Aerosol Disinfection in a Pandemic World:

Using Science to Inform Decision-Making

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In the midst of the current human coronavirus pandemic, building cleaning and sanitation practices and protocols have been improved as to quality and frequency; and they have also been upgraded from the use of common sanitizer products to the more potent hospital-grade disinfectants. At the same time, this has raised the question of the effectiveness of the use of those disinfectants as gas or vapor-phase biocides, since aerosol disinfection can readily reduce the time and cost of application. The question that remains however is, does the use of aerosol disinfection achieve the same or higher level of infectious disease risk reduction that the manual application of those products achieve? And can they overcome neutralizing substances that may reduce their effectiveness, and yet maintain a critical dwell time for the exposure to effectively kill the microbes? Also, the issue generates additional concern regarding the integrity of some surfaces and materials which are exposed to the aerosols, as there is no selective exclusion as to where the aerosols land. These and related issues thus becomes the focus of this article.

Cleaning and Manual Disinfection

Whether conducting business of a routine nature, or dealing with the challenges of a pandemic, facility management personnel have a responsibility for ensuring healthy indoor environmental quality across their properties. Accordingly, the current SARS-CoV-2 (COVID-19) pandemic emphasizes the need for health-based cleaning, which in particular, targets high contact touch points that may serve as vehicles of infectious agent transmission to uninfected individuals. This targeted hygiene approach typically involves manual detergent cleaning, followed by the application of an EPA-registered disinfectant. The cleaning process, through friction, physically removes microbes and their associated matrices in which they may be embedded, such as saliva and/or nasal secretions from the nose or mouth, as generated by coughing or sneezing. Thus, the cleaning process is crucial, as it removes soils, respiratory secretions, and other substances that may block or interfere with the antimicrobial action of the biocide to kill or otherwise inactivate any remaining microbial residues.

And for specific use against the COVID-19 coronavirus, disinfectant products have comprehensive microbiocidal claims, such as approval for use against specific viruses, to include a number of human respiratory viruses (e.g. Influenza A, Adenovirus, RSV), appropriate animal surrogate viruses similar to human viruses, or an emerging pathogen claim, that indicates the product can be used against the SARS-CoV-2 (COVID-19) coronavirus. The emerging pathogen claim confirms that the product has: 1) demonstrated efficacy against a harder-to-kill virus (non-enveloped ones such as Adenovirus, Hepatitis A virus, Norovirus); or 2) demonstrated efficacy against another type of human coronavirus, similar to the SARS-CoV-2 virus. The EPA's *List N: Products with Emerging Viral Pathogens AND Human Coronavirus claims for use against SARS-CoV-2*, can be found on the agency's website. Fortunately, in regard to COVID-19, it is a virus with a lipid envelope that is very susceptible to dissolution by detergents, which contributes to the virus's inactivation directly, or by making it very susceptible to the actions of all classes of disinfectants.

Aerosol Disinfection

Consideration of the use of an EPA-registered disinfectant as an aerosol generates three potential avenues of inquiry: 1) will it be effective as a measure of targeted hygiene in the absence of cleaning; 2) will it be as effective as manual disinfectant application at inactivating residual microbial contamination if used following cleaning; and 3) is there a rationale for its use both pre- and post-cleaning, as a matter of additional concern and precaution for building occupants, custodians, and perhaps contracted restoration professionals? In an attempt to answer these questions, it's important to review the specifics of what is referred to as aerosol disinfection, and that begins with terms and definitions.

In the context of this discussion, an aerosol is a collection of tiny particles or droplets suspended in air, and the size and/or density of those particles or droplets typically has a bearing on terms used in aerosol disinfection. Commonly referenced terms for treatment include gas-phase, vapor-phase, fogging (mists), and sprays.

