Rotating Dielectric Barrier Discharge Plasma Source for Effective Bacterial Decontamination of Bioaerosols

Rotating Dielectric Barrier Discharge (RDBD) Plasma Source for effective bacterial decontamination of bioaerosols

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Abstract

The airborne transmission of pathogens such as bacteria and viruses via aerosols is one of the most insidious ways of spreading diseases, such as COVID-19, health-acquired infections (HAIs), and, in the food industry, contamination of processed foods with food pathogens is often airborne. Due to their small size, the nuclei of such aerosol droplets can remain suspended in the air for a long time and travel long distances. It is then of high importance to identify increasingly effective solutions in terms of microbial decontamination of air to be used as a stand-alone application or in synergy with traditional techniques (e.g., filters and UV lamps). In this study, a particular DBD architecture was presented, called rotating dielectric barrier discharge (RDBD). The efficacy of the RDBD plasma source was tested inside a chamber containing bioaerosols contaminated with *Staphylococcus epidermidis*. The results showed that the RDBD source can obtain bacterial inactivation levels greater than 3.6 Log10 CFU, comparable to those obtained with a commercial device operating at comparable ozone concentrations. Moreover, an observable distinction lies in the reduced average discharge power exhibited by the RDBD source compared to the power output of the Jonix device. Additionally, it is noteworthy that the air flow rate elaborated by the RDBD source surpasses that of the commercial device by a factor of 3.5. Furthermore, the empirical demonstration has established a strong correlation between the mean discharge power and the resulting ozone concentration, underscoring their pivotal roles as influential factors in bacterial inactivation. Conversely, the voltage range examined in this investigation does not manifest any discernible effect on the inactivation of

microorganisms, given comparable power levels and ozone concentrations. Consequently, these last parameters are critical in scaling a plasma source for air decontamination.

Keywords: Airborne pathogens, Antimicrobial, Bioaerosol, Nuclear technology, Plasma technology

I. INTRODUCTION

Nowadays, the spread of infections in indoor environments, especially in healthcare, is a crucial issue with substantial social, health, and economic impacts. The most recent example is the spread of the SARS-CoV-2 virus and the outbreak of the COVID-19 pandemic. The pandemic's effect on the global economy is challenging to quantify, but undoubtedly significant. The International Monetary Fund (IMF) estimates that the median global gross domestic product (GDP) fell by 3.9% from 2019 to 2020, making it the worst economic recession since the Great Depression (1). The social impact is evident; from the start of the pandemic until December 2022, the World Health Organization (WHO) claims over 650 million confirmed cases and over 6.5 million deaths (2). Moreover, COVID-19 has significantly affected people's lives and habits. Personal protective equipment, disinfectants, social distancing, attention to air quality, and so on have become a constant topic. So, COVID-19 forced the human population to adapt rapidly to the new, highly contagious virus. At the same time, the COVID-19 crisis highlighted the vulnerability of human societies and healthcare systems in a pandemic. It focused on another problem, namely the spread of health-acquired infections (HAIs), which also have a substantial economic and social impact. For example, HAIs in U.S. hospitals are estimated to have direct medical costs of at least $28.4 billion annually (3). A key strategy to fight the spread of a pandemic or HAIs is to break the infection chain. Therefore, it is crucial to understand how pathogens spread. The transmission modes can differ, but airborne transmission is considered the most likely mechanism explaining the diffusion of HAIs due to resistant bacteria and the SARS-CoV-2 virus. Pathogens can become airborne through respiratory droplets that are either directly in contact with another person or evaporate and become droplet nuclei that may be suspended as an aerosol for an extended period, for SARS-CoV-2 up to 3 hours (4–6).

The concentration of airborne microorganisms in hospital environments exhibits significant variability due to a confluence of factors. These factors include the specific ward type, ongoing activities, the presence of patients with infections, air ventilation, and filtration systems, and the implemented cleaning and disinfection protocols. Stockwell *et al*. (7) conducted a systematic review investigating indoor air and the impact of ventilation on bioaerosols within hospital settings. Their findings revealed a higher concentration of bioaerosols in inpatient areas (77 CFU/m^3) compared to public areas (14 CFU/m^3). Notably, hospital areas with natural ventilation demonstrated the highest total bioaerosol concentrations (201 CFU/m^3) compared to those utilizing conventional mechanical ventilation systems (20 CFU/m^3). The review also identified *Staphylococcus* spp., *Streptococcus* spp., and *Escherichia* spp. as the predominant bacterial genera in these environments.

In this context, in recent years, many scientific works emphasized the importance of Heating, Ventilation, and Air conditioning Systems (HVACs) in the transmission/spreading of infectious diseases, especially in healthcare facilities (8–10). Moreover, during the COVID-19 pandemic, the

Federation of European HVAC Association published updated guidance to stop air recirculation and increase the inflow of outdoor air (11).

