SENTRYSCIENCES
INFO@SENTRYSCI.COM
1551 S. SUNSET STREET
SUITE B
LONGMONT, CO 80504
720-340-4752

Clinical Space Decontamination With VHP

Ambulance

Mark Berdovich and Don Pfeffer
SentrySciences, Inc.
www.sentrysci.com

BACKGROUND

In the early stages of the Covid-19 pandemic in spring and early summer 2020, one of the most serious concerns for front-line health care workers like doctors and nurses was a shortage of protective masks of all types. The issue became so pressing that on March 29, 2020, the U.S. Food and Drug Administration (FDA) issued an Emergency Use Authorization (EUA) to Battelle for a system capable of decontaminating certain types of masks in large quantities using Vapor-Phase Hydrogen Peroxide (V-PHP or VHP) as the bio-decontamination agent. That approval was based on a project Battelle did for FDA in 2016 in case of a pandemic. Material compatibility issues limited the authorization to non-cellulose masks, and each mask could only be decontaminated a dozen or so times before the elastic bands would begin to break down. But in an extreme PPE shortage situation, having a validated decontamination method available for compatible materials was potentially lifesaving for many healthcare workers.

VHP decontamination has been in use throughout the pharmaceutical industry for a couple of decades. It is the preferred method of choice for decontaminating the most critical manufacturing environments where drug products that are injected directly into patients' veins are filled and sealed. VHP is very effective at achieving a 6-log kill level, a measure of decontamination effectiveness commonly associated with sterility. This is advantageous because sterilization normally requires very high temperatures compared with VHP, which works at ambient temperature. Additionally, the breakdown byproducts of H_2O_2 gas are only water and oxygen, which means no surface bleaching and no residues are left after the job is done.

As a proud member of the National Institute for Innovation in the Manufacture of Biopharmaceutical Products (NIIMBL, an organization funded by the United States' Department of Commerce through the National Institute of Standards and Technology, NIST), and inspired by Battelle's EUA announcement that March, in April 2020 SentrySciences applied for funding under the CARES act to study using VHP to decontaminate clinical and public spaces. Our project, COVID19-1.07: Validation of the Use of Vapor-Phase Hydrogen Peroxide as a Rapid Viral Decontamination Agent for Clinical and Public Spaces, produced several key results:

- In spaces containing only hard, non-porous surfaces, decontamination was reproducibly effective to the 6-log kill level using a recipe-driven approach.

- In spaces that also contained a lot of porous materials (carpeting and furniture upholstery, for example), decontamination was effective to the 6-log kill level, but a recipe-driven approach could not be used. The cycle time became variable due to those porous materials absorbing the H_2O_2 gas in ways that could not be sufficiently predicted or modeled.

- With repeated treatments of spaces containing a lot of porous materials, the absorption issue caused the aeration portion of the cycle to also become variable because low levels of H_2O_2 vapor could be detected very close to absorbent materials for long time periods after average room levels had dropped to 0 ppm H_2O_2 vapor.

Battelle's achievement of a validated cycle is notable in this regard: masks clearly contain porous materials. So how did they do it? Using cycle control parameters that were designed with overkill in mind.

In Q4 2021, SentrySciences was awarded additional funding through the American Rescue Plan under a Project Award Agreement from NIIMBL and financial assistance award 70NAB21H085 from the U.S. Department of Commerce and NIST. Project ARP-5, which was completed on August 31, 2022, was called Evaluation of an Automated Vapor-Phase Hydrogen Peroxide Decontamination System for Rapid Non-Residual Decontamination of Clinical Spaces. The practices, procedures, and recommendations contained in this paper are a product of the NIIMBL ARP-5 project.

OBJECTIVES

Amidst the reports of significant hospital overcrowding and PPE shortages, an often-overlooked population of front-line healthcare workers were the EMTs that were transporting patients to hospitals and urgent care facilities. In larger cities, before vaccines became more widely available near the end of 2020, reports of ambulances waiting 4 to 5 hours, or longer, outside of emergency departments, were routine. These stories inspired the ARP-5 project team to study, as an example of their small clinical space, an ambulance (Figure 1, at left).