Gas-Phase

Gases are formless fluids that expand to occupy the confines of a space or enclosure, and are so small that they are not visible. Air is our most common gas, and when ultra-fine particles or droplets are introduced into air and also remain unseen, those particles or droplets can be said to be in gas-phase. For decades, formaldehyde gas was used to decontaminate laboratories that were used for work with highly infectious human pathogens, until it was declared a carcinogen. While it was effective, it involved a cumbersome and time-consuming process, and was never proposed or used for office buildings or homes. Unfortunately, what was proposed by some for

buildings and home environments suffering water damage and mold growth more than two decades ago, was gas-phase ozone. Ozone (O_3) can be generated by corona discharge or UV light, to where high concentrations in the air can be achieved. Unfortunately, ozone is extremely hazardous to human health, wherein as little as 0.08 ppm exposure can result in respiratory irritation and inflammation. And neither is it effective in inactivating microbial growth on surfaces and materials. While ozone is recognized as very effective as an aqueous biocide and also as a deodorizer in smoke damage restoration, research has never shown a meaningful effect of gas-phase ozone on either airborne or surface microorganisms, relative to significant control of biological pollution in the indoor environment[1,2].

Vapor-Phase

A vapor is the volatile, gas-phase form of a substance that exists in the liquid state at room temperature and pressure. But as those change, the substance can be "vaporized" and mix with air in various concentrations. Presently, the most common vapor-phase biocide used today for microbial contamination control in various situations in the indoor environment is vaporized hydrogen peroxide (VHP). Over 20 years ago it was shown to be a suitable replacement for the toxic formaldehyde and ethylene oxide gases that were used at that time for decontamination of hospital and research laboratory equipment. A 30-minute VHP exposure was shown effective at inactivation of a variety of exotic animal disease viruses, with no effects on exposed equipment[3]. A few years later VHP was shown to be much more effective than manual terminal cleaning in surgical wards contaminated with Methicillin-Resistant *Staphylococcus aureus* (MRSA), as 66% of post-cleaning samples were positive for MRSA compared to only 1.0% for post VHP treatment[4]. And a later study investigated the effects of VHP on viruses suspended and dried in 10% and 50% horse blood to simulate the virus being present in blood or body fluids. The VHP reduced virus concentration by 6 $\log_{10}$ in 30-minutes at the lowest concentration of viruses, while 60-90 minutes was required for inactivation of virus at the highest concentration. The study demonstrated that the effectiveness of vapor-phase disinfection is a function not only of viral concentration, but the degree of soiling. The authors noted that the results highlighted the importance of effective cleaning prior to disinfection to ensure adequate decontamination[5].

Fogging (Mists)

Mists consist of very fine droplets, typically less than 10 µm and dispersed in air. They are generated by breaking up a liquid into a dispersed state, such as by atomizing. And when the mist is dense enough to affect visibility, it is called a fog. Fogging has long been used in the food processing and agricultural industries to reduce microbial surface contamination, and improve air

quality through reduction of airborne dusts and microbes[6, 7, 8, 9]. Likewise, fogging has a history of use in varied infection control scenarios employing a variety of disinfectants, to include quaternary ammonium compounds[10], hypochlorous acid[11, 12], peracetic acid[13, 14, 15], guanidine[16], and hydrogen peroxide/silver nitrate[17], among others. A recent study looked at the effectiveness of two fogged disinfectants, hydrogen peroxide (7.5%) and a chlorine dioxide (0.2%)-surfactant based product against two strains of human norovirus and a norovirus surrogate, feline calicivirus[18]. Human norovirus is the leading cause of foodborne illness in the U.S. In the study, viruses were inoculated onto steel coupons, dried, and exposed to fogging from a machine capable of generating fogs at 30ml/min until desired concentrations were achieved. The hydrogen peroxide (HP) exposure was 5 min and the chlorine dioxide (ClO_2) exposure was 10 min. Results showed that while HP reductions of only 2.5 and 2.3 $\log_{10}$ against the human noroviruses were achieved, its 4.3 $\log_{10}$ reduction against the surrogate calicivirus met EPA criteria of acceptability; while the ClO_2 product only showed reductions of 1.7 $\log_{10}$, 0.6 $\log_{10}$, and 2.4 $\log_{10}$ respectively. However, the exposure times used in the study were extremely short relative to the longer times needed to effectively decontaminate rooms or areas of large buildings. This was shown during a 22-month period in a 500 bed hospital where 1,565 rooms that had housed patients infected with multi-drug resistant pathogens over that time were decontaminated using VHP[19]. The decontamination required a mean time of 2-hours and 20 minutes, compared with 32 minutes for conventional cleaning. Despite the greater time required for decontamination, VHP use was deemed feasible based on its efficacy for infection control, and its use in a hospital with a very high occupancy rate. These studies emphasize the fact that successful disinfectant fogging depends upon multiple factors, to include the targeted organism(s), chemical formulation and concentration, fogging rate and airborne density, exposure or dwell time, and temperature and relative humidity.