Furthermore, it has been shown that air can carry bacteria, yeasts, and molds in a food production environment (12). In such settings, aerosols could originate from processing water, the dispersion of droplets generated during cleaning operations (e.g., with the use of high-pressure hoses), operators washing their hands in the room, environmental air from outside (although it has been shown that bacterial load outside is often lower than inside the factory) and operators on the site (e.g., by sneezing and coughing) (13–18). Aerosols from these sources could all carry (pathogenic) bacteria and therefore be a potential hazard. Other sources of airborne contamination could be dust (e.g., from milling or weighing of dry ingredients), skin particles, and free-floating bacterial and fungal spores (13).

Air decontamination is thus an important topic, and finding innovative solutions to reduce the chance of exposure to airborne pathogens has a significant impact in several contexts, particularly in healthcare environments where the risk of contamination is high. Various methods to decontaminate air from pathogens, such as filters, UV lamps, chemicals, or gas spray, are commonly used in indoor environments. A single strategy can hardly completely reduce the risk of infection, so various methods are often combined. However, systems such as filters or UV lamps are not without flaws. For example, filters can induce significant pressure drops in ventilation systems and require maintenance, and above all, they do not inactivate pathogens but merely intercept them.

Plasmas comprise electrons, ions, and neutral particles, with the neutral particles and ions considered heavy components. Plasmas can be classified as natural or man-made, such as lightning or electrical discharges, depending on their origin. Naturally occurring plasmas include the ionosphere and the nebulae with different energy densities (19). Man-made plasmas cover various energy levels, from atmospheric arcs to high-pressure RF discharges, and are also studied in nuclear reactor fusion plasmas (19). Cold atmospheric plasmas (CAPs), also known as nonequilibrium plasmas, exhibit low temperatures for the heavy species compared to the electrons, resulting in a macroscopic temperature close to room one, and represent a promising technology in the ecosystem of valuable methods to prevent airborne transmission of pathogens and thus decontaminate the indoor air, reducing the risk of spreading HAIs or viruses such as SARS-CoV-2 or contamination of foods during processing. It is known that the antimicrobial power of CAPs could be attributed to their ability to produce different biocidal components such as reactive oxygen and nitrogen species (RONS), electric field, and UV rays (20–23). For example, one possible way of generating CAP and treating air is to use the method of dielectric barrier discharge (DBD), which produces many reactive species (OH^-, H_2O_2, O_3, NO, NO_2, HNO_2, HNO_3, $ONOO^-$, •OH and many other), both long and short-lived species with antimicrobial efficacy. In this field, the efficacy of CAP generated using a parallel-plate DBD configuration for the decontamination of bioaerosols containing *Staphylococcus epidermidis* and SARS-CoV-2 virus has been demonstrated before (24,25).

Oliveira *et al.* explored various technologies for aerial decontamination of cold storage rooms of foods, e.g., fogging of disinfectants, UV technology, photocatalysis using TiO_2, etc. The study also considers the plasma technique, but rather as a requirement to produce ozone that could be blown through the cold storage room (26). Those systems, however, are not fit for a production environment where people are present but rather for such storage facilities.

Although there is evidence of the efficacy of CAP in inactivating bacteria and viruses, the inactivation mechanisms are still under investigation. The composition of CAPs is complex, and different biocidal agents may play a role, either exclusively or in synergy. Additionally, the droplets involved in the airborne transmission of pathogens have a mean diameter of less than 5 μm (*droplet nuclei*), so the high surface-to-volume ratio of these droplets may facilitate the absorption of RONS from the gas phase to the liquid phase. Reactive oxygen species (ROS) produced by the CAP, such as atomic oxygen, ozone, peroxide, superoxide, and hydroxyl radicals, can both react with the cell envelope and diffuse through the cell membrane leading to oxidation of the intracellular components. The former, causing cell leakage and therefore cell death, mainly happens for gram-negative bacteria, while the latter is associated with gram-positive species (27). Liang *et al.* showed the scanning electron microscopic (SEM) images of aerosolized *Bacillus subtilis* and *Pseudomonas fluorescens* treated by a wire-to-plate type DBD reactor highlighting severe membrane ruptures (28). The spectroscopic analysis showed a high concentration of OH species in the plasma produced with this DBD reactor and under experimental conditions. The authors suggested that OH species play a role in the inactivation processes of bacterial cells (28). Reactive nitrogen species (RNS) also have bactericidal power. Peroxynitrite can diffuse within the cell membrane, initiate lipid peroxidation, and cause cell wall damage (29). A further mechanism of inactivation could be due to bombardment by charged particles on the cell walls by breaking chemical bonds, erosion by etching, formation of lesions and holes in the membranes favouring the escape of cellular material, or the entry of biocidal components in the bacterial cell (23,30).

