WHITE PAPER

EFFECTS OF INTENSITY VARIATIONS IN UV AIR TREATMENT SYSTEMS

Introduction

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. This White Paper describes a new Advanced UV System (AUVS) technology that provides a breakthrough capability to create highly uniform, very high intensity UV treatment systems for air sterilization.

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 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 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 sufficient long times to produce high doses for air travelling at high speeds in an air duct is difficult. The AUVS technology developed by Novatron, Inc. provides an innovative means for accomplishing this.

UV Uniformity

The UV power density or irradiance emitted by a UV lamp depends strongly on the distance from the lamp, decreasing rapidly as distance from the lamp increases. Figure 1 shows a lamp of length, L, positioned in an air stream. The UV power density, P, measured at a point x located a distance d from the lamp can be calculated if the total lamp UV output power and lamp length are known. Figure 2 shows a plot of the normalized power density at the lamp axial mid-point as a function of normalized distance from the lamp. In the plot, the distance from the lamp, d, is normalized as a fraction of the lamp length, L, and the UV power density is normalized to the power density at d = .05 L.

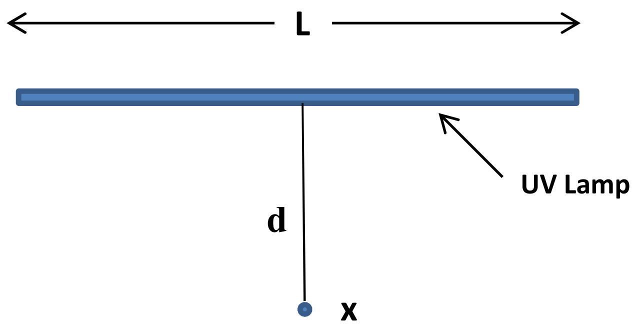


Figure 1: Measurement point x located a distance, d, from a UV lamp of length, L.

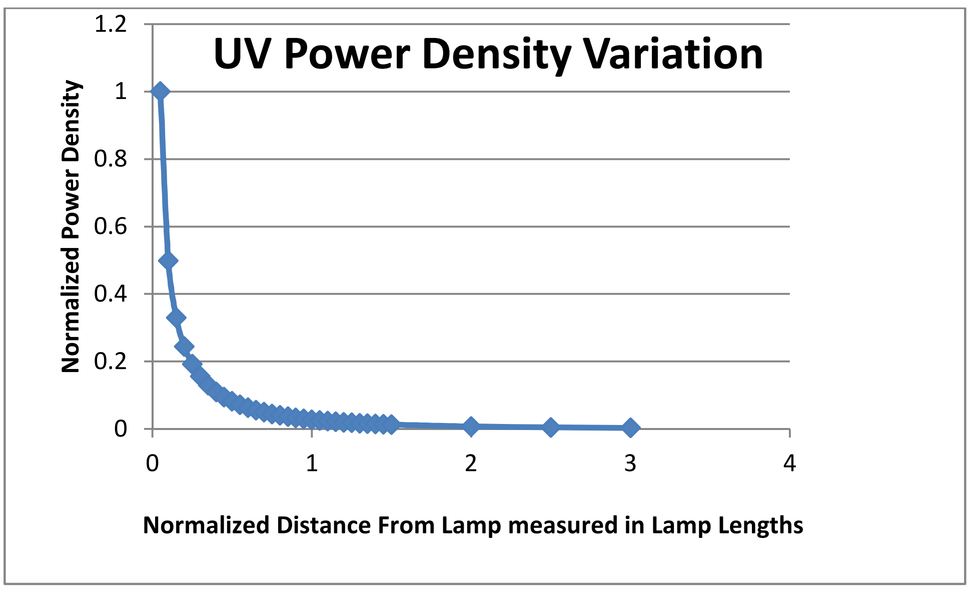
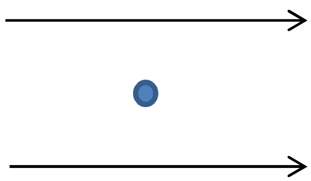


Figure 2: UV power density as a function of distance from a lamp of length L. Distance from the lamp is measured in lamp lengths and power density is normalized to the power density at d = 0.05L.

As can be seen from Figure 2, the UV power density decreases very rapidly with distance from the lamp. For example, at a distance of d = 0.5 L from the lamp, the UV irradiance is only about 8% of the irradiance at d = 0.05 L. If the lamps are placed in a rapidly moving air stream perpendicular to the airflow as shown in Figure 3a, the air will spend a very short time in the relatively high irradiance region near the lamp. Even if the lamps are oriented parallel to the airflow, as shown in Figure 3b, much of the air volume will never be near the lamp and consequently will not receive a high dose.



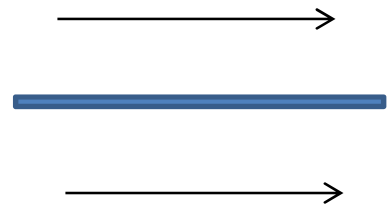


Figure 3a: Perpendicular airflow. ***Figure 3b: Parallel airflow.***

To illustrate the issue, a typical germicidal lamp 71 cm (28 inches) long producing a total UV power of 13.5 watts would produce an irradiance of about 8500 $\mu W/cm^2$ at a distance d = 0.05 L = 3.6 cm (1.4 inches) from the lamp. At a distance d = 0.5 L = 36 cm (14 inches), the irradiance would be only about 700 $\mu W/cm^2$. If the air is travelling at a velocity of 500 ft/min = 254 cm/sec, which is a typical air velocity for air sterilization applications, the air in Figure 3a would spend only a very short time near the lamp and would reach the point d = 36 cm in only about 0.14 seconds. The total accumulated dose, which is determined by the product of the irradiance at each point along the trajectory and the exposure time at that irradiance, would be very low. Thus, resistant organisms such as *Bacillus subtilis*, which as discussed earlier, require about 25,000 $\mu W\text{-}s/cm^2$ for one log kill would not be efficiently killed with such an arrangement.

The AUVS Solution

Novatron 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.

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 substantial increase in 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.

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.

Uniformity is another important factor in microorganism kill, since regions where air is exposed to lower levels of UV can significantly degrade the over-all kill achieved. As described above, the irradiance from 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.

The reflective cavity technology developed by Novatron provides a solution to this problem by producing 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.

Summary

High doses are required to achieve high microbial kill levels with UV energy. 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.