Reducing Viral Load with UV-C Air Sanitization

A review of the Efficacy of UV-C Air Sanitization in Reducing Viral Load

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1 Overview

Airborne viruses account for millions of illnesses worldwide and are a constant and ubiquitous source of nuisance and danger on a global scale (Turner, 2009). Developing effective ways to reduce viral load is of utmost importance to improving human health and well-being. Here, we review the efficacy of using UV-C Air Sanitization in reducing airborne viral load in various capacities. We found that UV-C air sanitization is an effective means of significantly reducing airborne viral load in an enclosed space. This literature review suggests that implementing this technology into existing air filtration and HVAC systems has an important role in indoor health and safety.

2 Factors Affecting Viral Load

Viral load is directly correlated with an increased risk of transmission. Proper and regular monitoring of viral load is useful in reinforcing the need for enhanced adherence to safety measures and measuring the effectiveness of safety interventions (Bonner et al., 2013). Therefore, methods that are effective at reducing viral load could potentially be employed as a useful risk reduction method. Environmental factors are one key element in the transmissibility of viral illnesses. In mouse and guinea pig transmission studies, relative humidity was shown to have a bimodal impact on transmission. In one study, the maximal transmission of airborne viruses was seen at 20-35% relative humidity. The transmission was poor at 50%, peaked again at 65%, and was absent at 80% relative humidity (Lowen et al., 2007). In addition, cooler temperatures ($5°C$) resulted in increased transmission when compared to room temperature, and transmission was not seen at higher temperatures ($30°C$). The impact of airflow and ventilation is less understood. One case study during the 2002 outbreak of SARS coronavirus used fluid-dynamic modelling to reveal the dispersion pattern of transmission stemming from a single individual, causing viral particles to get lodged and subsequently recirculated in U-loop plumbing traps and air vents (McKinney et al., 2006). Therefore, equipping existing airflow and ventilation systems with proper sanitization equipment could be a sensible way of reducing viral load. In addition, proper circulation allows for better mixing of air pockets. This is relevant to viral transmissibility, as increased stratification, where upper and lower room air remains isolated, could impair the ability of disinfection tactics used to eliminate aerosolized viral particles (Beggs and Sleigh, 2002). Beggs and Sleigh showed that the number of passes that aerosolized particles can make in an enclosed space, assuming steady-state conditions, is independent of the ventilation rate. Furthermore, UV-C radiation in highly ventilated regions may be of less efficacy compared to lower ventilation rates.

3 Mechanism of UV-C Air Sanitization

Ultraviolet radiation is one example of electromagnetic radiation that carries a short wavelength and a higher level of energy. At a wavelength of 254 nm, UV-C radiation has been employed as a virucidal and bactericidal agent since the 1900s (Biasin et al., 2021). UV light is capable of penetrating through cell membranes, including the lipid envelopes of many viral particles, and reaching the genetic content enclosed within. DNA serves as the genetic "blueprint" of living cells and its accurate and faithful replication is a crucial step of cell division and virus propagation (Portin, 2014). Any disruption to this intricate replication process can introduce an error, or mutation, within the genetic code. The effect of mutations depends on their location within the genome and can range from not having any appreciable effect on viral phenotype (silent mutation), to entirely knocking out a protein critical for cell function (nonsense mutation). UV mutagenesis is a well-established phenomenon, known to be responsible for the increased risk of skin cancers after prolonged sun exposure, and is deployed purposefully in research to induce mutations in model organisms. (Pitts, 1990).

Upon reaching DNA molecules, UV light acts to disrupt their binding, leading to the formation of pyrimidine dimers (Douki et al., 2017). Pyrimidine dimers are the result of covalent bond formation between adjacent pyrimidines, namely thymine or cytosine, that links them together. In normal DNA, each nitrogenous base is linked in a linear chain by their phosphate backbones. In the event of a pyrimidine dimer, carbon-carbon bonds form between carbons within the nitrogenous base ring itself.

DNA replication enzymes are unable to properly read bases linked by this kind of bond, resulting in faulty replication and a highly increased chance of mutation. Various DNA repair mechanisms also exist as a protective trait to increase the fidelity of DNA replication. However, base excision repair of pyrimidine dimers is prone to introducing mutations in and of itself (Douki et al., 2017). Thus, UV radiation is effective at causing random mutagenesis within a viral genome. The accumulation of enough mutations is effective at rendering a virus incapable of further propagation, effectively neutralizing its pathogenicity.