The current study aims to develop a new system based on cold plasma technology to decontaminate the air of hospital, school or office rooms from airborne pathogens. Besides the bactericidal effect, the focus is on possible harmful products, such as ozone, generated by plasma discharge. Ozone is one of the reactive oxygen species produced during plasma generation, and it has an important role in microbial inactivation due to its strong ability to oxidize bacteria and viruses. At the same time, ozone production must be evaluated appropriately, as high environmental concentrations are harmful to human health. The Food and Drug Administration (FDA) requires the ozone output of indoor medical devices to be no more than 0.05 ppm, and workers should not be exposed to an average concentration of more than 0.10 ppm for 8 h (31). Several procedures exist in the literature to assess the emission rate of indoor ozone sources. Still, at the same time, it is challenging to find a unique way to evaluate the ozone concentration produced by a plasma source within an indoor environment (32).

The primary goal of this work is to design and develop a novel system based on CAP technology to decontaminate indoor environments, targeting airborne pathogens. To achieve this, a distinctive architecture for a Dielectric Barrier Discharge (DBD) plasma source, referred to as the Rotating DBD (RDBD) plasma source, has been devised and implemented. The efficacy of this RDBD plasma source in decontaminating *S. epidermidis* bioaerosol in an enclosed airtight test chamber was assessed through rigorous experimentation, considering various operational parameters. Moreover, the ozone concentration generated by the RDBD plasma source within the chamber was quantitatively monitored employing optical absorption spectroscopy (OAS). The antimicrobial efficacy and ozone production of the RDBD plasma source were compared against those of a commercially available CAP-based air purifier, specifically the Jonix Cube device (https://jonixair.com/en/products/cubeline)

II. MATERIALS AND METHODS

A. Plasma sources

The RDBD plasma source (Fig.1). is confined in a case and is equipped with a large upper circular section (A=211.25 cm^2) for the air inlet and three bottom sections (A=78.2 cm^2) for plasma-treated air output. The plasma source consists of six AISI 328L steel high-voltage electrode rods fixed by epoxy resin inside glass dielectric tubes (with ε_r between 5 and 10); the electrodes are opposed to a grounded aluminum fan which has a dual function: it is an essential component for plasma generation being the grounded electrode, and it is the element able to drive the airflow inside the prototype (airflow rate around 130 m^3/h). Therefore, six plasma discharge zones are formed between the HV rods and the fan blades. This study also compared the RDBD plasma source with the Jonix cube device, which is a device based on CAP technology for indoor air decontamination and consisting of two surface dielectric barrier discharge (SDBD) plasma sources with a tubular shape. The high voltage and ground electrodes are concentrical metal grids spaced by a glass tube that serves as a dielectric. The plasma discharge is localized between the meshes of the external grid. The datasheet of the device mentions a power consumption of 10 W and an airflow rate of 40 m^3/h (33).

