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A Natural Catalytic Converter® for Continuously Inactivating Air and Surface Pathogens with More Effect than Ventilation and Filtration

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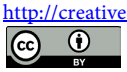

Abstract

Study Objective: The purpose of the study is to present independent laboratory testing for a novel technology in air and on surfaces. Since 2020, public health goals have focused on improving indoor air quality. This includes protection from airborne pathogens, such as tuberculosis, RSV, SARS-CoV-2, common cold or influenza viruses, measles, and others. Engineering controls are highly effective at reducing hazardous pathogens found in indoor air and from recontamination of surfaces. This occurs from a continuous cycle of settling of small, sustained airborne pathogens, which may become dehumidified, becoming airborne again, carried by room air currents around indoor spaces, then repeating the cycle. Methods: The novel technology utilizes a catalytic process to produce safe levels of hydrogen peroxide gas that are effective in reducing pathogens in the air and on surfaces. Air testing was performed with the MS2 bacteriophage, the test organism for ASHRAE standard 241, and *methicillin-Resistant Staphylococcus aureus* (MRSA). Surface testing was performed with SARS-COV-2 (Coronavirus COVID-19) and H1N1 (Influenza). Typical ventilation and filtration does not effectively remove disbursed pathogens from the entire facility, due to inconsistent air circulation and surface deposits of pathogens. Results: MS2 was reduced by 99.9%; MRSA was reduced by 99.9%; SARS-CoV-2 was reduced by 99.9%; H1N1 was reduced by 99.9%. Conclusion: This novel catalytic converter reduces a variety of pathogens in the air (99%) and on surfaces (99%), by actively disinfecting with the introduction of gaseous hydrogen peroxide. This active disinfection provides a strong solution for protecting the entire facility and its occupants.

Keywords

Pathogen, Bacteria, Virus, Reduction, Gaseous Hydrogen Peroxide, Disinfection, Indoor Air Quality, Surface

1. Introduction

Following the emergence of the COVID-19 epidemic in early 2020, a group of interdisciplinary scientists from around the world alerted the World Health Organization about the public health imperative to control airborne transmission of SARS-CoV-2. These concerns were dismissed, resulting in transmission of avoidable infections worldwide, with millions of lives lost [1]. Before this time, scientific research had established that the size distribution of exhaled particles is concentrated in close proximity to infected individuals [2], which are also dispersed throughout indoor space [3].

Since then, new, and emerging science has significantly advanced our understanding of how airborne particles from infected individuals can be transmitted from one person to another in close proximity indoors. In addition, what is most important is advanced understanding of the patterns of contamination by airborne particles throughout indoor space. In the United States, early studies in a quarantine facility at the University of Nebraska documented air and surface contamination around the rooms of individuals infected with SARS-CoV-2. This included under the bed on the floor, at room air vents, and at the waist and shoes of health workers [4]. In fact, while distances of 3 feet from infected individuals were implicated in transmission efficiency early in the pandemic, some called into question this limit [5]. This is a dynamic area of scientific investigation, and methods to reduce risks from air and surface contamination in indoor space are important in a variety of indoor settings.

Ventilation is known to impact the concentration of airborne particles in indoor spaces, although even in reviews of ventilation studies, higher ventilation rate should not be the only consideration for designing ventilation systems for risk reduction, in which multiple factors should be considered [6]. Clearly, ventilation along is necessary but insufficient to reduce indoor air pathogens, although this is not an exact science. This would be dependent on several factors: balancing natural and mechanical ventilation [7], impact of concentration of airborne microbes [8], exact risk reduction from various ventilation strategies [9], and impact of increasing natural ventilation in built spaces [10]. Moreover, while various models have been proposed for quantifying optimal ventilation, risk reduction and energy consumption should be balanced with occupancy [11], optimization to control level of risks [12] and optimal room air exchange rates [13].