From a microbial contamination control perspective, an ideal space design includes only hard, non-porous surfaces with minimal cracks and seams. Unfortunately, with ambulances, it is not practical to apply these design concepts to one hundred percent of the space. For example, sliding doors on storage cabinets must ride in narrow tracks that are hard to decontaminate manually. But more practically, some level of porous materials is expected: the linens, blankets, cushions, and pillows commonly found on a gurney in the back are required to ensure minimal patient comfort.

Fortunately, linens are laundered separately, and are easy to remove prior to performing a decontamination procedure. The problem often extends to the cab. Most ambulance rigs are customized versions of large trucks mass produced by major automobile manufacturers, and this usually translates to two captains' chairs furnished with cloth upholstery and carpeting on the floor. Although ARP-5 demonstrated that these limitations do not prevent successful 6-log decontamination, contamination control best practices suggest a reevaluation of the materials of construction of most ambulance cabs is warranted. (Figure 2, at left)

PROCEDURE

The ARP-5 project decontamination protocol is based on the U.S. Environmental Protection Agency's Protocol for Room Sterilization by Fogger Application. This protocol includes a formula for calculating the number of Biological Indicators that must be installed throughout the space.

Biological Indicators (BIs) are test devices that contain viable micro-organisms with a defined resistance to specific sterilization processes. For ARP-5 the BIs were stainless steel coupons seeded with a minimum of 1 million spores (e.g., minimum of 6-log) of Geobacillus Stearothermophilus and housed within a Tyvek pouch. This is the organism called out in the EPA protocol; it is also the organism of choice used throughout the pharmaceutical and biotech industries for validation of sterilization cycles because of its high resistance to heat.

Bioreset® MAX from Amira Srl is the VHP decontamination system that was selected for study in ARP-5 by the SentrySciences project team. Bioreset® MAX was chosen because it is unique in the marketplace in that two different parameters indicative of room conditions are monitored throughout the gassing portion of the cycle, and the feedback data from both parameters are used to provide automated control over the cycle. During the gassing portion of the cycle, both the parts-per-million (ppm) concentration of hydrogen peroxide vapor in the air in the room is monitored as well as the temperature and relative humidity (relative saturation). The hydrogen peroxide vapor probe ensures a minimum concentration is maintained for at least one hour, while the relative saturation control point is used to ensure the cycle operates very closely to, but just below, the dew point in the room. (The term relative humidity applies to only water vapor content in the air. The term relative saturation is used in place of relative humidity when referring to a mixture of both water vapor and hydrogen peroxide vapor in the air.) The former control point ensures a 6-log kill is achieved, and the latter control point ensures no condensation-related damage occurs due to bleaching, corrosion, or bubbling of any painted surfaces during the decontamination cycle.

The Bioreset® MAX automated VHP decontamination system is comprised of 3 main components:

(a) a vapor-phase hydrogen peroxide vaporizer / generator

(b) a separate self-contained blower and catalyst system

(c) the combination temperature / relative humidity (relative saturation) and hydrogen peroxide vapor concentration monitoring probe