Also, any discussion of disinfectant fogging, whether in food and agriculture, healthcare, or in office buildings in particular, raises the question of its effectiveness compared to manual cleaning and disinfection. Fogging aims to kill microbial inactivation where it lies, and concern focuses on whether or not all key surfaces receive an equal distribution of chemical, aside from the question of interference from soiling and the presence of biofilms. Manual cleaning and disinfection however focuses on the removal of the bulk of microbial contamination from key surfaces to a maximum extent, prior to the application of a chemical disinfectant meant to inactivate any remaining residual. This issue was addressed by the USEPA, the federal agency that registers antimicrobial pesticides. In April, 2013 the Director of EPA's Office of Pesticide Programs sent a letter to all EPA registrants of antimicrobial pesticide products which made claims to provide control of public health microorganisms when applied by fogging and/or misting[20]. The issue was efficacy. The letter then explained why the EPA believed that fogging/

misting methods of application may not be adequately effective, and afforded the following rationale:

> "Application by fogging/misting results in much smaller particle sizes, different surface coverage characteristics, and potentially reduced efficacy when compared to sanitization or disinfection product applications by spraying, sponging, wiping or mopping.
>
> The absence of pre-cleaning in the presence of soil contamination, potential reaction with or absorption of the active ingredient for different surfaces, and humidity/temperature fluctuations can also impact distribution and efficacy of the product.
>
> A surface treated by fogging/misting does not receive the same amount of active ingredient per unit area as the standard methods of application and, as a result, the level of efficacy actually achieved may not be the same level claimed on the label."

In reality, disinfectant fogging and manual cleaning and disinfection are both subject to human error in a number of ways, and neither approach can be expected to eliminate all microbes on all targeted surfaces. In general, fogging tends to be quicker, yet potentially less effective at inactivating the bulk of the microbial bioburden, but more cost effective; while manual cleaning tends to be more effective at decontamination, yet slower to achieve, and perhaps more costly. Depending upon the need for decontamination, it is also conceivable to use both approaches, that is, manual cleaning followed by disinfectant fogging. But prior to consideration of such a scenario, the last approach to aerosol disinfection, namely spraying, needs to be addressed.

Sprays

Spraying involves chemicals typically dissolved in water and dispersed under pressure as tiny droplets greater than 10 μm. The size of the droplets and the extent of their distribution on surfaces depends largely on the pressure exerted to dispense them, along with nozzle size. Thus, a pressurized can of aerosol spray disinfectant will deliver a very fine spray across surfaces, as opposed to the larger droplet sizes delivered by pump or hand trigger spray containers. And with all of these methods, the extent of distribution of the product across the targeted surfaces, is also a factor of distance from the nozzle to those surfaces. So, a key question that arises in the use of sprays, as well as the use of gas-phase, vapor-phase, and fogging methods is, will the product deposition be contiguous across all targeted surfaces to maximize microbial contact, and also penetrate all cracks and crevices that might also harbor contamination? Such thorough coverage with any of those methods can't ever be assured, but the one methodology designed to address those issues is electrostatic spraying (ES).