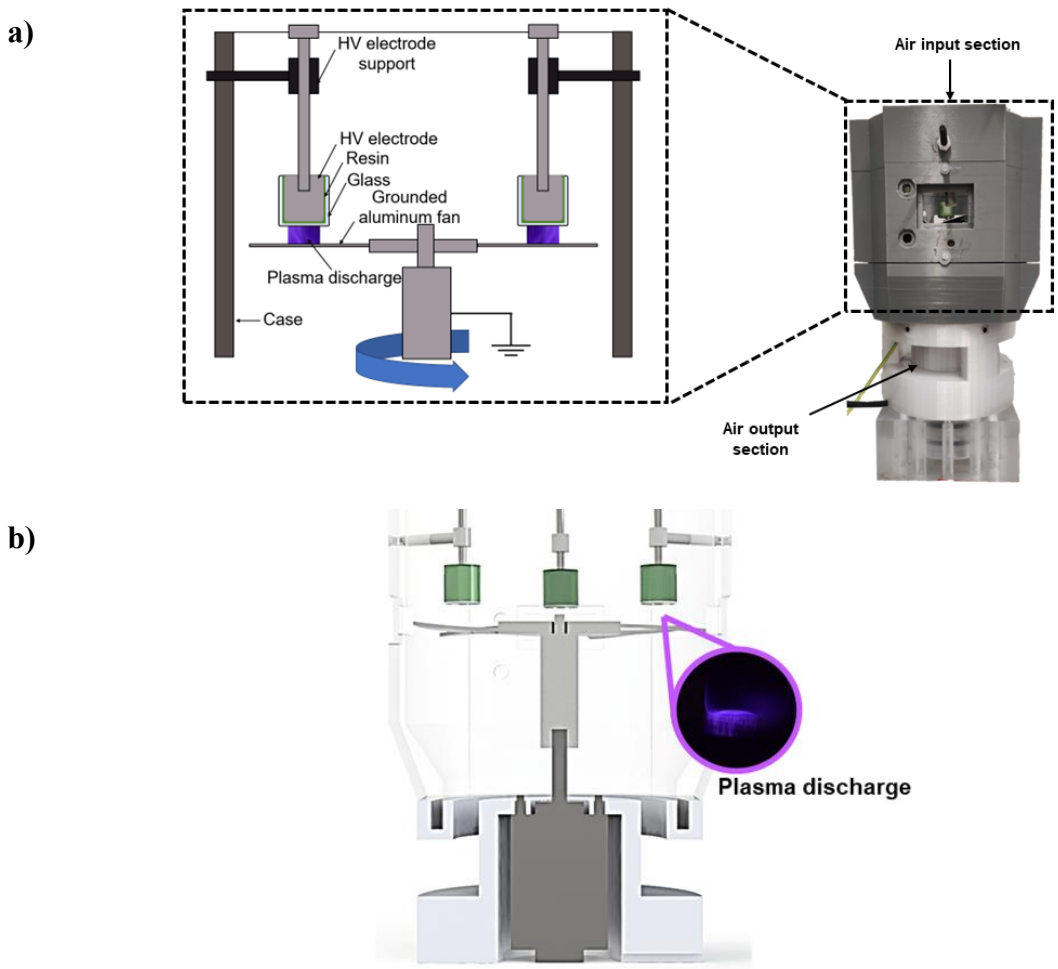

Fig. 1-a) Rotating Dielectric Barrier Discharge (RDBD) plasma source and its components; **-b)** Render of the inner section of RDBD plasma source and real picture of its plasma discharge.

B. Statistical Analysis

All experiments were performed in three independent replications. The results are presented as the mean ± standard deviation (SD). Significant differences in the results were assessed using the Student's test and were specified with asterisks (* $p \leq 0.05$, ** $p \leq 0.001$).

C. RDBD plasma source electrical characterization

The RDBD plasma source was driven by a micropulsed high-voltage generator (AlmaPULSE; Alma Plasma s.r.l., Bologna), allowing the application of a tuneable **duty cycle (D.C.)** (1-100%). Four operating conditions (o.c.) were identified to obtain three different average discharge powers. Specifically, two D.C. values were selected, resulting in two operating conditions (B and C) with statically different peak-to-peak voltages values but similar average discharge power values. The electrical characterization was performed for all four chosen operating conditions (Table 1).

o.c.	$V_{p\text{-}p}$ (peak-to-peak voltage) [$kV_{p\text{-}p}$]	f (frequency) [kHz]	D.C. (duty cycle) [%]
A	29.4 ± 0.09	4	100 %
B	29.4 ± 0.09 **	4	60 %
C	26.6 ± 0.08 **	4	100 %
D	26.6 ± 0.08	4	60 %

Table 1 – Operating conditions (o.c.) applied for the RDBD plasma source.

The applied **voltage** ***v(t)*** and the **current** ***i(t)*** were measured using a high-voltage probe (Tektronix P6015A) and a current probe (Pearson 6585), both positioned on the high-voltage cable. The corresponding waveforms were recorded using a digital oscilloscope (Tektronix MSO46) (Fig. 2).

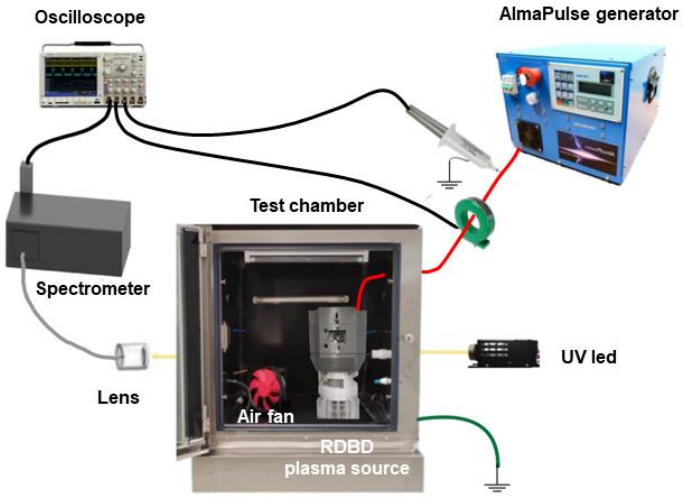

Fig. 2 – Experimental setup for the electrical characterization and evaluation of ozone and nitrogen dioxide concentration inside the test chamber.