2. Methods

The Natural Catalytic Converter® (CASPR) unit utilizes a high-powered plasma bulb in conjunction with a honeycomb with a proprietary coating that creates

the catalytic reaction converting the ambient air into hydrogen peroxide gas. These low levels of hydrogen peroxide (0.01 - 0.04 ppm) are dispersed into the environment and actively destroy pathogens where they are in the air and on surfaces. In normal operation, these oxidizers reach equilibrium in the space and can quickly attack any pathogens as they enter the environment. In the laboratory testing, the pathogen is introduced and then the device is turned on. This leads to longer efficacy times in the lab than would be seen in a real-world installation of the CASPR units that operate 24/7/365.

The testing methods utilized in these studies varied depending on the type of testing (air or surface) with appropriate sampling, the specific organism, and the location of either airborne or surface contamination. Type of testing/sampling, specific organism, and methods used for either air or surface contamination are detailed in this section.

2.1. Airborne Contamination Testing Methods

2.1.1. Pathogen 1: Aerosolized MS2

The testing methods recommended in the standard ASHRAE 241-2023, Control of Infectious Aerosols [14] were used for this test. An airtight bioaerosol 30 m^3, (1060 ft^3), as shown in Figure 1, aligned to the Association of Home Appliance Manufacturers (AHAM) AC-5 was used for testing. Effectiveness testing was

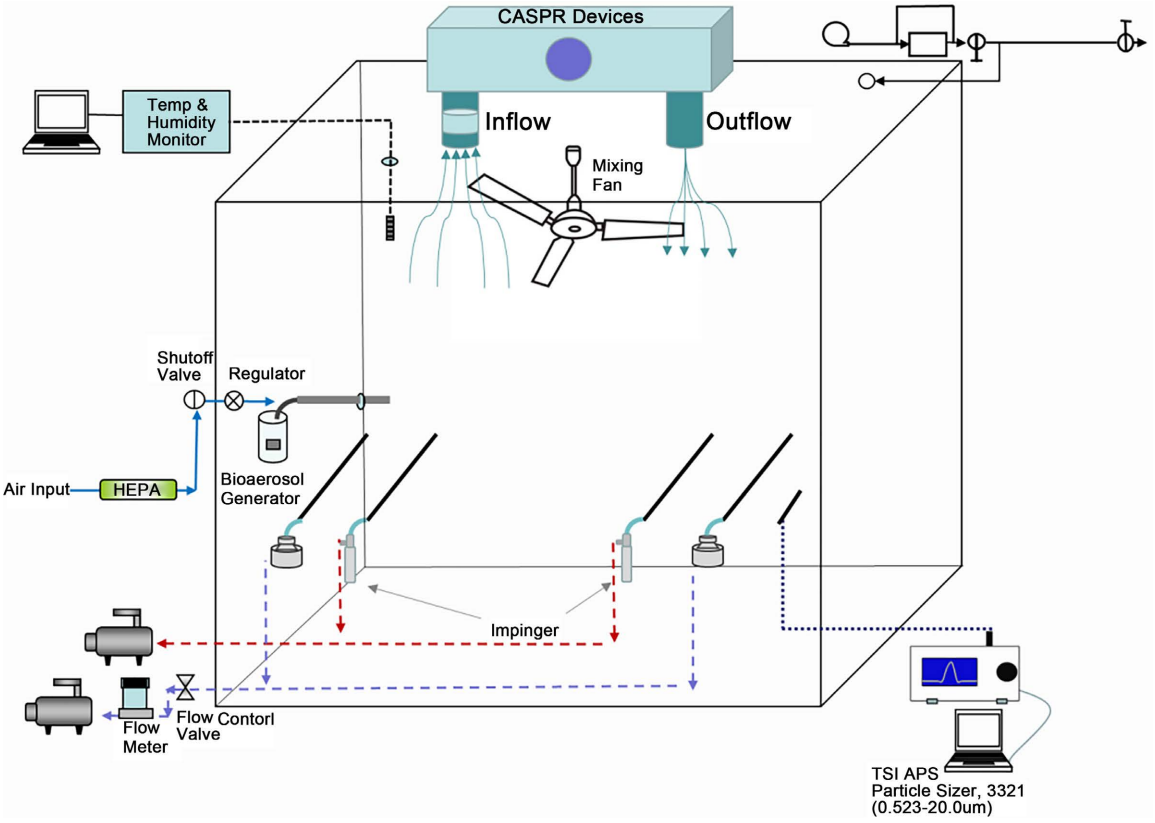

Figure 1. Environmental test chamber flow diagram. Chamber includes bioaerosol induction, multiple bioaerosol sampling ports, particle size monitoring, internal mixing fans, and temperature and humidity controls. Main system HEPA evacuation system not pictured.

