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White Paper

Using UV-C Light for Personal Airborne Pathogen Protection

Method and Apparatus

February 2021

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Abstract

This white paper addresses the issues with current personal airborne pathogen protection (PAPP) methods and describes a new wearable device with UV-C light disinfection for PAPP. The device uses UV-C light at wavelengths around 265 nm, reaching peak efficiency of pathogen inactivation. The main causes of pathogen inactivation using UV-C are mutations in genetic code that lead to a loss of reproductive ability. Our personal device reduces the infectivity of airborne pathogens in breathable air, allowing the immune system to prepare a better response against the active species. The paper also refutes claims of hazardous ozone emissions during UV-C disinfection and shows that at the utilised wavelength, ozone destruction takes place instead.

Introduction

With the recent increased awareness of airborne pathogens and the ongoing COVID-19 pandemic, more effective personal protective equipment (PPE) is in great demand. The situation is made worse by the fact that the typical measures of disease control, namely vaccines and antibiotics, are slow to be developed while pathogens can mutate, reducing the effectiveness of disease control measures.

For individuals, the most common preventative methods for decreasing the spread of airborne infectious diseases are social distancing and passive PPEs, e.g. surgical masks. Unfortunately, social distancing is not always a possibility, while surgical masks are hardly effective.

Face masks are generally unable to filter particles below 300 nm in size effectively (the size of an individual virion can range from 20 to 400 nm [1]) and become increasingly ineffective as the mask becomes obstructed by pathogens, dust and condensing water vapour. Additionally, in the case of an improper seal, the contaminated air can bypass the mask completely, making it ineffective. As surgical masks require frequent replacement and disposal, they have a comparatively high daily cost. Moreover, the constant disposal of used masks is wasteful and environmentally harmful.

Germicidal UV Light

Ultraviolet light is characterized by wavelengths ranging from 10 to 400 nanometres on the electromagnetic spectrum. It is classified into four main categories: UV-A (315-400 nm), UV-B (280-315 nm), UV-C (100-280 nm) and vacuum ultraviolet (V-UV, 10-200 nm). Germicidal properties of UV have been known for over a century. The medical industry has mainly been interested in UV-C, which has germicidal properties with peak effectiveness at about 260-265 nm [2]. The disinfection method of using UV-C is called ultraviolet germicidal irradiation, or UVGI.

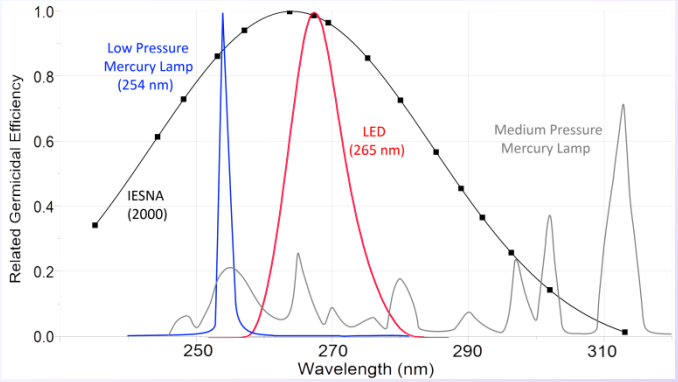

Figure 1: Standardised germicidal response function (black) with superimposed emission spectra of various UV light sources [2].

For decades, low-pressure mercury vapour lamps have been used in UV-C disinfection applications, as they radiate a significant amount of energy at 254 nm, which is close to peak germicidal efficiency. However, newer generation UV-C LEDs are able to emit an even more efficient spectrum of wavelengths while being smaller and more energy-efficient than mercury vapour lamps. The germicidal

efficiency of UV light at different wavelengths can be seen in Figure 1.