4 UV-C Air Sanitization Testing on a Bacteriophage

The MS2 bacteriophage is a non-enveloped, single stranded RNA virus bacteriophage that infects E. coli bacteria (Zhang et al., 2020). It is often used as a surrogate for RNA viruses that infect humans, including Norovirus and the SARS-CoV-2 virus, in testing air filtration and air purification systems. Because the efficacy of bacteriophage MS2 as a testing surrogate is well established, we used it to test our Air Sniper Induct 300W sanitization system. We collected air sam-

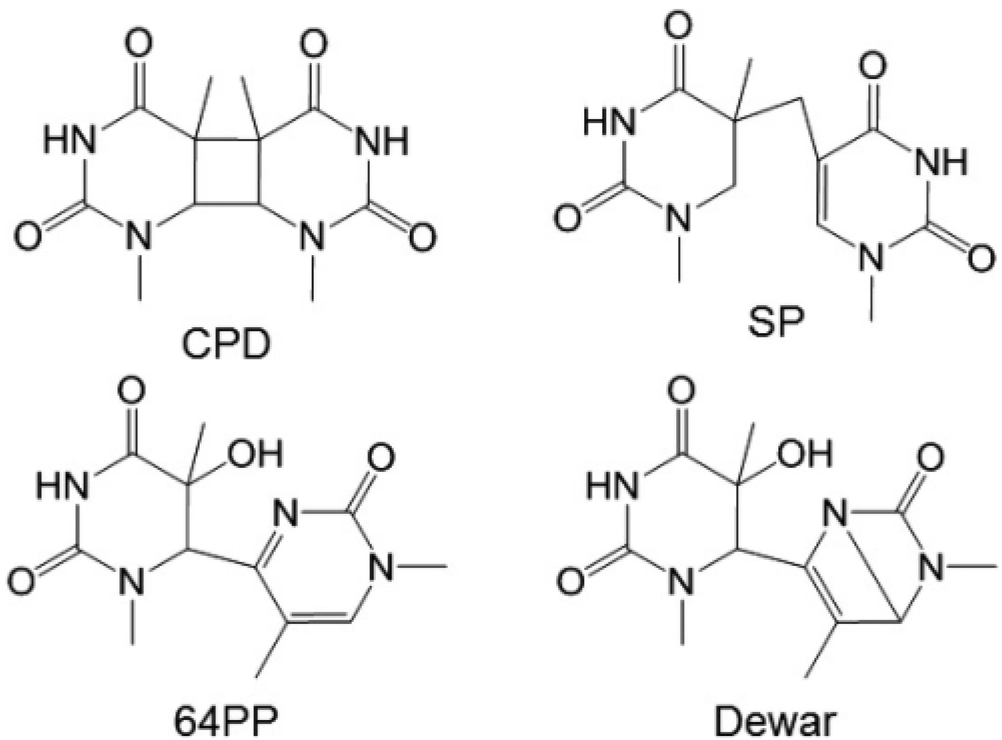


Figure 1: Figure: Douki et al., 2016.

