Biocidal agents and their by-products: The flip side of disinfection

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One of the main reason to use an automated room disinfection system such as STERISAFE in healthcare settings is the reduction of healthcare-associated infections (HAIs). The ability of an airborne disinfectant to reach every corner of a treated room is a non-negligible advantage over conventional cleaning and disinfection.

Another reason, which is regrettably overlooked sometimes, but is nonetheless critical, is the health and safety of the cleaning operator. Occupational exposure to disinfecting products can be hazardous due to the toxicity of the product itself or due to volatile disinfection by-products (DBPs), which are substances resulting from reactions between disinfectants and natural organic matter. For example, several studies demonstrated that healthcare workers show higher risks of developing work-related asthma and other respiratory syndromes such as chronic obstructive pulmonary disease (COPD) (Ioannou et al., 2017 & Dumas, 2019 & LeBouf, 2014).

Those studies demonstrated a direct correlation between exposure to frequently used cleaning products, including bleach, hydrogen peroxide, alcohol, quaternary ammonium compounds and adverse effects on respiratory health. Therefore, while the frequent and thorough use of disinfecting products is essential in healthcare settings, healthcare personnel such as nurses and cleaning staff may find themselves overwhelmingly exposed to harmful agents.

An important feature of automated room disinfection systems such as STERISAFE is thus to guarantee that no one, employee or patient, comes in prolonged, direct contact with disinfection by-products.

Generation and removal of active substance

In a typical automated airborne disinfection system, a sealed room is filled with a biocidal compound. The concentration of the active compound is increased and stabilized for a given amount of time, which allows it to spread on every exposed surface. Finally, the concentration of the biocidal compound is lowered to a safe level, and re-entrance in the room is permitted. In the case of STERISAFE, those 3 steps are referred to as the *Build-up*, *Disinfection* and *Purification* phases, and the entire process is appropriately named *Full-Depth Disinfection Cycle* (FDDC). As the entire process is taking place in a sealed room, the *Purification* phase is the most crucial stage when it comes to potential exposure to biocidal products. While the total decay time can differ greatly depending on surroundings (initial ozone concentration, room size, airflow, temperature, relative humidity), in a closed room under normal conditions, ozone has a half-life of approximately 12 hours (McLurkin et al., 2013). This makes the purification phase the most time-consuming phase during an automated room disinfection process.

To ensure a rapid, near-complete decomposition of ozone down to safe levels for employees, STERISAFE PRO uses a catalytic process. The efficacy of the system used is shown in Figure 1, where the natural decomposition of ozone in a closed room is compared to the catalysed decomposition of ozone during the FDDC's Purification phase. The catalyst used by STERISAFE is composed of a manganese oxide catalyst that converts ozone into oxygen. Under regular operation, the catalyst is not consumed by the reaction and is therefore maintenance-free. Additional advantages of this method include the absence of harmful by-products, as oxygen is the sole product of the catalysed degradation of ozone. Active carbon may also be used, however this solution requires frequent replacement as active carbon is consumed during reaction with ozone, in addition to releasing CO and CO_2. Thermal degradation of ozone is unfeasible as it requires a high energy input and may increase the temperature

of the room significantly. Other methods to remove ozone include the injection of chemicals that are oxidized by ozone. While the ozone may be removed, many reaction by-products are formed, which may be more detrimental to health than ozone alone.

Other technologies using alternative biocidal products may or may not include an active removal of their agents. Omitting this step can cause extended delays in the required cycle time, or the need to buy costly, complementary accessories. Incomplete decomposition of active agents can also cause notable discomfort for employees and patients. For example, newly disinfected rooms using an automated system based on aerosolized H_2O_2/peracetic acid solutions were reported to have an unpleasant smell, and to trigger irritation of the eyes and upper airways (Blazejewski et al., 2015). It is important for the safety of workers and others to always ensure a room can be safely re-entered following an automated disinfection process.