UV-C Pathogen Inactivation

The primary mode of inactivation takes place when the absorption of a photon from UV-C wavelengths forms pyrimidine dimers between adjacent thymine bases, by making the crosslink more energetically stable than a hydrogen bond in the DNA. This process is illustrated in Figure 2. Analogously, dimers between adjacent cytosine or uracil bases are formed in RNA. As DNA and RNA are responsible for microbial reproduction and protein synthesis, damage to them renders the microbe incapable of replicating and surviving. The "weakest links" of microorganisms are the DNA of bacteria, DNA of DNA viruses, the RNA of RNA viruses and the DNA of fungi. [3]

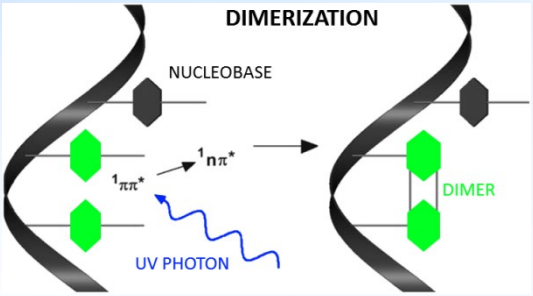

Figure 2: Illustration of the dimerization process for a thymine doublet [3].

Similarly, thymine cross-linking can occur between DNA/RNA and proteins in membranes of viruses, disrupting the functionality of both. Furthermore, the formation of other photoproducts can lead to cell death. [3]

Effectiveness Against Airborne Pathogens

The disinfection module of our device was tested in the Laboratory of Department of Environmental Biotechnology at Lodz University of Technology (Poland) for assessment of the effectiveness of bioaerosol disinfection at conditions of bacterial filtration efficiency (BFE) test of the EN14683 standard. The BFE is given by the number of colony-forming units (CFU) passing through the filter expressed as a percentage of the number of CFU present in the challenge aerosol.

The tests were conducted using *Staphylococcus aureus* and *Escherichia coli* as the tested organisms. The disinfection module of our device was used instead of filters, which are typically used for this type of tests. A liquid suspension of bacteria was aerosolized and passed through the module at a constant flow rate of 30 litres per minute.

The decrease in the number of pathogens from the initial N_0 to the final N number can be expressed via the number of log reductions, Q:

$$Q = -\log_{10}\frac{N}{N_0}$$

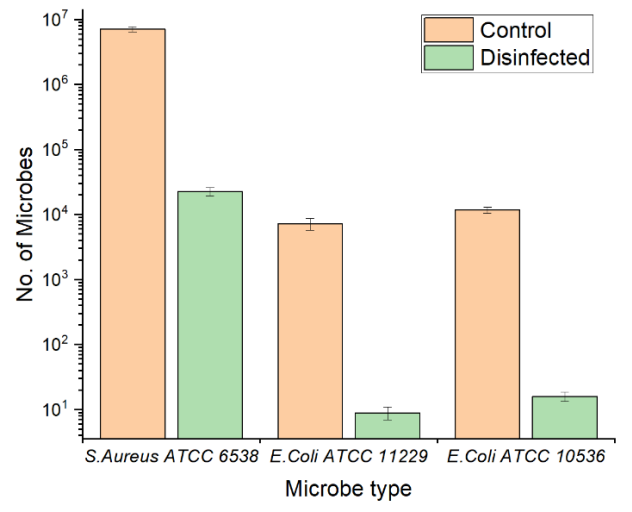

Figure 3: Number of active bacteria in bioaerosol without UV-C treatment (control) and after the treatment at 30 l/min airflow.

The test results presented in Figure 3 show 99.68 and 99.89% efficiency in reducing the amount of *S. aureus* and *E. coli*, or about 2.50 and 2.95 Log reduction respectively.

According to the Ultraviolet Germicidal Irradiation Handbook, the coronavirus family has a similar, slightly decreased resistance to UV-C irradiation when compared to E. coli [3]. Due to the required biosafety level precautions, it has been difficult to test the novel coronavirus SARS-CoV-2. Indirect observations can be made that in terms of genomic characteristics important to UV-induced damage, SARS-CoV-2 is

very similar to the previous and more researched SARS-CoV-1 at 254 nm [4].