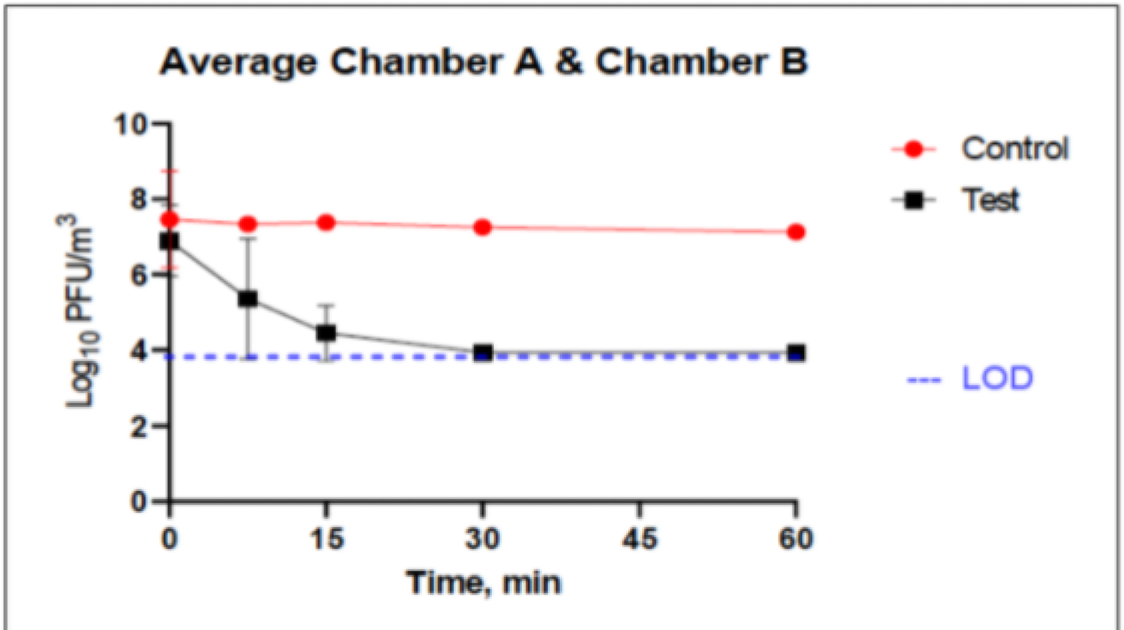
ples at 7.5 minute, 15 minute, 30 minute, and 60 minute time intervals and assayed for viral load using a viral plaque assay, which we reported as the number of plaque forming units per cubic metre. Compared to the control, which detected an average MS2 concentration of $2.04*10^7$ PFU/m^3 (7.31 Log($_{10}$) PFU/m^3) after 30 minutes of exposure to our UV-C system, our treatment sample showed a viral load below detectable levels. Similar trends were seen in other time-points (ZiuZina, 2021). Our testing demonstrates a high level of efficacy of UV-C in eliminating bacteriophage MS2 levels. While this bacteriophage is well established as a model of other similar RNA viruses, further testing on causative pathogens would be ideal to better understand more subtle differences in efficacy between individual viral structures.

5 UV-C Air Sanitization Testing on SARS-CoV-2

Ultraviolet light irradiation has been proposed as a potential effective intervention against COVID-19 since the beginning of the pandemic as early as January 2020 (Beggs and Avital, 2020). In particular, use of this technique in upper-room regions of enclosed indoor spaces could allow for the creation of an irradiation field that projects against SARS-CoV-2 while remaining safe for human occupants. In a liquid medium, SARS-CoV-2 has been shown to be easily inactivated by UV-C irradiation at a wavelength of 254nm (Beggs and Avital, 2020). It is well established that the intensity of UV light, or any EMR radiation for that matter, is decreased as it loses energy passing through a liquid medium (Gregory, 2005). Any other particulates within the medium, regardless of its phase, can also inhibit the total amount of energy that ultimately reaches the target virus. Therefore, one can postulate that aerosolized viral particles could be more susceptible to UV irradiation than those submerged in liquid media. Due to the novelty of SARS-CoV-2, less literature is available on this, but a few studies have demonstrated its effects.

To better examine the virucidal effects of UV-C radiation, one study exposed the SARS-CoV-2 virus at varying viral loads to varying degrees of UV-C exposure (Biasin et al., 2021). SARS-CoV-2 is the causative agent of COVID-19, and has led to the devastating impacts of the COVID-19 pandemic (Hussain et al., 2020). They found that a UV-C dose of 3.7 mJ/cm^2 was sufficient to result in a 3-log inactivation of viral load. Complete inactivation was seen at a larger 16.9 mJ/cm^2 dosage (Biasin et al., 2021). Even at concentrations lower than 3.7 mJ/cm^2, no viral replication was reported 6 days after treatment with UV-C radiation.