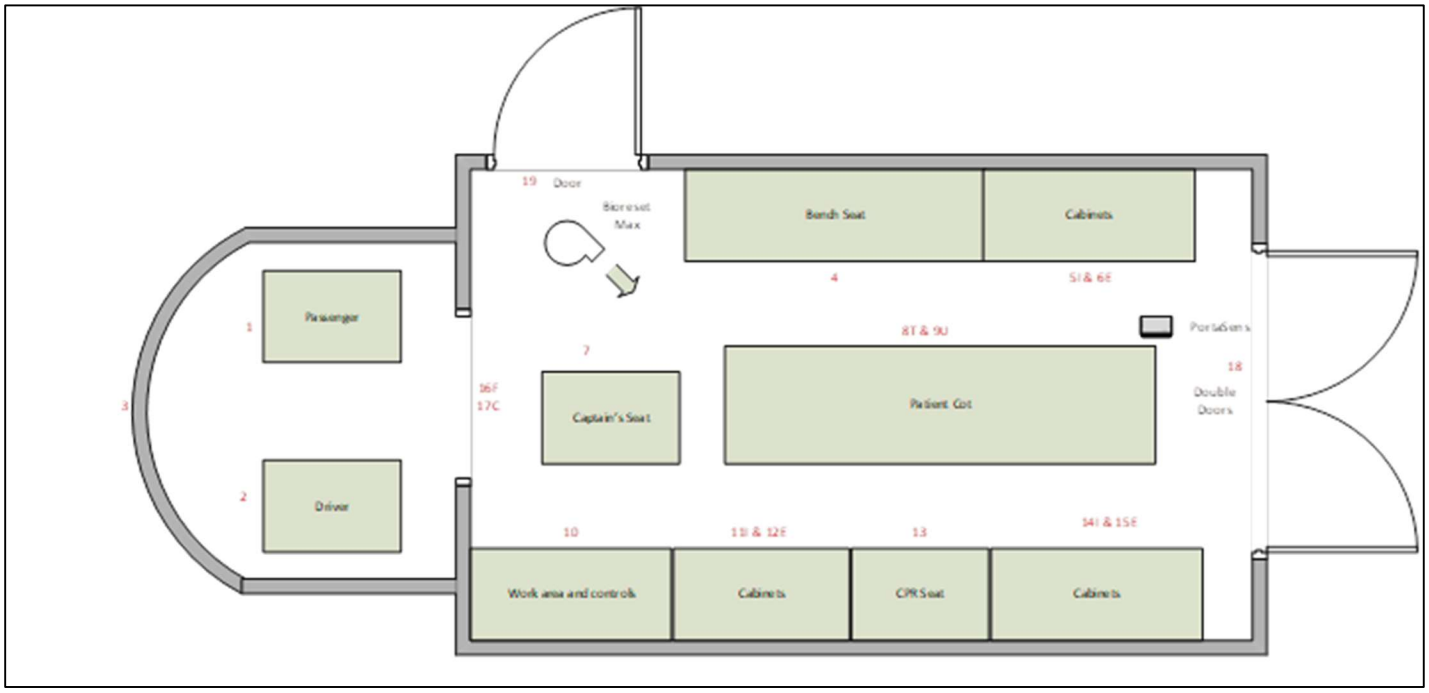
During the ARP-5 study, the system was set up with all components installed in the rear of the ambulance, and in accordance with the manufacturer's recommendations.

The catalyst module was positioned between the patient gurney and the cab. (Figure 3, at left, and Figure 4, below)

The vaporizer was placed on top of the catalyst module with the outlet pointing toward the back of the ambulance (Figure 4, above right). The temperature and relative humidity probe was placed on a shelf estimated to be in the coolest place in the back of the rig. This is a key point: by placing the relative saturation probe in the coolest place in the rig, which is where the relative saturation will be highest, the automated cycle control will ensure that surface damage due to condensation will be avoided. The hydrogen peroxide vapor concentration probe was co-located with the temperature and relative humidity probe as they are connected to each other by a short length of cable.

For each test, eighteen (18) BIs were installed in accordance with the formula in the EPA document, with 15 in the rear of the ambulance and 3 in the cab. The approximate location of each BI is notated in small red numbers in the figure below.

Also in accordance with the EPA document, some of the BIs were installed in areas designed to challenge the hydrogen peroxide vapor's ability to penetrate all areas and surfaces. For example, in corners, on the underside and in the back of counters or shelves and attached to one of the upholstered captains' chairs in the cab. Following each test, all 18 BIs were recovered and under HEPA filtered air conditions, each Tyvek pouch was opened and the stainless-steel coupon was transferred to a sterile glass tube containing a purple sterile nutrient growth media.