Particulates, dangers and removal

There is a second element in the FDDC's *Purification* phase, which targets another component volatile in air that has adverse health effects: particulates. Particulates, or particulate matter (PM), refers to the mixture of solid particles and liquid droplets that are present in suspension in the air. These particles vary greatly in size, composition and origin. They are often categorized by their size, and are known as either coarse particles or fine particles. Coarse particles, with a diameter ≤ 10 µm, are denoted PM_{10} whereas fine particles, with a diameter < 2.5 µm, are referred to as $PM_{2.5}$. Due to the small size of $PM_{2.5}$ particles, they are easily inhalable and can potentially cause serious health issues; chronic exposure to particles leads to increased risks of developing cardiovascular and respiratory disease. There is currently no identified minimal concentration threshold at which particles exhibit no-observed-adverse-effect level (NAOEL) (WHO, 2014). The World Health Organization's (WHO) current stance is to recommend minimal daily exposure values, set at 25 µg m^{-3} and 50 µg m^{-3} for $PM_{2.5}$ and PM_{10}, respectively.

Particulates can be produced by the erosion of a material (brake dust) or the aggregation and clumping together of gas molecules (nucleation in a fire). Some sources of particles are natural causes, for example forest fires, pollen or mould. Particle emission from human sources, while less than natural emissions, are collocated with industrial activity and development and have a significant impact on air quality and health. PM_{10} typically include dust, sand and pollen, while $PM_{2.5}$ consists of smaller elements, sometimes formed by the interaction of condensable gases and nucleation. Particles which are directly released in the air are called primary particles; the ones that are formed in the atmosphere are referred to as secondary particles. Secondary particles arise upon complex chemical reactions involving gases and other volatile compounds, including common disinfecting agents (ex.: ozone, hydrogen peroxide, bleach, ammonia…) (McDonald et al., 2018, Wang et al., 2019). While the benefits of having a properly disinfected environment far outweighs the drawbacks of particle generation, especially in healthcare settings, STERISAFE recognizes the need to address this issue.

This is why STERISAFE PRO units are equipped with an Electrostatic Precipitator (ESP), a filtration device which removes small particles during the *Purification* phase of the FDDC. The basic principle of an ESP is that it charges particles, so that they can be collected by means of electrostatic attraction. This type of particle collection is more effective on smaller particles than alternative technologies based solely on gravity or centrifugation (Muralikrishna & Manickam).

To illustrate the need for particle collection after a disinfection process, a comparison was made between two automated disinfection systems in equivalent conditions. The PM concentration was monitored throughout the regular disinfection cycles of a STERISAFE PRO (FDDC cycle) and a competitor's product (H_2O_2 as its biocidal agent), and the result is given in Figure 2. It is important to note that the generation of secondary particles by a disinfecting agent is highly dependent on the initial conditions of the environment. For that reason, the PM concentration is given in Figure 2 as arbitrary units. It can be seen that both methods trigger a sharp raise of PM_1 and $PM_{2.5}$ at their onset, but only the FDDC cycle manages to significantly drop the PM concentration back to their initial state.

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The fully automated FDDC solution of STERISAFE PRO thus provides a complete disinfecting solution, from the generation of biocidal agent, the disinfection itself, and the removal of both the active agent and potentially harmful compounds. With STERISAFE PRO, there is no need for external products or additional material to ensure a safe environment for employees and anyone involved in the disinfection process.

