WHITE PAPER

PROTECTING AGAINST AIRBORNE PATHOGENS

Background

Protecting people in buildings against airborne bacteria and viruses is become increasingly important. Reasons for this increase include: rising population density, resulting in increased likelihood of exchange of airborne pathogenic bacteria and viruses in enclosed spaces; the emergence of new pathogens such as SARS and Bird Flu; increases in antibiotic resistant organisms, including antibiotic resistant TB strains; the rising incidence of Hospital Acquired Infections (HAI); and the threat of bio terrorism.

Traditional methods of protecting against airborne microorganisms include filtration for removing organisms from the air and the use of conventional low power ultraviolet (UV) lamps to kill airborne organisms. Both of these approaches have substantial limitations. In this white paper we will discuss a new Advanced UV System (AUVS) technology that overcomes the limitations of traditional protection methods and provides a new level of capability for protecting people in buildings against airborne bacteria and viruses.

Filtration

Filters have been used for many years to remove particulates, including bacteria and viruses from air flowing in Heating, Ventilation and Air Conditioning (HVAC) systems. Filters remove airborne biological contaminants by trapping them. Particle filtration efficiency is measured on the Minimum Efficiency Reporting Value (MERV) scale, which ranges from 1 to 20. The HEPA (High Efficiency Particulate Air) designation is reserved for the higher efficiency filters, rated MERV 17 and above.

The efficiency of a filter depends on particle size, with minimum efficiency typically occurring for particles with a diameter of about 0.3 microns. Since some viruses fall in this size range, they represent the most difficult challenge for filtration.

HEPA filters can provide 99.97% reduction of particulates in flowing air and ULPA (Ultra Low Particulate Air) filters can provide even higher levels of particulate removal. However, filters suffer from a number of limitations. Filters are subject to leakage problems that can severely reduce their effectiveness. Even though a filter may be installed properly and tested at the time of installation, normal thermal expansions and contractions or other mechanical vibrations or movements in the HVAC system may result in a leak developing afterwards that allows some fraction of the air to by-pass the filter, creating downstream contamination. In addition, any pathogens removed from the air become trapped in the filter. This results in a risk of release of the microorganisms when the filters are replaced and necessitates special handling and disposal procedures. High efficiency filters also create a substantial pressure drop in the HVAC system.

Even though, as noted above, filters have some limitations, they are an important technology component for air systems. In particular, UV technology does not remove particulates such as dust from the air. In most air sterilization applications, it is likely that some level of filtration will be needed to remove dust and debris from the air. This might take the form of a lower efficiency filter rather than a HEPA filter, or depending on the application, could involve the use of a HEPA filter in combination with UV technology to provide a very high sterility assurance level.

UV Technology

Ultraviolet (UV) energy has been used to kill microorganisms such as bacteria and viruses in air since the early 1900s. If sufficiently high doses of UV are used, the technology can very effectively sterilize air. Low UV doses and lack of uniformity of the UV radiation can, however, significantly reduce the germicidal effects of UV.

UV energy causes germicidal effects by disrupting the DNA of microorganisms, thereby preventing the organisms from functioning and reproducing. The most effective UV wavelengths for inactivation of microorganisms are in the 220 to 300 nm range, with peak effectiveness near 265 nm. The germicidal effects depend strongly on the amount of UV energy delivered to the organism.

UV energy density is typically measured in units of microwatt–seconds/cm^2 (μW-s/cm^2). This is a measure of the UV energy per unit area incident on the microorganism. The energy density is also referred to as the UV dose. It is the product of the instantaneous UV power density and the time over which it is applied. The power density is typically measured in μWatts/cm^2 and is also known as UV irradiance. Thus, the energy density or UV dose is given by:

$$E\ (\mu W\text{-}s/cm^2) = P\ (\mu W/cm^2) \times t\ (s)$$

The UV energy density or dose required to kill a microorganism varies significantly from one organism to another. Some organisms are much more resistant to UV than others. In particular, some organisms form endospores, which are a semi-dormant form of the organism. Endospores are quite resistant to many sterilization technologies, including heat, chemicals, x-rays, and UV.

Germicidal effects of UV are often described in terms of logs of kill. A kill level of 1 log corresponds to a reduction by a factor of 10 (one order of magnitude) of the number of viable microorganisms. For example, if 1 million microorganisms were exposed to a 1 log kill process, 100,000 would survive. Similarly, 2 logs kill corresponds to a 99% reduction, or 2 orders of magnitude reduction, and 10,000 organisms would survive from an original population of 1 million organisms. In general, kill levels of 6 logs (1 million times reduction in microorganisms) is considered to be sterilization, since at these levels of reduction, it is extremely unlikely that a sufficient number of microorganisms would survive to cause infection or illness, even if the initial population was large.

As an example of the variation in resistance between different classes of organisms, endospores of *Bacillus subtilis var. niger* (name recently changed to *Bacillus atrophaeus)* require 25,000 μW-s/cm^2 for 1 log kill. Two logs kill would require 50,000 μW-s/cm^2, etc. By comparison, *Mycobacterium tuberculosis* (TB), which is a vegetative (fully metabolizing) organism, requires only 2330 μW-s/cm^2 for 1 log kill. Thus, in theory, the UV energy density required for 1 log kill of *B. subtilis* endospores would produce more than 10 logs kill of the TB bacteria.