The tubes were sealed and then incubated for 7 days at 57.5°C ± 2.5°C, along with 2 each positive and negative controls. (Negative controls are tubes that are never opened and never have BIs placed in them. Positive controls are tubes that contain BIs that are placed into the nutrient media without having been exposed to VHP.) A successful test replicate was defined as the 2 negative controls remaining growth-negative (e.g., purple), the 2 positive controls being growth positive (e.g., the purple liquid turns a brownish-yellow color), and 100% killing of all 18 test BIs (e.g., all 18 test BIs remain growth-negative because the liquid stays purple). As the data in the results section show, successful 6-log decontamination was achieved in 3 consecutive cycles.

RESULTS

Bioreset MAX Small Clinical Space Decontamination - REAR OF AMBULANCE

Test #	Test Date	Start Temp	Start RH	End RS	Gassing Time	H2O2 Conc.	Aeration Time	Aeration Time	BIs Killed
		(°C)	(% RH)	(% RS)	HH:MM:SS	(BR MAX ppm)	Portasens (First Reading < 75 ppm)	Portasens (First Reading < 1 ppm)	(% Killed)
1	5/3/2022	19.2	32.1%	84.0%	3:13:30	151 - 159	10 Mins to < 75 ppm	1 Hour, 24 Mins to 0 ppm	100.0%
2	5/12/2022	23.3	37.5%	91.1%	1:03:00	186 - 671	32 Mins to < 75 ppm	3 Hours, 11 Mins to 3 ppm	100.0%
3	5/19/2022	25.9	21.1%	81.3%	1:02:30	188 - 819	30 Mins to < 75 ppm	3 Hours, 54 Mins to 10 ppm	100.0%

Bioreset MAX Small Clinical Space Decontamination - CAB OF AMBULANCE

Test #	Test Date	Start Temp	Start RH	End RS	Gassing Time	H2O2 Conc.	Aeration Time	Aeration Time	BIs Killed
		(°C)	(% RH)	(% RS)	HH:MM:SS	(PortaSens ppm)	Portasens (First Reading < 75 ppm)	Portasens (First Reading < 1 ppm)	(% Killed)
1	5/3/2022	No MAX Data from Cab			3:13:30	0 - 83	12 Mins to < 75 ppm	1 Hour, 31 Mins to 3 ppm	100.0%
2	5/12/2022	No MAX Data from Cab			1:03:00	0 - 355	32 Mins to < 75 ppm	1 Hour, 40 Mins to 0 ppm	100.0%
3	5/19/2022	No MAX Data from Cab			1:02:30	0 - 417	34 Mins to < 75 ppm	1 Hour, 30 Mins to 0 ppm	100.0%

This results summary shows the benefit of two-parameter control for achieving automated 6-log decontamination of the ambulance. The gassing portion of the cycle for the first test replicate performed on 5/3 was 3 hours, 13 minutes and 30 seconds. But for test replicates two and three, the gassing times were nearly identical, and required only one-third the length of time (1 hour and 3 minutes) to achieve a 100% 6-log kill, when compared with the cycle performed on 5/3.

Because it was cool and relatively damp on 5/3, injection of liquid H_2O_2 into the vaporizer was stopped repeatedly during the cycle to keep the relative saturation below the dew point. This control point is important to prevent damage-causing condensation, which would occur if the Relative Saturation exceeds the dew point.

But cutting off the injection of liquid H_2O_2 too soon could result in an incomplete killing of the 6-log BIs. This is the benefit of the second control point – monitoring the H_2O_2 vapor concentration to ensure it stays above a minimum value for at least 1 hour.

During test replicates 2 and 3 on 5/12 and 5/19, respectively, the warmer starting air temperatures enabled liquid H_2O_2 injection to continue without stopping or ever reaching saturation. It is for this reason the gassing portion of the cycle only required little more than the minimum 1 hour to stay above the required H_2O_2 vapor concentration for 1 hour. This is, again, in stark contrast with test replicate 1, which required over 3 hours in order to ensure the H_2O_2 vapor concentration stayed above the required value for at least 1 hour.

