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Study on the effectiveness of an air treatment tool that combines filtration and photocatalysis

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Abstract

The microbiological quality of air in working environments is a very current topic. This study aims to evaluate the effectiveness of a machine equipped with EPA filters and photocatalytic activity. This type of treatment combines a physical action with a chemical activity. The latter occurs thanks to the production of reactive oxygen species (ROS), responsible for a marked bactericidal activity. The search for new sanitization techniques pushes companies to invest to improve the quality of work of their employees. Many tools are sold on the market, but it is important to check their actual effectiveness. Monitoring the activity of air treatments is always very complex, due to the variability and heterogeneity of airborne microorganisms. This study was conducted in a typical working environment, to better simulate normal conditions of use. To avoid potentially pathogenic contamination, microorganisms typically recountable in the air matrix were not used, but the species of bacteria *Lactococcus lactis* was used. These microorganisms are also naturally present in the outdoor environment and represent a population of bacteria that could potentially cause indoor air pollution. The results confirm the effectiveness of this type of treatment. It was not possible to determine the impact of the catalytic feature installed.

Keywords: Biotechnology; Sanitation; Air treatment; HAVC; UV-C; Photocatalysis

1 Introduction

Air sanitization is a topic that is receiving increasing attention from many companies. Modern air treatment methods have numerous problems: high energy expenditure, expensive maintenance and non-specific activities on different possible targets. Many air treatment systems, especially those dedicated to offices and large spaces, are represented only by HAVC (Heating, Ventilation and Air Conditioning) packages. Generally, after a filtration treatment, they introduce a part of external air and a part of air taken back from the offices themselves. One of the greatest dangers of this mode of air distribution is the accumulation and distribution of microorganisms in the workplace. For this reason, more and more companies are investing time and money in the search for devices that can safely and significantly break down the airborne microbiological load. In this sense it is not possible to use detergents or disinfectants, this is because in large quantities they are toxic if inhaled by employees, they would also favor the onset of adaptations in microorganisms aimed at resistance. A possible solution is to combine the photocatalytic activity of special machinery already equipped with filtering systems. In this study, the sanitizing activity of an instrument equipped with EPA filters and a UV lamp surrounded by a catalytic metal composed of titanium dioxide (TiO_2) was tested. The efficiency of EPA/HEPA filters has long been proven [1-3]. Titanium dioxide photocatalysis is a photon-driven reaction process. It is generated as a result of a photo adsorption event of light that hits a material called catalytic. When TiO_2 is hit by photons

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with a specific energy it can lead to induced reduction phenomena or oxidative phenomena [4, 5]. Often the source of photons is represented by UV lamps, since they can provide the energy necessary to activate the material. The biocidal activity, consequently to photocatalysis, turns out to be a process defined as "indirect" because it is based not on the direct interaction between microorganisms and titanium dioxide, but on the activity of free radicals produced by the irradiation of the latter. As soon as TiO_2 is irradiated by ultraviolet light this can generate free radicals in two ways, either by exploiting the energy hole produced in the valence band or the excited electrons that have now moved into the conduction band. In the first case it will be able to induce the oxidation of a water molecule, producing a hydroxyl radical (OH•) [6]; in the second case, an oxygen molecule will be able to acquire the electron of the conduction band generating a series of cascade reactions that will lead to the production of a series of extremely reactive free radicals [6]. Some free radicals, due to their common oxygen component, are called reactive oxygen species (ROS). The main ROS are superoxide anion ($O_2^{\bullet -}$), hydrogen peroxide (H_2O_2), hydroxyl radical (OH•) and singlet oxygen ($^1O_2$). These compounds are extremely reactive and their life is very short, given the tendency to interact extremely quickly with a large class of compounds. These molecules are often employed by the innate immunity of individuals as a defense against pathogens and many in vivo studies have shown their effectiveness [7]; However, the mechanisms of action are still not fully understood. Studies of *Echerichia coli* have shown that low concentrations of hydrogen peroxide can induce DNA damage, while high concentrations affect other cellular targets. Proteins, in turn, can undergo a series of oxidative changes, in particular at the level of cysteine, methionine, tyrosine, phenylalanine and tryptophan. In addition, ROS also seem to be able to prevent the formation of bacterial biofilms [8-10]. The study of the effectiveness of the instrument under consideration was conducted in a typical working environment. The selection of the bacterial species to be used was continued with the aim of using a microorganism that is not pathogenic to humans and that could potentially be present in a natural environment, thus making it a possible component of the bioaerosol. For all these reasons, the species of *Lactococcus lactis* was selected. These microorganisms are part of the intestinal microbiota of humans, and are found in many dairy foods, and their natural presence in the air has been demonstrated [11-13].

2 Material and methods

2.1 Sanification unit and sampling points

To test the combined sanitizing capacity of a photocatalytic activity and a filter package, a fan was equipped with a UV lamp (with a wavelength between 100-400 nm) and an EPA E11 filter. The fan flow rate was measured to be 315 m^3/h without filters and 215 m^3/hour with filters. The UV lamp was placed before the filter package and adjacent to a titanium dioxide plate. The instrument was placed 2 meters from the wall of a standard meeting room, with a volume of 120 m^3. The instrument was raised from the ground by about 30 cm. Multiple experiments were conducted on several different days. All sampling was conducted in tripled or duplicated. The sampling points are POINT 1 and POINT 2 (Figure 1).