performed with the non-enveloped bacteriophage MS2 (host *Escherichia coli*) that is a recognized surrogate for more pathogenic viruses, such as SARS-CoV-2, that virus that causes COVID-19; influenza; and respiratory syncytial virus (RSV). MS2 is utilized in a BSL-1 laboratory setting. A partial HVAC system was constructed with installation points for the CASPR Medik X unit, with a blower rate set at 5 room air changes per hour (5 ACH). MS2 was nebulized, using a Collison 24-Jet Nebulizer. Previously prepared aliquots of MS2 were used to maintain consistent concentration throughout all testing.

Bioaerosol samples were collected 48 inches from the floor and 12 inches from the walls for proper separation. The test chamber's temperature and humidity were kept at 73˚F ± 5˚F and 50% ± 10%, using a Proportional Integral Derivative (PID) humidity controller in combination with an ultra-sonic humidifier to nebulize filtered deionized (DI) water. A suspension of test microbes was nebulized into the chamber air, and an initial measurement of the microbial concentration was taken before activating the air cleaner device.

Bio-aerosol samples were taken, with impingers, at multiple time points throughout each trial, using ASHRAE 241-2023 and AHAM AC-5 testing parameters, to quantify the reduction rate capability of the air purification device. The impinger samples were serially diluted, plated, incubated, and enumerated in triplicate to yield the viable bioaerosol concentration for each sampling time point. Chamber control trial data, or natural decay, was subtracted from the device trial data to yield the net log reduction attributable to the devices for each of the bioaerosol challenges.

2.1.2. Pathogen 2: *Staphylococcus epidermis* (MRSA)

Staphylococcus epidermidis (MRSA) was the test organism for other aerosol trials. Previously prepared aliquots of MRSA were used to keep a consistent concentration throughout all contact testing. The microorganism was aerosolized into a sealed 16 m^3 (565 ft^3) environmental bioaerosol chamber, containing the CASPR unit and a Collison 24-Jet Nebulizer. The bioaerosols in the testing had a mass median aerodynamic diameter (MMAD) ranging from 0.7 - 4.0 μm (species dependent). Bioaerosol samples were taken at multiple time points throughout each trial, to quantify the reduction rate capability of the air purification device. Impinger samples were serially diluted, plated, incubated, and enumerated in triplicate to yield viable bioaerosol concentration for each sampling point. Chamber control trial data, or natural decay, was subtracted from the device trial data to yield the net log reduction for each of the bioaerosol challenges. Additionally viable cascades, ran at 30 L/min, were used to further resolve the lower detection limits achieved by the CASPR unit.

2.2. Surface Contamination Testing Methods

2.2.1. Pathogen 1: SARS-COV-2 (Coronavirus COVID-19)

The CASPR Unit was placed inside a Biosafety cabinet (BSC) and turned on. Sterile aluminum foil pieces of 24 mm × 24 mm (0.94 in × 0.94 in) previously

disinfected with 70% ethanol and exposed to UV light for 25 minutes, were individually placed in a petri dish inside the BSC and were kept at room temperature. A 200 µl inoculum of 1 × 105 PFU of SARS-CoV-2 was placed and extended on each aluminum piece using a micropipette tip. Three replicates were prepared per treatment and enough samples were prepared to evaluate 8 exposure times (15, 30, 60, 120, 360, 720, 1440 and 2880 minutes). Following each exposure time, 2 ml of collection media (DMEM with 2% FBS) was added to each petri dish, making an initial dilution of 1:11, and the aluminum material was washed out by resuspending four to five times, using a micropipette; the viral suspension was collected, mixed for homogeneity and aliquoted into 1 ml centrifuge tubes. Each collected sample was immediately labeled and stored at −80˚C for titration assays.