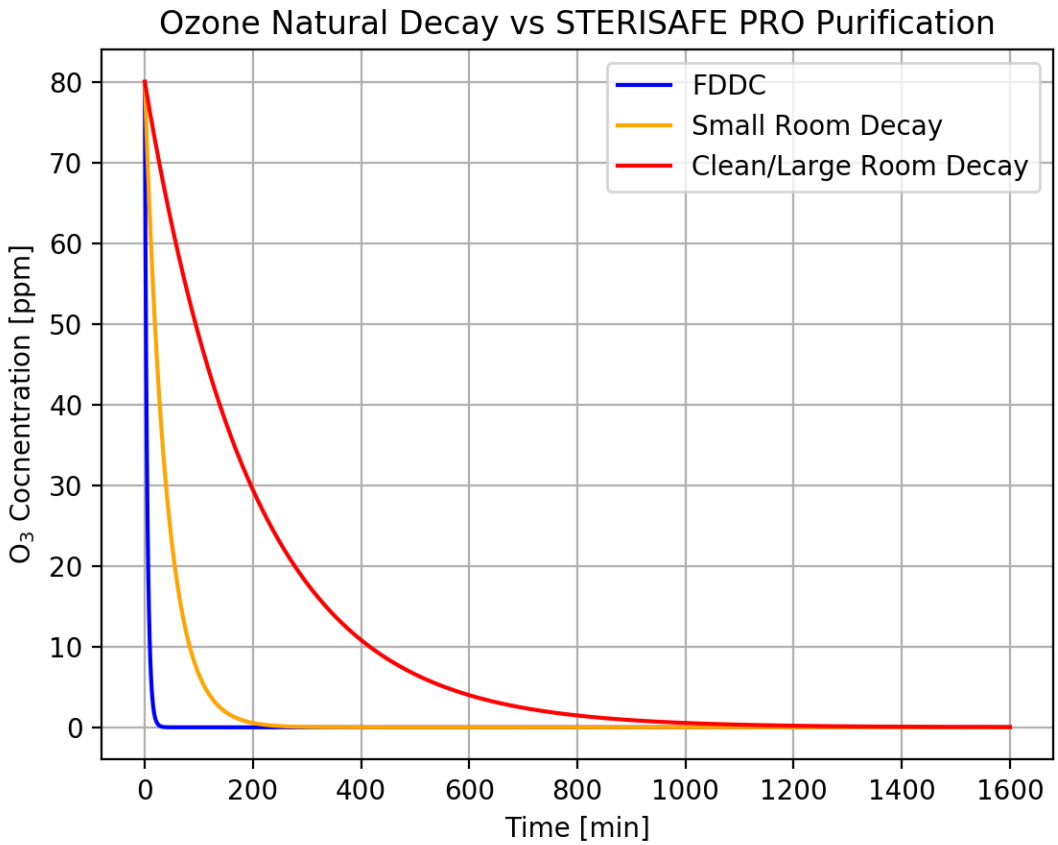

Figure 1. Natural decay of ozone in a closed room vs. catalysed decomposition of ozone by STERISAFE. In-house data.

