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Efficacy of radiant catalytic ionization to reduce bacterial populations in air and on different surfaces

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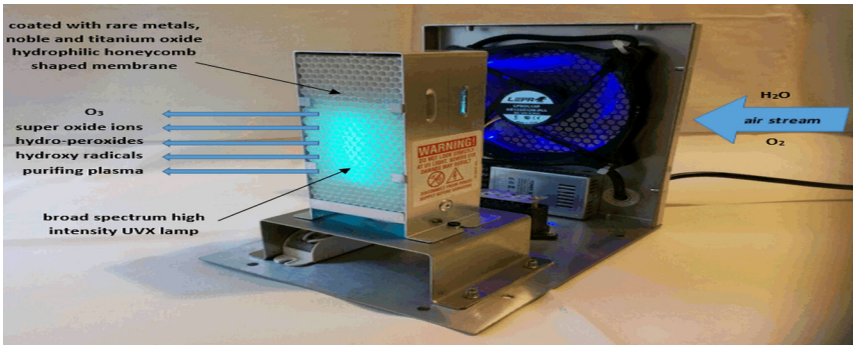
HIGHLIGHTS

- The radial catalytic ionization biocidal efficiency (RCI) has been evaluated.
- The coefficient of microbial elimination from the air was >95% after RCI usage.
- RCI usage causes visible elimination of microorganisms from tested surface.
- RCI biocidal efficiency depends on strain and type of surface.
- Spores of *Clostridium* spp. were more resistant than vegetative form of bacteria and fungi.

GRAPHICAL ABSTRACT



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ABSTRACT

Air contamination by biological agents is often observed in medical or veterinary facilities and industrial plants. Bioaerosols may sediment and pose the surface contamination. Microorganisms present on them may become a source of infections among humans and food contamination. This study determined the use of oxidative gases, including ozone and peroxide, generated by the Radiant Catalytic Ionization (RCI) cell for the inactivation of *Acinetobacter baumannii*, *Escherichia coli*, *Enterococcus faecalis*, *Pseudomonas aeruginosa*, *Salmonella* Enteritidis, *Listeria monocytogenes*, *Staphylococcus aureus*, *Streptococcus epidermidis*, *Bacillus subtilis*, *Clostridium sporogenes*, *Candida albicans*, *Aspergillus niger* and *Penicillium chrysogenumon* in air and on different surfaces. Results showed that oxidative gases produced by the RCI cell reduced all tested microorganisms. The full elimination of studied microorganisms from the air was obtained for *E. coli* and *C. albicans*. RCI also proved to be an effective method of eliminating microbes from the examined surfaces. Regarding of the species, strains origin and the type of surface, the reduction rate ranged from 19.0% for *C. albicans* to over 99% for *A. baumanii*. For both, air and surface, the most resistant to RCI was *C. sporogenes* spores, for which the percentage reduction rate ranged from –2.6% to 71.2% on the surfaces and was equal 71.7% in the air.

1. Introduction

One of the major problems of air quality is the presence of microorganisms in it, which include bacteria, molds, and viruses.

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Microorganisms present in the air compose bioaerosol. In this form microorganism may spread over considerable distances, sediment on different surfaces and causing their contamination. Ventilation ducts can be the source of airborne microbial communities (Hayleeyesus and Manaye, 2014; Hospodsky et al., 2012). Air contamination by biological agents is often observed in medical or veterinary facilities, industrial plants (e.g. food processing plants, waste segregation and recycling plants, steel and ironworks) and in agriculture (Brewczyńska et al., 2015; Douwes et al., 2003). Workers dealing with industrial waste recycling or production of highly purified biological substances are exposed to high concentrations of bioaerosols (Rim and Lim, 2014). Most particles of biological aerosols range from nanometric (e.g. bacterial endotoxins), to submicrone (e.g. fragments of bacterial or fungal cells), to particles whose diameter may exceed 100 μm (e.g. plant pollens) (Douwes et al., 2003; Dutkiewicz et al., 2011; Górny, 2010). Bioaerosols with a diameter of 1.0–5.0 μm usually remain in the air, whereas the fraction of large molecules descend on surfaces (Gąska-Jędruch and Dudzińska, 2009). It was proven that in houses the level of bacterial aerosol amounts on average to 10^3 CFU × m^{-3} (Colony Forming Units), and in workplaces 10^2 CFU × m^{-3} (Pastuszka et al., 2000).

Many surfaces, such as stainless steel, plastic, rubber org glass, are used in hospitals or food industry. Microorganisms present on them may become a source of infections in people and food contamination (Bagge-Ravn et al., 2003). The degree of surface contamination depends on their properties, such as the material of which they are made, porosity, hydrophobicity/hydrophilicity, etc. (Ismaïl et al., 2013). Schlegelová et al. (2010) indicated that surfaces that come into contact with food may be contaminated with such bacteria as *Listeria monocytogenes*, *Salmonella* spp., *Escherichia coli*, *Bacillus* spp., *Staphylococcus* spp., *Enterococcus* spp.