The average discharge **power (P)** dissipated over the applied voltage **period (T)** was determined using the formula given in Eq. (1).

$$P = \frac{D.C.}{T}\int_0^T v(t)i(t)dt \qquad (1)$$

D. Evaluation of ozone and nitrogen dioxide concentration inside the chamber

Ozone is one of the long-lived reactive oxygen species produced by CAP, with a strong ability to oxidize bacteria and viruses (34,35). Optical absorption spectroscopy was used to evaluate the ozone and nitrogen dioxide concentration of the two devices inside a stainless-steel airtight test chamber (Fig. 2). The test chamber (V=0,09 m^3) was designed to simulate an indoor environment potentially contaminated by airborne pathogens. It has two quartz optical windows and enabled measurements without interference from the plasma discharge emission in the optical path (L = 410 mm), which was chosen near the air outlet section for both devices. A deep-UV LED module (Omicron Laserage Laserprodukte GmbH) served a light source for the ozone concentration measurement. A commercially available LED with a specific emission wavelength of 400 nm was employed for the measurement of nitrogen dioxide (NO_2) concentration. The light beam was focused using optical fibers and fused silica lenses (50 mm of focus length) to achieve a parallel beam which passed through the test chamber and collected into a 500 mm spectrometer (Acton SP2500i; Princeton Instruments) to spectrally resolve the light beam in the UV, VIS, and near-infrared regions. The width of the inlet spectrometer slit was fixed as 10 µm for OAS acquisitions, and a grating with a resolution of 150 mm^{-1} was adopted. A photomultiplier tube (PMT Princeton Instruments PD439) connected to a fast oscilloscope (Tektronix MSO46) was operated as the detector. To ensure the same initial conditions, the test chamber was opened and flushed for 5 minutes with fresh air before every measurement. The Lambert-Beer law was considered following the same procedure reported by Bisag *et al.* (25) to evaluate the O_3 concentration from the absorption measurement using a wavelength value of 253 nm and the absorption cross-section of (1.12 ± 0.02)E−17 cm^2. Similarly, for NO_2 measurement, a wavelength of 400 nm and an absorption cross-section of (6.4 ± 0.02)E−19 cm^2 were used. The two species concentration inside the chamber were monitored for 500 s (480 s plasma discharge ON and 20 s plasma discharge OFF). The same experimental conditions used for microbial inactivation tests were reproduced for the OAS analysis.

E. Evaluation of bactericidal efficacy in bioaerosols

The microbial inactivation efficacy of the RDBD plasma source was evaluated by contaminating the air inside the test chamber with a bioaerosol containing *Staphylococcus epidermidis*, a Gram-positive bacteria commonly present on human skin and not ordinarily dangerous but often involved in HAIs (36). For this, a culture of *S. epidermidis* (ATCC 12228) cells, kept at -20 °C, was incubated in brain heart infusion (BHI, Biolife, Italy) broth for ± 24 h (37 °C), after which a loopful of cells were transferred to tryptic soy agar (TSA, VWR, Belgium) plates by means of the four quadrants streak method. After incubation (± 24 h, 37 °C), a pure culture was picked and grown (± 24 h, 37 °C) on a TSA slant. Finally, the slants were kept in the fridge (4 °C) until further use. For every test, a subculture of *S. epidermidis* was taken from a slant, cultivated on TSA, and incubated at 37°C for ± 24 hr. Colonies were used to prepare a standardized suspension in Dulbecco's phosphate-buffered saline (DPBS, Corning, USA) at $OD_{600\ nm}$ = 0.2 (i.e., 7 – 8 Log_{10} CFU/mL).

The same experimental setup employed in Bisag *et al.* (25) was used to produce the bioaerosol; a bacterial suspension flow rate of 0.852 mL/min and an airflow rate of 1.2 mL/min were delivered to a nebulizer (single-jet Blaustein Atomizer – BLAM; CH Technologies) using a syringe pump (Legato 100; kdScientific) and a digital flowmeter (EL-FLOW; Bronkhorst), respectively. The bioaerosol flowed inside the test chamber for 10 minutes up to a challenge concentration of approximately 5 Log10 CFU/m. After the nebulization period, the chamber air was sampled to assess the initial bacterial concentration (No) by using a biosampler (SKC-impinger; SKC INC.) containing 20 mL of DPBS. Subsequently, the RDBD prototype treated the bioaerosol-contaminated chamber air for 8 minutes. At the end of the treatment, sampling was carried out identically to evaluate the final bacterial concentration within the chamber (Nt). During the entire procedure, a fan was employed inside the chamber to move the air to avoid the accumulation of droplets on the chamber walls. The DPBS sampling liquid was plated using the standard spread plating technique on TSA, and the plates were incubated at 37°C for 24 h for viable colonies counting. The inactivation efficacy of the treatment was evaluated according to the formula given by Eq. (2).

$$\mathbf{Log_{10}\, R = Log_{10}\, N_o - Log_{10}\, N_t} \qquad (2)$$

Control samples were collected using the same procedure, but the plasma discharge was not generated to assess the possible impact of fan rotation on bacterial bioaerosol and possible droplet deposition on the chamber walls. To ensure the same initial conditions, the test chamber was sterilized in between tests using UV lamps installed in the chamber. Furthermore, the chamber was opened and flushed with fresh air for 5 minutes before each measurement. The same experimental setup and biological protocol were used to evaluate the antimicrobial efficacy of the Jonix cube device.