2.2 Preparation, spraying and sampling of micro-organisms.

For the multiplication of microorganisms, a 200 mL mother culture of tryptic soy broth (biolife italiana srl, Viale Monza, 272 - 20128 Milan) was prepared in which 0.5 g of powdered milk was dissolved. Subsequently, 1 g of *Lactococcus lactis ssp* was inoculated. *Lactis* and *Lactococcus lactis ssp.* was purchased freeze-dried (Lyofast MWO 030, Sacco, Via Manzoni, 29/A 22071 Cadorago, CO). The solution is incubated at 30 °C. After 24 hours, 10 mL of stock solution is distributed in 490 mL of sterile ringer solution. This solution is sprayed for 15 minutes within the environments selected. Aerosol sampling is conducted with 90 mm diameter plates containing yeast extract agar containing glucose (0.5 g/L) and milk powder (0.5 g/L). The plates were used with the microflow-α impactor (Aquaria srl, Via della Levata, 14 - 20084 Lacchiarella, MI). The culture of the samples was done at 30 °C for 72 hours. Inside the conference room, sampling was carried out at two distinct points, one near the sanitizer, and one on the opposite side of the room.

3 Results

The ability of *Lactococcus lactis* to survive for more than 30 minutes in the air matrix has been demonstrated, making it an excellent candidate for contamination studies in working environments. The effect of reducing the bacterial load was verified by monitoring the variation of this parameter over time in two specific cases: using the active (ON) and non-active (OFF) disinfection system. The microbiological charge was reported as colony-forming units at m^3 (CFU/m^3). The behavior of the bacteria was detected at POINTS 1 and 2 after 0, 30 and 60 minutes (T0, T30 and T60) from the end of the nebulization (Table 1). At T0 it was not possible to quantify the colonies grown on the plates, in this case a figure >20000 is imposed, which is the maximum of colonies identifiable with our sampling method. The same phenomenon occurs at the T30 when the instrument does not have the abatement systems. In POINTS 1 and 2 it is possible to highlight a reduction of the consistent microbiological load. At POINT 1 this effect is more marked, probably this is due to the proximity of the sampling with the sanitizing tool. At POINT 1 the natural decay is slower than at POINT 2, this is

probably due to the greater proximity to the source of microorganisms. To verify the effectiveness of the contribution of photocatalysis products only, the experiment was replicated by removing the filters. The results are shown in Table 2. The results show no difference between a natural decay of the microbial load and a decay induced by the photocatalytic effect.

Table 1 Summary of the results obtained by monitoring the microbiological load over time following a treatment with an instrument equipped with filters and photocatalytic activity

		Treatment unit			
		On		**Off**	
Sample	**Treatment time**	**Mean (UFC/m³) ± SD**	**5th-95th percentiles**	**Mean (UFC/m³) ± SD**	**5th-95th percentiles**
POINT 1	T0	>20000	-	>20000	-
	T30	2474 ± 1127	1408 - 3864	>20000	-
	T60	285 ± 55	223 - 307	1600 ± 592	940 - 2293
POINT 2	T0	>20000	-	>20000	-
	T30	1253 ± 777	610 - 2368	5683 ± 777	4625 - 6960
	T60	118 ± 64	58 - 214	788 ± 64	655 - 845

