An Innovative a Far-UVC

Light-based Respirator Mask Cartridge for Protection against Microorganisms

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1. Introduction

The recent COVID-19 pandemic has created an urgent need for more effective respiratory protection against airborne diseases. This research project presents the development of an innovative, reusable respirator cartridge that integrates far-UVC LEDs to disinfect inhaled and exhaled airflows. Far-UVC has germicidal effects and is safe for human exposure. This novel approach represents an advancement over previous disposable masks and passive-filtration techniques.

2. Methodology

2.1. Proposed Design Concept

The central concept proposed involved disinfecting air containing airborne pathogens as they enter and exit the human respiratory system. The primary goal was to ensure the safety of uninfected individuals by preventing them from inhaling contaminated air and preventing infected individuals from transmitting pathogens in their exhaled breath. This can be achieved by implementing a respirator incorporating far-UVC light for disinfection.

The proposed design envisions a respirator with a specially equipped cartridge containing far-UVC light (Figure 1). Air entering the respirator passes through the cartridge and is exposed to UVC radiation for disinfection during inhalation and exhalation. This innovative approach provides a protective barrier that safeguards individuals from inhaling infectious agents and mitigates the risk of pathogen transmission via exhaled air.

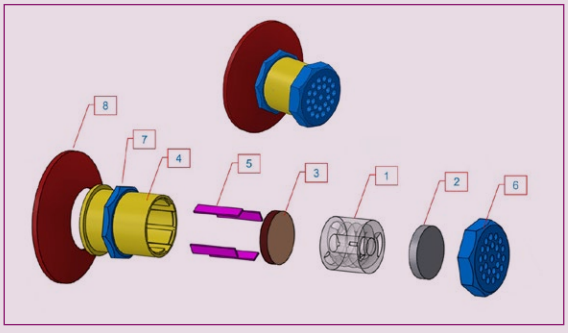

Figure 1: Exploded view of the proposed UV respirator cartridge.

2.2. Optimization of the Design

The efficacy of germicidal UV irradiation in disinfecting respirator cartridges relies on two key factors: UVC radiation intensity and duration of exposure. The exposure time should be maximized to achieve a high level of decontamination. Optimizing both UVC intensity, through proper selection of the UV light source, and sufficient exposure time will lead to the most effective disinfection, enabling the safe reuse of respirator cartridges.

Since most commercially available UV systems operate at the optimal germicidal wavelength, the exposure time, primarily determined by the design of the cartridge (length of the helical tube), is the key factor in optimizing disinfection efficacy. Increasing exposure time lengthens the airflow path inside the cartridge, allowing the air to remain in contact with UV radiation for an extended period. This can be achieved by adding baffles, turns, and labyrinthine passages within the cartridge's interior. However, extended air paths create significant pressure drops, making inhalation and exhalation more difficult.

2.3. Respirator Standards

To ensure safety and efficacy, the respirator's design must adhere to established performance standards. The National Institute for Occupational Safety and Health (NIOSH) provides the testing protocols and requirements for respiratory resistance. According to NIOSH's regulation 42 CFR Part 84, respirators must be tested at an airflow rate of 85 L/min (approx. 0.00142 m^3/s) to determine the maximum inhalation and exhalation resistance. The allowable limit is less than 70 mm of water pressure during inhalation and exhalation. Exceeding these resistance thresholds impedes airflow, making breathing through a respirator difficult and fatiguing. Compliance with NIOSH criteria helps guarantee that respirators do not impose unreasonable physiological burdens during their intended use.

2.4. Process of Optimizing the Design

An iterative process was undertaken to optimize the design of a respirator cartridge, maximizing disinfection efficacy while minimizing breathing resistance (pressure differences) and ergonomic impact on the user. Multiple concepts were evaluated using the following key parameters:

- Shape and length of the air path: A more extended, convoluted path increases the time of exposure to UV but also increases the size and breathing resistance.
- Cross-section of the air path: A larger cross-section reduces resistance but increases the cartridge's size. The shape affects exposure to UV radiation.

