As a result, the UV energy that is not directed in the desired direction is essentially lost and is not useful for microbial disinfection at point P. Also, since the UV source radiates its power in many directions, the area over which the power is being spread increases significantly at points that are further from the source. As a result, the irradiance, which is the UV power divided by the area, is significantly reduced at these more distant points. This greatly diminishes the antimicrobial effects since they depend directly on the irradiance.

As an example, a common commercial high power UV lamp approximately 5 feet long produces a UV power of 54 Watts. At a distance of 1 meter (about 40 inches) from the lamp, the irradiance is about 0.4 mW/cm^2. A 1 second air transit time past this lamp in the approach #1 configuration would result in a dose of 0.4 mW-s/cm^2. Since a few mW-s/cm^2 of UV dose is needed for even a 1 log reduction for typical microbes, this would not provide an effective air disinfection configuration.

Approach 2: Installing a Specially Designed UV Air Treatment Unit into the HVAC System

Figure 2 illustrates the concept underlying approach #2. In this approach, a reflective chamber constructed of special materials designed to reflect UV energy with high efficiency is used to contain the UV energy and allow it to be reflected many times within the chamber. This configuration can significantly increase the irradiance in the chamber. The figure illustrates conceptually how, rather than lose the UV energy not initially directed toward the point of interest, rays from many different directions are reflected from the chamber walls and the multiple reflections result in much more energy reaching the point of interest, P.

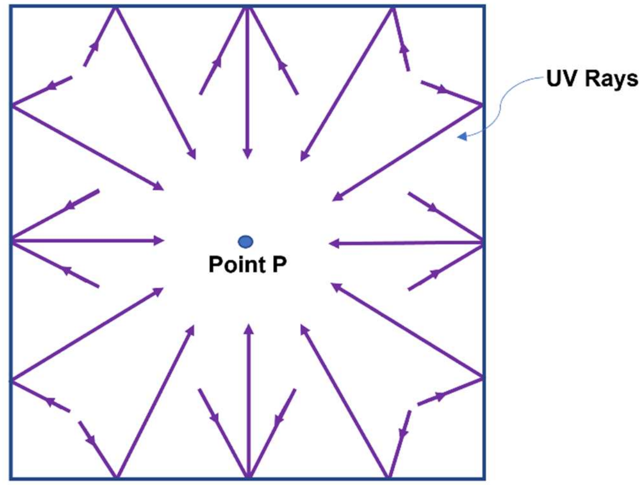

Fig. 2: UV Rays With Reflections

A patented air disinfection unit* using this reflective chamber concept has been 3rd party tested to increase irradiance levels and provide high levels of microbial inactivation. The test unit has a measured irradiance of 14.7 mW/cm^2, which equates to a UV dose of 14.7 mW-s/cm^2 for a 1 second time through the chamber. This is many times the dose of a few mW-s/cm^2 needed for a 1 log reduction of many typical microorganisms. As a result, this approach can provide very high disinfection levels. For example, using the test unit, microbial disinfection levels of 5.1 logs for a typical test bacterium and 3.7 logs for a test virus have been measured in fast flowing air in an air duct.

Another very important benefit of the reflective chamber approach is that multiple reflections within the chamber lead to a much more uniform distribution of the UV energy. This is important because if some parts of the airstream are not adequately disinfected, these elements will mix with other parts of the air volume, significantly diluting the overall disinfection effects. For example, if 10% of the airstream only receives negligible disinfection, the highest achievable disinfection level for the overall airstream would only be about 1 log.

In summary, the reflective chamber technology provides a much more effective approach for disinfecting fast moving air in HVAC systems than the simpler, but much less effective approach of just inserting lamps into an existing HVAC airduct.

* The test unit referenced in Approach 2 is the patented BioProtector 3131 designed and manufactured by Advanced Ultra-Violet Systems, LLC with 3rd party tests conducted on Staph Aureus (aerosolized MRSA) and MS-2 bacteriophage, an EPA-approved surrogate for SARS-CoV-2. Tests yielded disinfection rates of 5.1 log, 99.999% and 3.7 Log, 99.97%, respectively.

About the Author:

Dr. Wayne Clark, The US DoD's "Go to Guy" for Germicidal UV

Dr. Wayne Clark is a senior scientist with extensive experience in high technology environments. He holds B.S., M.S., and Ph.D. degrees in electrical engineering from the University of Texas at Austin, and studied business management at the University of California, San Diego, CA. He was a founder of PurePulse Technologies, Inc., where he led the development of new sterilization and pasteurization technology using intense pulsed ultraviolet source technology. He also founded Novatron, Inc., where he has led the development of innovative intense UV technology for air sterilization. His patented application of UV-C, used in the building's air handlers, has been protecting the US Pentagon from bioterrorism for more than two decades. Dr. Clark holds 18 patents and has authored more than 25 published technical articles.

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