While some organisms can be killed at lower levels than others, application of sufficient UV energy or dose to kill the most resistant organisms is necessary to assure that all organisms are killed. Since the UV dose is the product of the instantaneous UV irradiance and the time over which it is applied, both factors are important in achieving high kill levels. Applying high UV irradiance for sufficiently long times to produce high doses for air travelling at high speeds in an air duct is a challenge.

Uniformity is also an important factor in microorganism kill, since regions where air is exposed to lower levels of UV can significantly degrade the overall kill achieved. The irradiance produced by a UV lamp depends strongly on distance from the lamp. As a result, in conventional UV systems, the UV irradiance varies significantly from one location in the treatment region to another. If only a few percent of the air flowing through the treatment region is under-treated, the over-all kill level will be significantly decreased. For example, if 10% of the air experiences negligible germicidal effects, the maximum kill level that can be achieved is only about 1 log.

Conventional approaches to treating air with UV typically consist of inserting a lamp or array of lamps into an air duct, either with or without reflective material in the vicinity of the lamps. These "open duct" techniques do not produce a high UV irradiance and the uniformity of the irradiance is poor. As a result of the low UV irradiance and significant variation in irradiance with position in the air stream, germicidal effects are limited.

Advanced UV System (AUVS) Technology

Novatron, Inc. has developed an Advanced UV System (AUVS) technology that provides unique benefits for air sterilization applications. The technology is based on a proprietary reflective cavity technology that significantly increases the intensity and uniformity of UV energy, enabling very high and uniform UV irradiance. The high UV irradiance and high uniformity lead to previously unobtainable levels of air sterilization. The AUVS technology forms the basis for the Novatron BioPretector™ line of air sterilization products.

The AUVS reflective technology developed by Novatron provides a multiplication of UV irradiance by a factor of 20 to 50 times that produced by UV lamps alone. This occurs due to cavity effects somewhat analogous to those in a microwave or laser cavity, where energy is contained and intensity increases due to accumulation of reflected energy.

The result of Novatron's reflective cavity technology is that irradiances in excess of 150,000 $\mu W/cm^2$ can be produced. This means that the 150,000 $\mu W\text{-}s/cm^2$ dose required for 6 logs kill of UV resistant endospores such as *Bacillus subtilis* can be delivered with residence times of 1 second or less, enabling single pass sterilization of air flowing at speeds of several hundred to 1000 ft/min. Without the reflective technology 20 to 50 times as many lamps would be required to achieve these sterilization effects. Such a large number of lamps is not only undesirable in terms of the electrical energy that would be consumed, it is not feasible in terms of cost and the amount of physical space that would be required to install such a large number of lamps.

The AUVS technology enables true sterilization of air. The kill levels of >6 logs (1 million times reduction) for UV resistant endospores achieved with the AUVS technology translates to even higher kill levels for vegetative bacteria such as TB, Legionella, Staph, etc. and viruses. By comparison, a HEPA filter gives a reduction of about 99.97%, or 3.5 logs, (a reduction of about 3300 times). This means that if 1 million organisms were initially present, about 300 would remain downstream of the filter. It is important to keep in mind that because the scale is logarithmic, a 6 log removal efficiency is 300 times more than a removal efficiency of 3.5 logs.

The reflective cavity technology developed by Novatron also creates a very high level of uniformity throughout the cavity. This occurs because the cavity is designed to assure that UV energy reflects to every location in the cavity from every direction. The large number of reflections from all directions within the cavity add together to create a very uniform UV irradiance. UV irradiance has been measured in AUVS cavities to be uniform within a few percent throughout the cavity. This is a unique capability of the AUVS technology that is not obtainable from other approaches and that is essential for achieving high kill levels.

Finally, the AUVS technology is not susceptible to the leakage/by-pass problems that can occur with filters. The AUVS cavity integrates into the HVAC system and is constructed so that all of the airflow through the system must pass through the high intensity UV region. As a result, leakage/by-pass is not an issue. Moreover, by monitoring the UV intensity and knowing its relationship to kill, it is possible to electronically monitor the effectiveness of the system on a 24/7 basis to assure that proper kill levels are being achieved.

Summary

HEPA filters are a standard technology for removing microorganisms from air. However, if HEPA filters are poorly sealed in their frames, either initially or as the seals deteriorate over time, the resulting leakage and bypass may cause performance degradation and downstream contamination. HEPA Filters can also create a significant pressure drop and since they trap rather than kill microorganisms, handling and disposal of contaminated filters are an issue. Even though they have some limitations for high level air disinfection, filters are an important air system component since they provide removal of dust and debris.

UV germicidal irradiation systems provide another means for removing microorganisms from air. The advantage of UV disinfection is that the organisms are killed as opposed to being trapped.

High UV doses and high uniformity are required to achieve high microbial kill levels. High doses require a combination of high instantaneous UV irradiance and substantial exposure time. Uniformity of the UV irradiance is important for achieving high kill levels in flowing air, since all elements of the air stream must be exposed to high irradiance for a sufficient time to create the required dose level needed for high kill.

Conventional UV systems do not provide the high UV irradiance or the uniformity required to sterilize rapidly moving air. The AUVS technology used in Novatron's BioProtector products incorporates a patented reflective cavity technique that creates the very high and very uniform UV irradiance needed to provide high level air sterilization effects in rapidly moving air streams.

The AUVS technology provides a means of achieving the high UV intensities and high uniformity required to achieve true sterilization effects. No other technique, including ULPA filters, can provide the levels of air sterilization achievable with the AUVS technology.