- Dimensions of the cartridge: Height and diameter affect the fit, the user's field of view, and the overall weight.
- Transparency of the material: Highly transparent materials improve UV transmission into the air's path. Transparency depends on the material used and the surface finish of the final product.
- Weight: Excess weight contributes to fatigue during prolonged use.
- Breathing resistance: The drop-in pressure across the cartridge must remain below 70 mm H_2O as per NIOSH's standards.

2.5. CFD Simulation

A numerical investigation using SolidWorks was conducted to assess the breathing resistance of several respirator cartridge designs through CFD simulations (Figure 2). The objective was to determine compliance with NIOSH's inhalation and exhalation resistance criterion, which is a drop-in pressure of less than 70 mm H_2O. The CFD models simulate the airflow and pressure fields inside the cartridge under normal breathing conditions. The tests measured the pressure differential across each cartridge prototype at an inlet airflow rate of 85 L/min (0.00142 m^3/s).

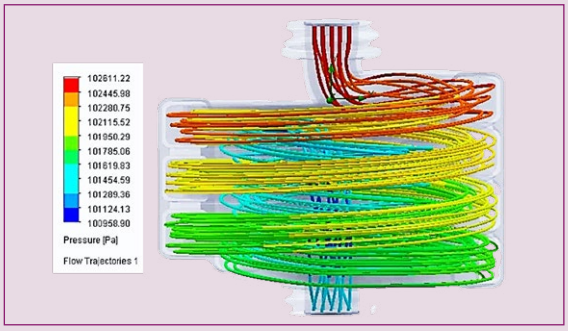

Figure 2: Results of the computational fluid dynamics simulation.

In summary, the selected design (Figure 3) uniformly addressed all critical objectives of optimization:

- It maximized the delivery of UV via a lengthy dual helix path.
- It complied with the standards for breathing resistance.
- Its compact and lightweight construction ensured its usability.
- The streamlined dimensions ensured the visibility and mobility of the user.

The integrated strengths of Design 6 made it the ideal candidate for final optimization and commercialization as a far-UVC respirator cartridge. Further design refinement will focus on finalizing the materials, printing parameters, and ergonomic factors, while preserving the superior performance.

The outcome will be an optimized cartridge that combines industry-leading disinfection efficacy with uncompromising user safety, comfort, and regulatory compliance. This will expand access to reusable respiratory protection, helping to safeguard frontline personnel against airborne pathogens.

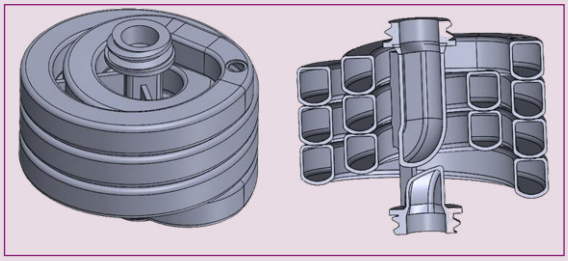

Figure 3: The final design of the cartridge with a section view showing the internal details.

3. Laboratory Experiments and Results

In a proof-of-concept experiment, we tested the effectiveness of a novel far-UVC 3D-printed cartridge mask. Four volunteers were asked to exhale three times while wearing the 3D-printed mask with the UVC lights off and then three times with the UVC lights on. The aerosolized oral bacteria in their exhaled breath were collected on bacterial agar plates before the subjects wore the mask. These samples were incubated at 37°C overnight. The next day, we assessed the number of viable bacterial colonies on the agar plates, comparing the results between the conditions with and without UVC. The data suggest that using far-UVC in the cartridge of respirator masks can reduce aerosolized bacteria. However, the study's limitation is that it could not capture the mask's effectiveness against aerosolized viruses. Future research to examine the efficacy against viruses using human cell culture methods is warranted.

4. Conclusion

In conclusion, the resulting modular cartridge assembly effectively delivers far-UVC disinfection, meets NIOSH's breathing resistance standards, and prioritizes user safety, comfort, and mobility. It also displayed promising bacterial inactivation, warranting further validation of its efficacy in eliminating viruses.