The recovered virus suspension was diluted (10-fold, 3 dilutions: 1/10, 1/100, 1/1000) in a mixing plate in duplicate and added to 96 well Vero E6 seeded plates. Plates were incubated for 1 hour at 37˚C. Inoculum was discarded and a 2% carboxymethylcellulose overlay was added and incubated for 24 hours at 37˚C. Next, the overlay was discarded, plates washed and fixed for 10 minutes at −20˚C (using acetone-methanol solution). Following fixation, plates were washed two times with PBS-T and a primary antibody (IgG Human anti-Coronavirus, 1:2000) was added and incubated overnight at 37˚C. The primary antibody was then discarded, and plates were washed twice with PBS-T. A secondary antibody (Goat IgG Anti-Human HRP conjugated, 1:2000) was added and left to incubate for 2 hours at 37˚C. After removing the secondary antibody, plates were washed twice with PBS-T and plaques were developed with a Chromogen substrate. Plaques were counted using Immunospot Image analyzer and open-source software, Viridot, to determine the viral titer.

2.2.2. Pathogen 2: Influenza (H1N1)

ASTM International, formerly the American Society for Testing and Materials (ASTM), is an internationally recognized organization that develops and publishes product and testing standards. The ASTM E1053 test method is used to determine the virucidal effectiveness of liquid disinfectant products designed for use on hard, nonporous environmental surfaces. In an ASTM E1053 test, a viral inoculum is dried onto carriers, followed by exposure to a test formulation via spray device or pipette (modified use-dilution) for the specified contact time(s). Control carriers are concurrently processed, using an equivalent volume of cell culture medium or other suitable buffer. Following neutralization, the carriers are enumerated using standard cell culture (e.g. TCID50) or plaque assay techniques. Log10 and percent reduction values are calculated to determine the effectiveness of the test product relative to the control carriers. The ASTM E1053 test method for use with spray devices or pipette delivery is used because it is recognized by regulatory agencies as an approved method for claim substantiation.

Stock virus is thawed and may be supplemented with an organic soil load, if requested. Sterile glass petri dish carriers (100 × 15 mm) are inoculated with a

volume of virus suspension containing an adequate titer to recover a minimum of 4-log10 infectious viruses per carrier. A sufficient number of test and control carriers are prepared. Inoculated carriers are dried at room temperature under laminar flow conditions. The test substance is prepared according to the Study Sponsor's instructions, as requested, and applied to the test carriers using a spray device or pipette. For spray tests, the distance, angle, and number of sprays applied are recorded. For use-dilution (pipette delivery) tests, the volume applied per carrier is recorded. The treated carriers are held for the predetermined contact time(s), and then neutralized in a manner appropriate for the test substance (e.g. dilution and/or gel filtration). The control carrier is harvested using an equivalent volume cell culture medium or other suitable buffer.

3. Results

3.1. Airborne Contamination Testing Results

3.1.1. Pathogen 1: Aerosolized MS2

The CASPR device achieved an average net log reduction of 2.28 ± 0.03 net log (99.4775% ± 0.0335%) across all trials. The range of reductions was from 2.25 net log (99.4388%) to 2.30 net log (99.4968%). These reductions reflect the total trial time of 60 minutes. The first sample time was at 4 minutes and the average reduction across all trials was 0.53 ± 0.06 net log (70.278% ± 4.234%). By 30 minutes, the average reduction was 1.5 ± 0.17 net log (96.6866% ± 1.22264%).

3.1.2. Pathogen 2: *Staphylococcus epidermis* (MRSA)

The CASPR device achieved an average net log reduction of 5.62 ± 0.29 net log (99.9997% ± 0.0002%). The range of reductions was from 5.29 net log (99.9995%) to 5.86 net log (99.9999%). These reductions reflect the total trial time of 120 minutes. The first sample time was at 30 minutes and the average reduction across all trials was 1.12 ± 0.17 net log (92.0147% ± 3.3141%). By 60 minutes, the average reduction was 2.89 ± 0.31 net log (99.8467% ± 0.1184%).