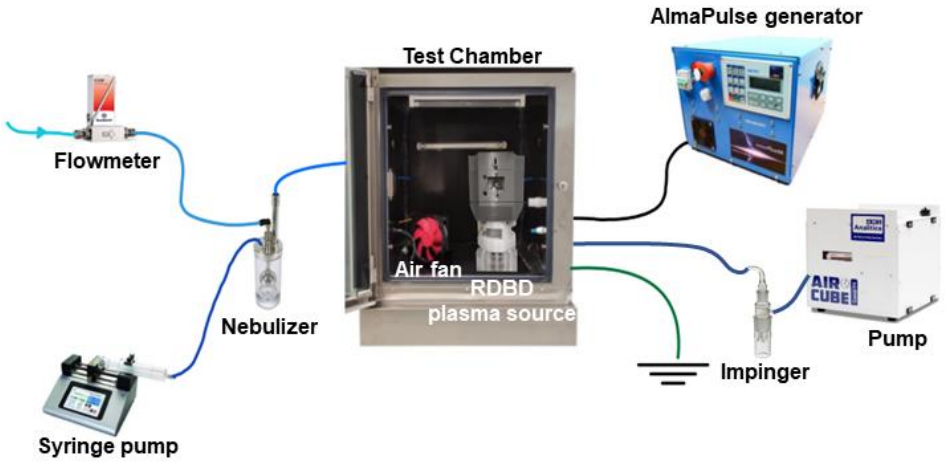

Fig. 3 - Experimental setup for microbial inactivation tests.

III. RESULTS AND DISCUSSION

A. RDBD plasma source electrical characterization results

Figure 4-a shows an example of current and voltage waveforms at the operating condition of 29.4 ± 0.09 kVp-p with a fixed frequency of 4 kHz (o.c. A). During the applied voltage period (250 µs), multiple spikes can be observed on the current waveform (at around 54 and 176 µs), corresponding to the active phase of filamentary discharge typical of DBDs operated in the air at atmospheric

pressure. The behavior of waveforms at the o.c. of 26.6 ± 0.08 kV_{p-p} and 4 kHz (o.c. C) is similar apart from the reduced voltage measured (Fig. 4-b). In Fig. 5, the average discharge powers are evaluated using Eq.2., o.c. A corresponds to the highest average discharge power, while the o.c. B and C have a value not statistically different (Student's test, $p \geq 0.05$). Finally, o.c. D has the lowest average discharge power.

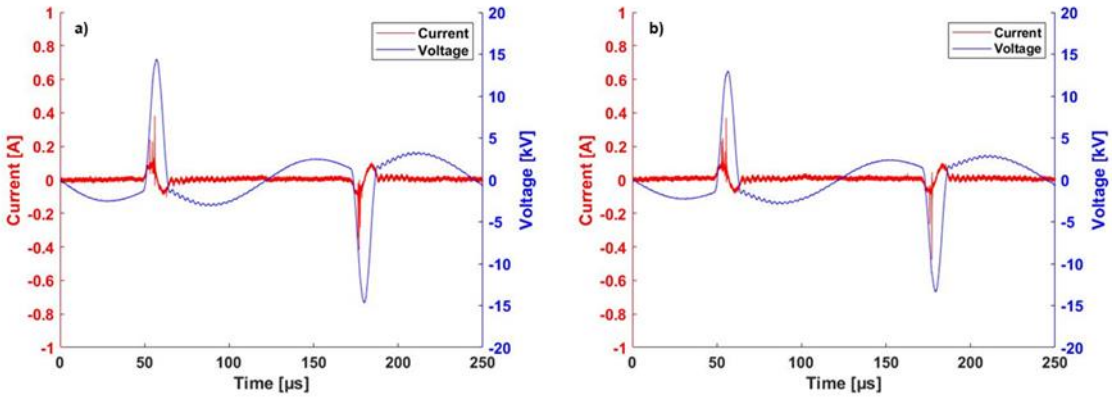

Fig. 4 – a) Current and applied voltage waveforms at operating conditions A and b) C.

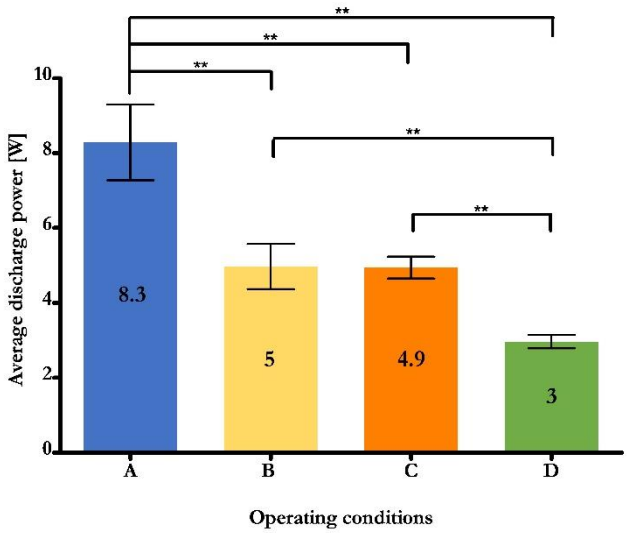

Fig. 5 – Average discharge powers for the four operating conditions applied for the RDBD plasma source.