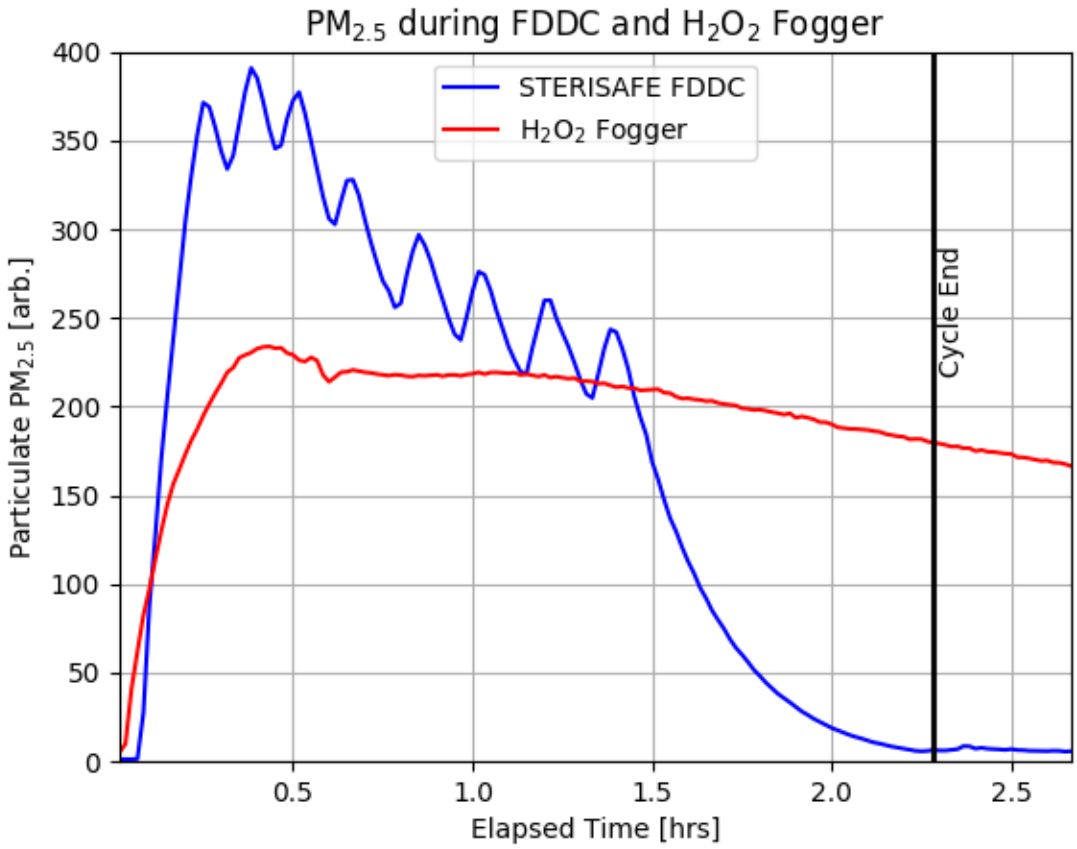

Figure 2. Particulate matter (PM) concentration over a full disinfection cycle by STERISAFE PRO (FDDC, left) and by hydrogen peroxide (H_2O_2, right). In-house data.

References

1. Blazejewski C., Wallet F., Rouzé A, Le Guern R., Ponthieux S., Salleron J. & Nseir S. (2015) *Critical Care* 19 (1) : 30
2. Dumas O., Varraso R., Boggs K.M., Quinot C., Zock JP., Henneberger P.K., Speizer F.E., Le Moual N. & Camargo Jr C.A. (2019). Association of Occupational Exposure to Disinfectants With Incidence of Chronic Obstructive Pulmonary Disease Among US Female Nurses. *JAMA Network Open* 2 (10): e1913563
3. Ioannou S., Andrianou X.D., Charisiados P. & Makris K.C. (2017). Biomarkers of end shift exposure to disinfection byproducts in nurses. *Journal of Environmental Science* 58: 217-223
4. LeBouf R.F., Virji M.A., Saito R., Henneberger P.K., Simcox N. & Stefaniak A.B. (2014). Exposure to volatile organic compounds in healthcare settings. *Occupational and Environmental Medicine* 71 (9): 642-650
5. McClurkin J. D., Maier D. E. & Ileleji, K. E. (2013). Half-life time of ozone as a function of air movement and conditions in a sealed container. *Journal of Stored Products Research* 55: 41–47
6. McDonald B.C., de Gouw J.A., Gilman J.B., Jathar S.H., Akherati A., Cappa C.D., Jimenez J.L., Lee-Taylor J., Hayes P.L., McKeen S.A., Cui Y.Y., Kim S.W., Gentner D.R., Isaacman-VanWertz G., Goldstein A.H., Harley R.A., Frost G.J., Roberts J.M., Ryerson T.B. & Trainer M. (2018). Volatile chemical products emerging as largest petrochemical source of urban organic emissions. *Science* 359 (6377): 760-764
7. Muralikrishna I.V. & Manickam V. (2017). Chapter 14 – Air Pollution Control Technologies. In Muralikrishna & Manickam (Eds.), *Environemental Management* (pp.337-397). Oxford, UK: Butterworth-Heinemann
8. Wang C., Collins D.B. & Abbatt J.P.D. (2019). Indoor Illumination of Terpenes and Bleach Emissions Leads to Particle Formation and Growth. *Environmental Science & Technology* 53: 11792-11800

9. World Health Organization (WHO) (2014). Ambient (outdoor) air quality and health. *Media Center*, Fact Sheet N°313. Retrieved from <https://web.archive.org/web/20160104165807/http://www.who.int/mediacentre/factsheets/fs313/en/>