SUMMARY

In summary, and as our results show, the key to an automated decontamination cycle that achieves repeatable 100% 6-log killing is using two parameters to control the decontamination cycle. By monitoring H_2O_2 vapor concentration, a minimum concentration can be assured that will achieve 100% 6-log kill, even if it means extending the time required to complete the cycle. Simultaneously, by monitoring Relative Saturation and controlling it below the dew point, damage-causing condensation of liquid H_2O_2 can be avoided.

ACKNOWLEDGMENTS

SentrySciences, Inc., and the ARP-5 project team wishes to thank the National Institute for Innovation in the Manufacture of Biopharmaceutical Products (NIIMBL), the National Institute for Standards and Technology (NIST), and the United States Department of Commerce for providing project funding and valuable project management guidance, technical advice, and other input throughout the execution of the Covid19-1.07 Project (May 15, 2020 – January 31, 2021) and also the ARP-5 decontamination study (October 15, 2021 – August 31, 2022).

SentrySciences, Inc., and the ARP-5 project team also wish to express our profound gratitude to Engineer Patrick Kramer and Station Chief Troy Reed of Longmont, Colorado Fire Station #1 for their permission to use an out-of-service ambulance to conduct our small clinical space decontamination study.

ABOUT THE AUTHORS

Mark Berdovich, Director of Sales, has nearly 30 years of experience solving customer problems related to particles and other unwanted sources of contamination. Starting in 1995 with Micro Measurement Labs, a particle testing laboratory and particle standards manufacturer, Mark received his GMP training and spent 6 years developing products and test methods for customers and in support of a sister company distributing particle counting and sizing instruments. In 2001, he was offered an opportunity to move to Florida to launch a new Southeast Territory for a design-build cleanroom construction contractor. After successfully building a multi-million-dollar territory from zero, he accepted an opportunity to move to Colorado in 2008 to manage the systems installation and validation services group at Particle Measuring Systems. He joined the SentrySciences team in 2017 and is proud to be leveraging his GMP and Project Management experience to serve customer's monitoring system needs. Mark has a B.S. in Mechanical Engineering from the University of Illinois at Urbana-Champaign.

Don Pfeffer, Product Marketing - Biodecontamination Products, founded Accurate Reimbursement Solutions, Inc. a healthcare revenue cycle management company in July 1996. As president and Chief Executive Officer, he was responsible for managing the company's overall direction, market strategy and business development. He retired from Accurate Reimbursement Solutions in July of 2019 and joined SentrySciences to put his healthcare and clinical experience to use developing applications and strategies for SentrySciences' family of biodecontamination products, Bioreset from Amiral Srl. Don received his bachelor's degree from Ohio University and his MBA from the University of Phoenix.

Appendix A
Example Ambulance Decontamination Procedure

1) Because H_2O_2 vapor cannot penetrate liquids or other surface soils, prior to performing the decontamination procedure, all surfaces inside of the ambulance should be cleaned to remove those soils.

2) To ensure the gas penetrates all areas and materials throughout the rig, the doors to all storage areas should be opened. Items that are usually folded before storing them, such as blood pressure monitoring cuffs, should be removed from cabinets and hung to enable the gas to contact all surfaces.

3) For ambulances with a small window between the rear and the cab (as opposed to a pass-thru walkway large enough for an adult human to walk through), a distribution fan should be installed in that window to ensure even mixing of the H_2O_2 gas between the rear and the cab of the rig.

4) The H_2O_2 vapor generator and catalyst modules should be installed in the rear of the ambulance with the vapor generator outlet pointing toward the back doors.

5) The combination Temperature and Relative Humidity (Relative Saturation) and H_2O_2 vapor concentration probe should be installed in the rear of the rig in what is estimated to the coolest place.

6) All doors should then be closed, and the automated decontamination cycle started.

7) When the gassing portion of the cycle has completed, the catalyst module will start up and aerate the ambulance to reduce the H_2O_2 vapor concentration to a safe enough level so that the doors can be opened.