B. Ozone and nitrogen dioxide concentration inside the test chamber

Figure 6 shows the evolution of the ozone concentration inside the test chamber when operating the RDBD source under the different operating conditions and when using the commercial device. The ozone concentration exhibits a consistent and incremental rise over the entire duration of the treatment. Notably, a decline in ozone concentration is evident in Figure 6 at 480 seconds, coinciding with the deactivation of the RDBD source. This is the result of ozone degradation, as this component is known to be unstable and decomposes in a few minutes at ambient temperatures (37). The highest ozone concentration achieved within the chamber was attained by employing the RDBD source under o.c. A, yielding approximately 83 ppm. Conversely, a confined range of ozone concentrations (ranging from 23 to 27 ppm) was observed when operating the RDBD source under conditions B and C (which exhibited statically comparable average discharge power levels) as well as the Jonix device.

Operating condition D with the lowest average discharge power is associated with the lowest ozone concentration (~9 ppm). Ultimately, for all tested conditions, the concentration of NO_2 remained undetectable within the chamber.

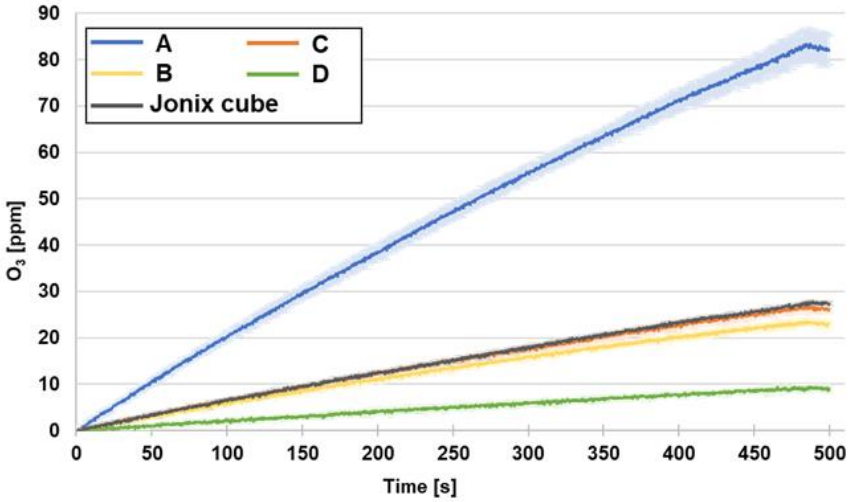

Fig. 6 - Ozone concentrations and respective standard deviations (SD) inside the test chamber produced by the RDBD plasma source using the four operating conditions and Jonix Cube device. The SD of the data is graphically displayed as the shaded colored band surrounding the mean line.

C. Biological inactivation test on *S. epidermidis* bioaerosol

As summarized in Figure 7, the RDBD source exerts a comparable antimicrobial effect to the Jonix cube device (Log R = 4.1 ± 0.6), with Log R = 3.8 ± 0.3, 3.6 ± 0.5 and 3.9 ± 0.4 for o.c. A, B and C, respectively. Statistical analysis (Student's test $p \geq 0.05$) shows no statistical difference between these values of Log Reduction. On the other hand, there is a statistical difference (Student's test, $p \leq 0.05$) between the bacterial inactivation results obtained with the operating condition D (Log R = 2.3 ± 0.4) and the other conditions, as well as the commercial device, with o.c. D resulting in a reduced bacterial inactivation. Control tests to assess the impact of fan rotation and possible droplet deposition on chamber walls showed no significant Log R.