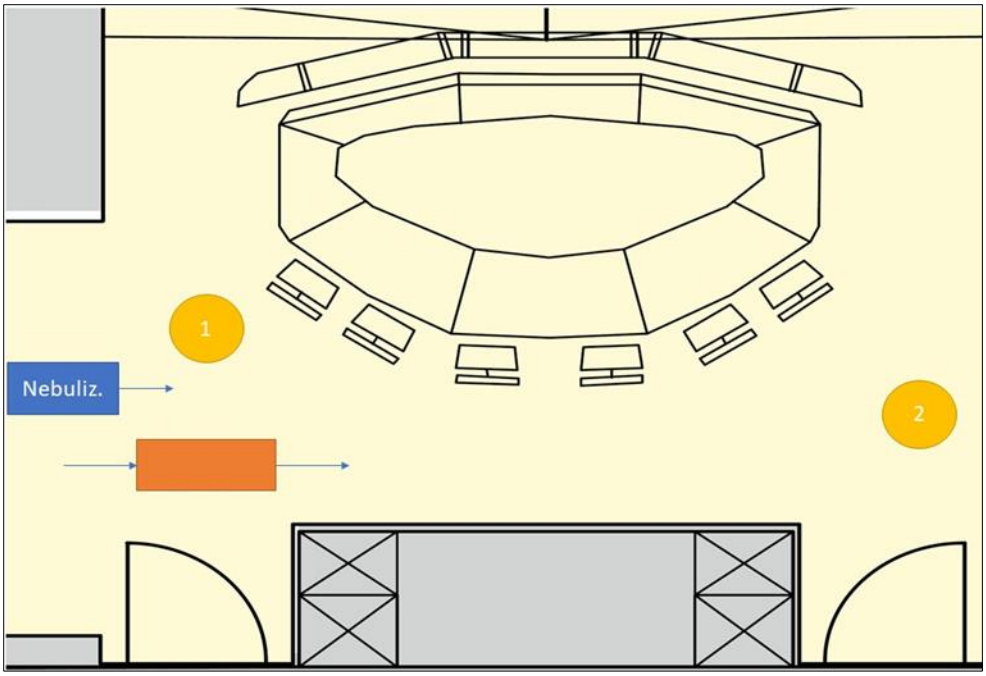

Figure 1 Plan of the room. The numbers 1 and 2 represent the sampling points. The direction of the air flow generated by the instrument is represented by the blue arrows. The blue square represents the nebulizer position. The orange rectangle is the sanitizing tool

Table 2 Summary of the results obtained by monitoring the microbiological load over time following a treatment with a photocatalytic equipped with filters and photocatalytic activity

		Photocatalytic unit			
		On		**Off**	
Sample	Treatment time	Mean (UFC/m^3) ± SD	5th-95th percentiles	Mean (UFC/m^3) ± SD	5th-95th percentiles
POINT 1	T0	>20000	-	>20000	-
	T30	642 ± 72	560 - 718	900 ± 37	865 - 944
POINT 2	T0	>20000	-	>20000	-
	T30	742 ± 87	648 - 839	1171 ± 36	1130 – 1209

4 Discussion

From what has been elaborated by analyzing the results of the experimental days conducted in the selected room, it can be summarized that the use of the bacterial species *Lactococcus lactis* has shown sufficient persistence in the air matrix following aerosolization, making it a useful element to evaluate a killing without having to use naturally airborne bacteria that are often in extremely low concentrations. Acting with the fully equipped instrument, the results of the killing of the microorganism are already evident after 30 minutes. It is still necessary to clarify what the contribution of photocatalytic treatment can be with respect to filtering activity. The photocatalytic activity of innovative photoactive materials, able to generate molecules capable of conducting bactericidal activity, has been tested both in vitro and in vivo by many research institutions around the world. The results of these biochemical tests have confirmed the ability of ROS to interfere with macromolecules (mainly proteins and deoxyribonucleic acids) imposing structural changes that affect their natural functionality, generating a whole series of cascading effects that lead, in some cases, to cell death. However, it must necessarily be specified that these laboratory experiments have been conducted in an extremely specific manner, exposing directly to the ROS the microorganisms contained in a solid matrix or inside a liquid suspension. Another factor to be taken into consideration is the parameter called "contact time": the time range of exposure to a specific concentration of a given molecule necessary for the expected bactericidal effect. A study conducted by Rajagopal and his team in 2006 showed that an effective reduction of the bacteriological load due to the activity of ROS produced by a material containing TiO_2 is detectable after 10 minutes of exposure to a concentration of 3 ppm of H_2O_2 [14]. It is important to note that, in this study, while demonstrating the effective bactericidal action of the technique, complete sanitization was not demonstrated, but only the bacterial load was reduced by a factor of 4 (from 10^6 to 10^2). A further study demonstrated the effectiveness of photocatalytic activity of materials containing TiO_2 using the in vivo imaging technique exploiting fluorescence [15]. This experiment La Russa confirmed what has been stated so far, namely the fact that the effectiveness of a photocatalytic treatment depends on the contact time between the vital component and expressed free radicals, not however materializing in a complete abatement. More recent research further corroborates this concept. An example is the study carried out by Yuzer Burak in 2022, in which a particular material containing titanium dioxide nanoparticles was tested that can consistently reduce microbiological contamination after about 10 minutes [16]. All these studies highlight the difficulty of treating a complex matrix such as air, especially in conditions of low concentration of bacterial suspension. Inside the aerosol, this meeting takes place in a completely random and not easily predictable way. In addition to this factor, it should be considered that it is not enough that a single ROS molecule hits a single bacterium to determine its death, but a sufficiently substantial quantity will be needed to evade the protection systems of the microorganisms themselves and act on all those intracellular macromolecules important for the survival of the cell. Again, to increase the chances of this happening it would be important that the matrix to be treated is subjected to photocatalytic activity for a long period of time. Although the effectiveness of the reduction of the airborne bacteriological load has been demonstrated. Based on what can be deduced from the information material provided by the manufacturer, and from the visual and experimental information collected during the experimentation of the instrument, it has not been possible to demonstrate that the photocatalytic activity of which it is equipped is sufficiently efficient to provide an appreciable additional effect to the filtration of the volumes of air treated every hour. It will be interesting to study the possibility of equipping the tested tool with a robot capable of moving autonomously in the working environment. This feature could allow him to intervene in a targeted manner.

5 Conclusion

This study demonstrated the possibility of using non-harmful airborne microorganisms for testing air treatment devices. The effectiveness of common filtration systems was confirmed. The actual usefulness of adding a photocatalytic system for air sanitation was not demonstrated yet.

Compliance with ethical standards

Disclosure of conflict of interest

No conflicts of interest present.

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