ABSTRACT

Prevention of the spread of diseases caused by airborne biological pathogens is of great concern. This was especially outlined by the Covid-19 Pandemic, which was caused by the SARS-CoV-2 virus. One method for preventing the transmission of airborne pathogens is UV-C irradiation, which has been proven to effectively inactivate a wide range of airborne pathogens, including influenza viruses and coronaviruses. Disinfection of air using UV-C is usually employed through upper-room Germicidal Ultraviolet Irradiation (UVGI) and UV-C based air cleaners in HVAC ducts or stationary cabinets. Near-field applications of UV-C disinfection are being explored through implementation in personal protective equipment.

A series of personal protective devices were developed for real time inactivation of airborne pathogens in military or civilian applications. The devices use UV-C radiation from low-pressure mercury lamps (254 nm) and UV-C LEDs (nominally 277 or 282 nm) to inactivate airborne pathogens that are inhaled or exhaled by users, thereby reducing the risk of disease transmission. The devices employ Porex PMR20, a material highly reflective of UV-C radiation, to increase photon recycling and improve the fluence rate fields inside the reactors. To determine the efficacy of these UV-C devices, testing procedures were developed and applied. A two-part procedure was employed: (1) measurement of the fluence rate using the Micro Fluorescent Silica Device (MFSD) and a positioning device and (2) biological experiments using T1 bacteriophage as an aerosolized challenge agent to quantify inactivation achieved.

The fluence rate measurements were completed by fixing the location of the MFSD probe and moving the reactors to precise locations using the positioning device. The MFSD measurements were converted to fluence rate using measurements from an NIST calibrated radiometer and collimated UV-C sources. When comparing the measurements with and without the PMR20, the local fluence rate for the LED reactors was found to be amplified by up to 10 times the value without the PMR20. A central peak was also found for both LED reactors, which was not present in measurements without the PMR20. Of the two LED reactors, the Nichia Reactor was found to have higher peaks in fluence rate due to the higher output from the LEDs when compared to the JLED brand LEDs. The LP Hg Pod was found to have less significant amplification from the PMR20, with the maximum amplification being only 3 times the value without PMR20. The fluence rate near the walls lined with PMR20 was found to have the highest amplification for the Pod reactor, due to the lamp being located at the center of the reactor (unlike the LED reactors, where UV-C sources were positioned along the reactor walls).

The biological experiments were conducted using aerosolized T1 bacteriophage as a challenge agent. T1 was selected for these experiments because it has been shown to be more resistant to inactivation at the wavelengths of interest than most airborne pathogens; as such, T1 is a conservative surrogate for airborne pathogens in these applications. Experiments were conducted first at one flow rate and subsequently at a range of flow rates to quantify the effectiveness of the reactors and the impact the PMR20 on the inactivation response. When tested at the lowest flow rate of 2.5 L/min, all three reactors were found to provide inactivation at least as effective as the nominal removal provided by an N95 mask (95% or 1.3 $\log_{10}$ units). The LP Hg Pod reactor was found to provide at least this level of inactivation (1.3 $\log_{10}$ units) at flow rates up to 52.5 L/min when PMR20 lined the reactor. When tested without the PMR20, the loss in inactivation was substantial at 52.5 L/min but not at the lower flow rates.

The testing protocol developed and applied in this project could be applied to a range of other reactors intended for disinfection of air. A need exists to standardize testing and validation methods for UV-C based reactors and devices that are used to disinfect air. As such, the methods described herein may allow translation to other UV-C based devices.