Ozone Safety

A common safety concern about UV-C based devices is the possible emission of ozone. Indeed, the energy of photons at wavelengths below 242 nm is sufficient to break the oxygen (O_2) bonds, leading to the formation of ozone (O_3). Older low-pressure mercury UV-C lamps had an additional, smaller peak at around 183 nm, which is in the ozone formation spectral range. Additionally, far UV-C LEDs (~222 nm) used in some newer disinfection devices will produce some amounts of ozone.

On the contrary, UV light in the 242-315 nm range has been found to do the opposite – disrupt the covalent bonds of the ozone molecules and lead to the formation of oxygen molecules. This process occurs most effectively at 245-265 nm [5], near the wavelengths of UV-C LEDs used in our device. An illustration of these processes can be seen in Figure 4.

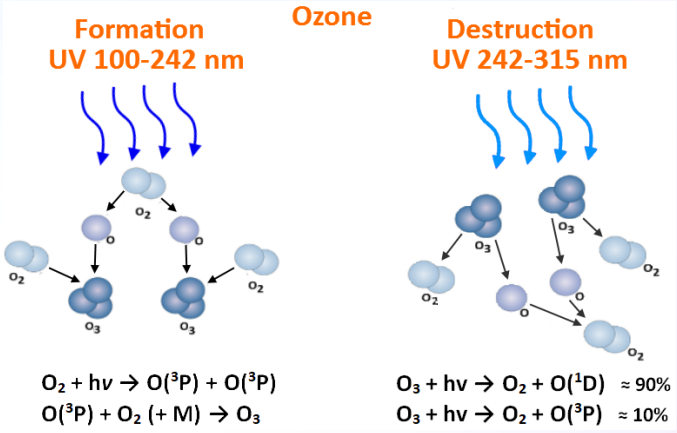

Figure 4: Atmospheric ozone formation/destruction [5].

UV Safety

Although UV-C light can cause mutations in the genetic material of microorganisms, the top layer of human skin has low transparency to UV-C light of the wavelengths in question, thus providing some protection against damage. However, exposure to UV-C light can still cause cutaneous (skin) and ocular (eye) damage. It is extremely important to avoid UV leakage from the device. These concerns are thoroughly addressed in our design to ensure the safety of customers.

UV-C can also break down chemical bonds, leading to rapid degradation of most polymers. We have considered this property in our design as well and have made necessary substitutions to our selection of materials.

Technology description

Our patented UV-C module uses a spiral-shaped tube design with a reflective interior surface to achieve high inner reflectivity. This provides UV-C irradiation from all directions to the airborne pathogens moving through the spiral, leading to a higher dosage and a lower time required in the module for high rates of inactivation. As most radiation dosage calculations for UV-C pathogen inactivation assume light coming from a single direction, calculating the received dosage in our module is notably more complex.

Device description

Our initial device is a PAPP device meant to be worn on its user's shoulders that provides disinfected air to the area in front of the wearer's face. The design prioritises comfort and keeping the mouth of the wearer unobstructed for unrestricted breathing and a better ability to show expressions. The device is able to disinfect 55 litres of air per minute, which is about 3-4 times more than an average resting adult human breathes in a minute [6]. Optionally, a face shield can be attached to the device to help control the air movement and protect against direct coughing and sneezing.

Immunisation

UV-C disinfection has also been hypothesised to provide immunity to viruses, as a reduced amount of

viral inoculum usually leads to reduced severity of the disease (theory of viral pathogenesis) and as most viruses reaching the host have been inactivated by the device, the immune system can start producing antibodies. This reduced dose of inactivated viruses has the potential to lead to a form of variolation [7]. Further research is needed to determine its actual effectiveness against viruses, such as SARS-CoV-2.

Conclusion

Improved and more effective methods of PAPP are needed to reduce the spread of disease and combat the ongoing pandemic. Germicidal UV-C radiation at around 265 nm can inactivate pathogens by causing changes in their genetic code and causing a loss of ability to replicate, providing a potentially superior method of disinfection. Although legacy mercury UV-C lamps caused the formation of ozone, newer LEDs destroy ozone instead. Our engineering solution is based on a spiral-shaped reflective air module which increases the irradiation efficiency of airborne pathogens passing through it, resulting in higher received UV doses and therefore higher inactivation rates.

References

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