3.2. Surface Contamination Testing Results

3.2.1. Pathogen 1: SARS-COV-2 (Coronavirus COVID-19)

While using the CASPR HVAC device, a maximum reduction of 99.991% of SARS-CoV-2 infectious particles on an aluminum surface was reached after 1440 minutes of exposure. More than 97.8% of this reduction was detected 360 minutes after the initial exposure.

3.2.2. Pathogen 2: Influenza (H1N1)

The CASPR device achieved an average net log reduction of 3.17 log (99.93%) over the 6-hour trial time period. There was just a single end sampling in the test, so there are no intermediate data points.

4. Discussion

These data demonstrate the efficacy of a natural catalytic converter in reducing

specific microorganisms in air and on surfaces, operating continuously. This is important because both direct and indirect contact with infectious pathogens in indoor space by individuals are implicated in a variety of studies [15]. In addition, both short (conversations and 3 feet distance or less) and long-range dispersion of aerosols is implicated in transmission of respiratory viruses among indoor occupants [16].

While filtration has been suggested within HVAC systems [17] for risk reduction from infectious agents, more recent data suggests that ventilation and contamination of forced air in an HVAC system is more efficient at causing infections from forced HVAC air emitted from ducts. For example, in an outbreak of COVID-19, patrons on the side of the room downstream from infected patrons, in line with contaminated air flow, were infected, while those on the other side of the room, which had another pattern of HVAC ventilation outside of that airflow pattern, were not [18].

In fact, the probability of infection based on ventilation rates in indoor space has been estimated [19]. Of note is that actual infections from infected individuals in enclosed spaces include reported outbreaks of tuberculosis and risks assessments in aircraft cabins [20] [21].

Other actual outbreaks of respiratory infectious diseases from presumed aerosol contamination have been noted in a variety of settings, such as health care [22] [23] [24], schools [25] [26] trains [27] and indoors [28]. Engineering controls may be more effective at reducing real and computed risks for transmitting and acquiring infectious agents, based on concentrations in dispersed air.

With both computed and real risks of infections, clearly more is needed to reduce infection risks in indoor space [29]. This catalytic converter may be the key to the intractable rates of healthcare associated infections (HAIs). Additional research is needed to assess reduction of HAIs in this setting, as well as other indoor building settings.

The CASPR units have not been directly tested against filtration and other air cleaning devices such as UVC. The active nature of the oxidizers compared to the passive approach of these other technologies allows for the CASPR units to impact the pathogens in the breathing zone and on surfaces without having to rely on the pathogen returning through the system to be removed. Additionally, ventilation introduces outside air that allows for the dilution of pathogens in the air but does not impact the pathogens on the surfaces.

The limitation of this study is that it is a controlled laboratory environment. It did not factor in more dynamic models necessary, air movement and currents or other issues, like dispersion in an open space [30]. It did not take into account dispersion over long distances such as coughs [31], ventilation strategies for risk reduction [9]; specific risks such as SARS-COV-2 or tuberculosis indoors [32], or changes in natural ventilation [33]. Future studies are needed to assess this engineering control in other settings, with varied occupancy, controls for dynamic airflow and alternative building design [34] and appropriate modeling [35].

5. Conclusion

These independent test data presented demonstrate that this novel catalytic converter reduces a variety of pathogens in air and on surfaces. For air and surfaces, reductions of pathogens met or exceeded 99% reduction on surfaces and 99% reduction in air, within specified time periods. Furthermore, given the understanding of the disbursement of pathogens in both the air and on surfaces within a facility, the use of conventional ventilation and filtration does not provide a consistent level of disinfection across the entirety of the facility. The implementation of active solutions like this novel catalytic converter provides such a consistent solution that reaches every corner of the facility.

Author Statement

The submitted manuscript has not been previously published in any form and is not currently under consideration for publication elsewhere. The co-author, Dr. Margaret Scarlett, acknowledges that she is a paid consultant to CASPR Technologies. The co-author, Brett Duffy acknowledges that he is a paid consultant to CASPR Technologies. All data was collected, and results analyzed by independent laboratories, as noted in the document.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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