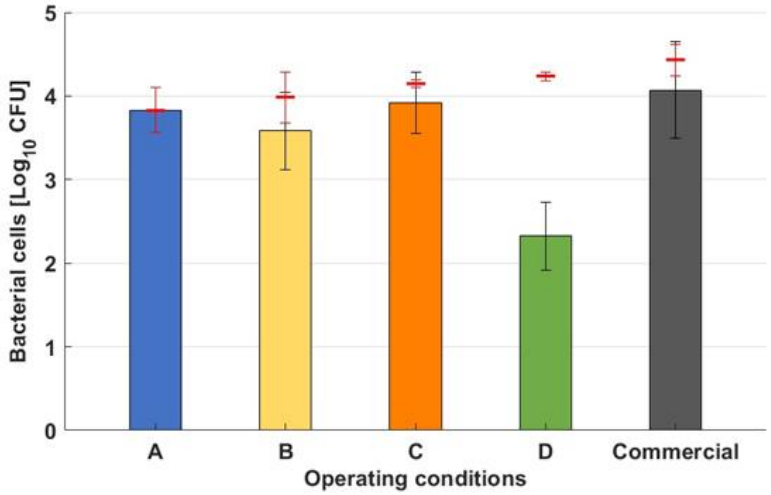

Fig. 7 - Average Log_{10} Reduction (R) of *S. epidermidis* in the bioaerosol after RDBD plasma source treatment using different operating conditions (A-D, see Table 1) and the commercial device, shown

as bars, with their respective standard deviations. UADL levels and respective standard deviations are indicated with red lines.

It is essential to notice that the upper antimicrobial detection limit (UADL) was reached for at least one repeat of operating conditions A, B, C and, the commercial Jonix cube, due to the practical limitations of the current sampling system. There was no statistical difference between inactivation levels and the UADL (Student's test, $p \geq 0.05$) for these conditions. Therefore, the Log R values corresponding to these specified operating conditions signify that both systems can achieve a satisfactory level of bioaerosol decontamination, nearing complete inactivation, equivalent to or surpassing 4 Log10 CFU. Only for operating condition A the UADL was reached for all repeats, which could indicate that the true bactericidal potential is the highest among all tested operating conditions. On the other hand, there was a significant difference between the inactivation level and its UADL for o.c. D (Student's test, $p \leq 0.05$).

It is reasonable to consider the average discharge power and consequent ozone production as pivotal factors when designing a novel air decontamination device based on CAP technology. Indeed, ozone is a strong antibacterial agent, acting on both cell membrane and cell content (38–40). An increase in ozone concentration leads to higher efficiency in deactivating microorganisms. Among the various operating conditions (A, B, and C) examined, o.c. A stands out due to its superior average power value and ozone concentration, consistently reaching the UADL in all experimental repetitions. Comparatively, when scrutinizing the outcomes of o.c. A and B, it becomes apparent that satisfactory levels of microbial deactivation can also be achieved by reducing the average discharge power by implementing a duty cycle. Consequently, bacterial inactivation is not compromised during short periods when the plasma discharge is inactive. Although conditions B, C, and the Jonix device do not consistently reach the UADL, they demonstrate satisfactory levels of bacterial deactivation, approaching complete inactivation while exhibiting a significantly lower ozone concentration, approximately three times lower. This outcome is advantageous in terms of minimizing the emission of ozone into the surrounding environment. Furthermore, the lack of statistical difference (based on the Student's test, $p \geq 0.05$) between the Log R values for o.c. B and C highlights that the fluctuation in voltage within the studied plasma source does not seem to affect bacterial inactivation. Indeed, these two o.c. have similar average discharge powers and ozone concentration but differ in their peak-to-peak voltage values. Conversely, an average discharge power of about 3 W (o.c. D) coupled with an ozone concentration lower than 10 ppm resulted in only partial bacterial inactivation. Thus, despite the potential for a higher antimicrobial efficacy under o.c. A, employing such a high ozone concentration is unnecessary for this specific application. Moreover, the RDBD source can achieve a comparable antimicrobial effect with reduced power compared to the Jonix device while providing a 3.5 times higher air flow rate.

IV. CONCLUSIONS

This research study introduces a novel portable system for indoor air decontamination based on plasma technology. The primary objective of this device is to optimize the process of plasma-assisted air decontamination by utilizing the fan, which serves as both the functional element for air movement and the constituent part of the plasma source. For this reason, the fan is employed as the ground electrode for the dielectric barrier discharge plasma source. To design the new system, the average discharge power and ozone concentration were identified as crucial parameters to monitor. These

parameters are considered key factors in the inactivation process of airborne microorganisms. Under various operating conditions, ozone production and antimicrobial efficacy were evaluated on the newly developed plasma source called Rotating Dielectric Barrier Discharge (RDBD). The results were then compared with those obtained from the commercial Jonix device based on surface dielectric barrier discharge (SDBD) sources widely used for ozone production and air decontamination. The RDBD source achieved a satisfactory microbial inactivation value, close to total inactivation, and similar to that achieved by the Jonix device, but with a lower average discharge power than the power consumption of the Jonix device (10 W) and a 3.5 higher air flow rate. This increased flow rate is particularly advantageous for decontaminating larger rooms. Therefore, the RDBD source could represent a promising approach to air decontamination using plasma technology, a viable indoor air quality control solution.

CONFLICT OF INTEREST

All authors declare that they have no known conflicts of interest in terms of competing financial interests or personal relationships that could have an influence or are relevant to the work reported in this paper.

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