Another group looked at the effect of UV-C on viral load on six different commonly used materials: glass, gauze, wood, fleece, and wool (Criscuolo et al., 2021). After 15 minutes of irradiation at a distance of 20 cm, greater than 99.9% reduction was seen on glass, plastic, and gauze, while an appreciable 90% and 94.4% reduction was seen on fleece and wool, respectively. While these studies



The average concentration of airborne MS2 determined in test chambers A and B. LOD: limit of detection 3.94 Log_{10} PFU/m^3

Figure 2: Air Sniper Third Party Test Results. (Figure: ZiuZina, 2021)

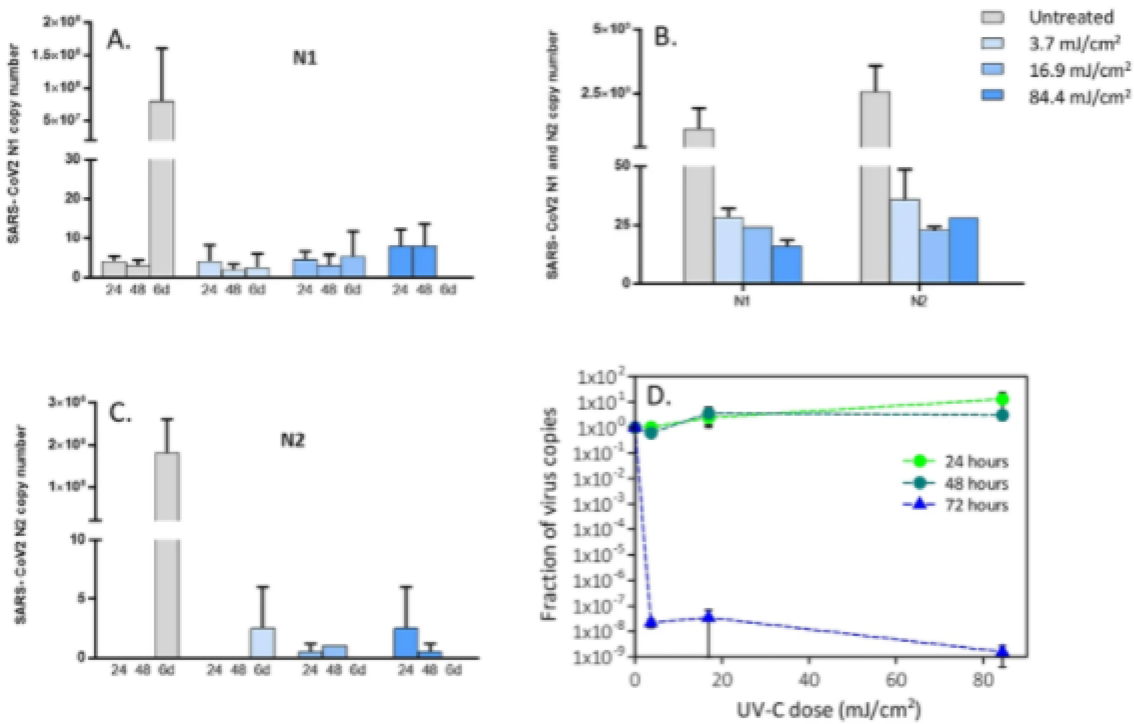


Figure 3: Biasin et al., 2021

present compelling evidence on the effectiveness of UV-C radiation, they did not examine UV-C efficacy in an airborne medium.

6 Applications of UV-C Air Sanitization in Various Contexts

Nosocomial infection poses a significant threat to patient safety in healthcare facilities. UV-C radiation has been shown to be 99.9% effective at eliminating common nosocomial pathogens, such as methicillin-resistant S. aureus, C. difficile, and Vancomycin-resistant Enterococcus species (Rutala et al., 2010). In addition, UV-C has also been shown to be effective at reducing the amount of bacteria including E. coli and E. faecalis, as well as fungi such as Candida albicans (Rodriguez-Chueca et al., 2019). UV-C sanitization equipment has been routinely used in wastewater treatment and disinfection. One of the benefits of upper-room UV-C sanitizing devices is the ease of which they can be retrofitted into existing infrastructure and airflow systems. Because of this, it is particularly useful when applied to surfaces or spaces that are difficult to sanitize through surface hygiene.

7 Conclusion

A multitude of factors, including temperature, relative humidity, and air stratification, work in tandem to impact viral load. Achieving a maximal reduction in viral load plays an important role in reducing the number of viral transmissions, particularly in the wake of the ongoing SARS-CoV-2 pandemic. We show that UV-C sanitizing technology, like that used in the Air Sniper Induct 300W, is effective at eliminating 99.99% of aerosolized viral particles within a given enclosed space. While its efficacy is high in and of itself, UV-C sanitizing equipment is most effectively deployed in combination with a layered approach alongside masks, surface hygiene, physical distancing, and hand hygiene to achieve a maximal viral load reduction.

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