ES technology has been used in the painting, agriculture[21, 22], and automotive industries for many years, although it has not been extensively researched in regard to control of human pathogens. Using EPA-registered disinfectants, fine droplets from electrostatic sprayers receive a positive charge just before they leave the nozzle. As charged droplets, they are then attracted to negative or neutral-charged surfaces, and can literally wrap around surfaces and materials, providing an even and consistent distribution. And while ES maximizes disinfectant distribution across both horizontal and vertical surfaces, the question of efficacy remains regarding its effectiveness in the absence of a pre-cleaning step. This has been emphasized in recently presented but unpublished studies that have recommended the use of ES disinfection following routine cleaning and disinfection[23, 24].

Discussion

Cleaning

While many manufacturers and contractors may tout their disinfectant products and services as stand-alone approaches to eliminating indoor microbial contamination, science continues to support the fact that the basic and fundamental approach to reducing the risk of infectious agent transmission is the process of cleaning. *Clean* is a condition free of unwanted matter, and *Cleaning* is the process of achieving the clean condition, so human activities can take place in a healthy environment[25]. And for cleaning to be effective, unwanted matter must become separated from the environment[26]. Thus, the removal of soil (organic dusts, cells, oils, and proteinaceous substances) and its associated microbes from key high contact surfaces and materials, remains the primary approach to achieving a healthy environment[27]. And if the process is carried out at an established frequency, then the clean condition becomes easier to achieve. And let's not forget that EPA-registered disinfectants (with the exception of one-step cleaner-disinfectants) are required by law to be used only on clean surfaces, to maximize their effectiveness.

Disinfection

Any type of cleaning may leave a residual behind, even if a one-step detergent-cleaner is used. Thus, if circumstances warrant, such as with a localized bacterial outbreak in an indoor facility, or a newly emerged virus in a global pandemic, the subsequent application of an effective disinfectant following the cleaning process becomes mandatory. That application may be done manually, or by a fogging or spraying process, either of which can be considered time-saving and cost-effective, whether done in-house or by a contractor. Currently, with the COVID-19 situation, reliable restoration contractors have the equipment, trained personnel, and expertise to effectively respond to a potential infectious agent situation, such as one where occupants of an office building have tested positive for the coronavirus. And decontamination protocols may

differ slightly among restoration professionals, wherein some may do an initial fogging to begin the disinfection process (and provide a measure of protection for workers), then perform the manual cleaning, and then follow with a post-cleaning fogging.

For many facility executives and managers, the current commercial environment regarding cleaning and disinfection in response to COVID-19, can be confusing, with many disinfectant manufacturers and contractors touting various claims for products and services. The answer of course is to seek to be informed, and in that regard, the following points of inquiry are offered for consideration in interacting with the many purveyors of decontamination goods and services:

- What disinfectant products will be used? What label claims do they have, and are they on EPA's L list of products approved for COVID-19 use? Do they have any incompatibility with any materials? Are the products' Safety Data Sheets (SDS) available?

- Will cleaning be conducted prior to disinfectant application? If so, how will that be done (spray and wipe, damp microfiber cloth, steam, other)?

- What fogging, spraying, or electrostatic spraying apparatus will be used? What size droplets will be produced? How long will surfaces remain wet (dwell time) to achieve disinfection? Will disinfectant residue need to be removed? What odors will there be?

- What projects has this protocol been successfully used for? What other clients have used these services? How often should this process be done to achieve best results?

- Will any post-cleaning/disinfection evaluation be done to confirm effectiveness, such as with ATP testing?

With a working knowledge and understanding of building decontamination through cleaning and disinfection, especially in the midst of an infectious disease pandemic, facility executives and managers will be better prepared to ensure the achievement of healthy indoor environments for all.

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