Ozone or UV-C radiation are commonly used for disinfection of rooms and air. (Kim et al., 1999; Kujundzic et al., 2006). It is necessary to search for and develop new methods for sterilization of air and surfaces which come into contact with patients or food. The technology of radiant catalytic ionization (RCI) is still not well known, but its popularity is gradually increasing. This technology uses the appropriate wavelength and the phenomenon of photooxidation in the presence of UV radiation and appropriate photo-catalysts, such as TiO_2, which compose the hydrophilic coating of surface of matrixes in the RCI module (Grinshpun et al., 2007). This leads to production of superoxide ions and hydroxides, and to generating plasma based on hydrogen peroxide (Cho et al., 2005). In contrast to passive methods of air purification which filter mechanically the air that flows through them, the RCI technology purifies the air outside. The advantage of this solution is the ability to perform constant disinfection of ventilated air, e.g. in food processing plants. In comparison with the effect of UV-C lamps, this technique reduces microbiological contamination and removes odors, and the resulting chemical compounds may sediment on the surface and have microbiocidal effect. It is advantage of these method, but biproducts, which are likely generated when using RCI, are of health concern. United States Environmental Protection Agency (EPA) indicate that ozone generators are not always safe and effective in removing pollutants. Harmful effects can occur following short-term exposure to low levels of ozone. Ozone generators should never be used around the ill, infirm, young or elderly people (US EPA, 1996a, 1996b). However, manufacturers of this type of air purification decelerate their safety for consumers. RCI generates very low level ozone and in the catalytic process breaks ozone down forming other oxidation products. Some authors suggest that low concentration of ozone have no effect on biological contamination (Dyas et al., 1983; Foarde et al., 1997). In this technology ozone is reduced odor, smoke and a wide spectrum of impurities in the air. Biological contamination is reduced by photocatalytic reaction with several other oxidizers. Photo catalytic oxidation must not produce any bi-products of the oxidation reaction. The EPA report confirmed the absence of bi-products using several methods, including gas chromatography, compound-specific detector tubes, and individual gas sensors (US EPA, 2000).

There are few studies in the literature assessing the efficacy of new methods for air and surface purification, such as RCI, therefore it is reasonable to conduct research on their efficacy. The study aimed to assess the efficacy of RCI towards selected microbial species present in the air and on selected solid surfaces.

2. Material and methods

The study involved the assessment of efficacy of microbial inactivation in the air and on selected types of solid surfaces as affected by radiant catalytic ionization. Ionization process was conducted using the device Induct 750 made by ActivTek Sp. z o.o, ensuring an air flow rate of 6 m × s^{-1}. The experiment was carried out in three replications for each studied strain.

2.1. Efficacy of air purification using radiant catalytic ionization

Material used for the study consisted of reference strains of bacteria (*Staphylococcus aureus* ATCC 25213, *Staphylococcus epidermidis* ATCC 35984, *Enterococcus faecalis* ATCC 29212, *Escherichia coli* ATCC 25922, *Bacillus subtilis* ATCC 8159, vegetative forms and spores of *Clostridium sporogenes* ATCC 19404) and fungi (*Candida albicans* ATCC 90028, *Aspergillus niger* ATCC 9142 and *Penicillium chrysogenum* ATCC 10106).

For the study, standardized microbial suspensions in saline with an optical density of 0.5 in McFarland standard were prepared. Next, 4 ml of each suspension was placed in a sterile nebulization chamber of the Medbryt MONSUN MP1 pneumatic inhaler. Nebulization was conducted until the complete removal the suspension from the nebulization chamber of the inhaler (about 15 min).

Nebulization chamber was placed in the testing room which was a hermetically sealed chamber with a capacity of 1.4 m^3 made of steel plates. Prior to each nebulization, the chamber walls were chemically disinfected with a preparation used for disinfection of solid surfaces, and the air contained in it was subjected to the action of the UV-C Philips TUV 36 W/G36 T8 lamp for 20 min. After that time the chamber was opened for about 20 min in order to remove the accumulated ozone. Prior to nebulization, the follow-up assessment of air microbiological purity was performed, to check the initial level of microbiological contamination. The detailed arrangement of the experiment is presented in Fig. 1, and the appearance of the research set in Fig. 2.

Air samples were collected with the compaction method using the device MAS-100 Eco (EMD Chemicals). To assess air microbiological purity after the use of UV-C Philips TUV 36 W/G36 T8 lamp and radiant catalytic ionization, 0.2 and 0.5 m^3 were collected. To assess the air microbiological contamination level in the chamber after nebulization of the microbial suspension, 0.014 and 0.052 m^3 were collected. The list of media used in the study for individual microorganisms and incubation conditions were presented in Table 1.

Colonies grown on media were counted and expressed in CFU × m^{-3} of air. Next the median was calculated for all the media studied for the given microorganism and collected air volumes. The effectiveness was expressed by giving the number of CFU of bacteria and fungi before and after the use of radiant catalytic ionization, as well as calculation of the percentage reduction rate (R[%]) according to the formula:

$$R[\%] = \frac{A-B}{A} \times 100$$

where: A – the output number of microorganisms after nebulization or drying of suspension on the solid surface [CFU × m^{-3}]B – the number of microorganisms after the use of device [CFU × m^{-3}]

Positive control in the experiment was a measurement of the number of microorganisms in the air made at 20 min after nebulization