Prospects, problems and chances of the use of plasmas in life-sciences

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Résumé

An overview of atmospheric pressure plasma sources (APPS) capable for microbiological inactivation is given along with recent research results considering their antimicrobial effectivity.

Introduction

The inactivation of microorganisms and the removal of biological hazardous contaminants are generally of great interest in the entire field of life science. This varies from antimicrobial treatment of food or food containing enclosures, the conditioning of pharmaceuticals, the prevention or cure of infectious diseases, the bleaching of teeth, the installation of appropriate hygiene strategies up to the sterilization of spacecrafts. Nevertheless, the sterilization of medical instruments is still a main topic. In particular, the increasing application of complex and expensive medical devices like endoscopes or central venous catheters requires innovative sterilization methods that fulfill all demands for such high tech instruments. Generally speaking and not limited to the medical sector, an optimal sterilization process is safe, fast, cost-efficient, nontoxic and nonhazardous, environmentally friendly, energy efficient and does not stress the sterilized device or the containing materials. Although many sterilization methods are well established, adapted or even new methods are required due to the development of new techniques and instruments, the invention or enhancement of modern medical devices as well as the initiation of stricter hygienic standards in the field of life science. Low temperature plasmas generated at atmospheric pressure consist of a variety of microbiological active agents and are therefore appropriate tools for biological decontamination. As no costly vacuum equipment is required APPS are easily adaptable even to complex devices and conventional processes. Hence, their development and characterization is in the focus of research for more than two decades and until now the entire potential of APPS is unforeseeable yet.

Atmospheric pressure plasma sources for biological inactivation

Only plasma sources are presented, which are reported to be effective against biological contaminants. They are classified by their excitation frequency and electrode configuration: coronas, dielectric barrier discharges, atmospheric pressure plasma jets and microwave driven plasmas.

Corona discharges

Bussiahn et al. [1] presented an intermittent negative DC corona discharge denoted as hairline plasma. A pointed hollow needle electrode is feeded with argon gas and connected to a negative high voltage. Between the cathode and the anode, which usually consists of biological material, an intermittent plasma with a temperature of ~ 300K develops. The discharge produces ns-short current pulses with a repetition frequency of ~ 1.8 kHz and an amplitude of several hundred mA. The radial extension and the length of the plasma are 30 µm and up to 1.5 cm, respectively. The biological effectivity was demonstrated generally for the gram negative bacteria *E. coli.* Furthermore the ability of the hairline plasma to enter small cavities is impressively.

Dielectric barrier discharges (DBD)

Polak et al. [2] showed a special setup to generate a gas discharge inside a long and flexible tube for the use as biopsy channels in endoscopes by means of DBD. To provide an extended electric field along the tube, two electrodes are equidistant twisted around the tube with 2 mm inner diameter. The electrodes are located inside the tube wall, whereby the interior tube is not disturbed by foreign material and the outer side is electrically insulated towards peripheral devices. With this called bifilar helix discharge setup an uniform plasma could be ignited along a 5 m tube with inner diameter of 2 mm for various gas mixtures of

He, Ar, O_2, N_2. Preliminary results concerning the antimicrobial efficiency were achieved using a *B. atrophaeus* spores solution mixed with 0.3 % bovine serum albumin (BSA). It was demonstrated that a gas mixture of 1.5 slm argon and 200 sccm forming gas (95 % N_2, 5 % H_2) leads to a reduction factor of more than 4 $\log_{10}$ for an initial microorganism concentration of 10^6 CFU/ml and 10 min exposure time.

Hähnel et al. [3] used the remote impact of a surface DBD in ambient air for inactivation of microorganisms. Therefore, a special electrode geometry was invented. The antimicrobial efficiency was tested with *B. atrophaeus* spores at varying relative process gas humidities. The results show a strong dependence on the humidity. As for 30 % humidity a maximum of 1 $\log_{10}$ reduction could be reached, for 60 % relative air humidity all bacteria were killed. This is a reduction factor of 4 $\log_{10}$ for 10^5 CFU/ml initial concentration after 150 s plasma treatment. Additional pulse length variations indicate an exponential correlation between the plasma on-time and reduction rate.

Atmospheric pressure plasma jets (APPJ)

Ehlbeck et al. [4] and Weltmann et al. [5] show APPJ setup for inactivation of catheters. The generated discharge completely surrounds the outer surface of the catheter. The inactivation efficiency was tested by dividing the catheter into six sections and contaminating five sections with vegetative *Staphylococcus aureus* solution. The 6th section was kept as control. It reveals a 5 $\log_{10}$ reduction for pure argon and a complete inactivation of 6 $\log_{10}$ for argon with 0.25% air admixture. Additionally, the dependency of the amount of inactivation cycles was tested and no increase of efficiency could be detected.

Microwave driven discharges

Microorganism inactivation in PET-bottles is demonstrated by Brandenburg et al. [6]. They developed a self-propagating microwave-driven discharge at 2.45 GHz and power up to 1.7 kW in usual air. The device consists of a wave guide connected to the process chamber and an ignition device mounted on a moveable lance. The lance with the ignition pin is guided into the bottle, the microwave field is applied and a discharge is ignited at the bottom of the bottle. After the ignition the lance is moved to its origin and the discharge propagates upwards through the bottle. This was repeated three times, whereby one cycle takes about 550 ms, so 1.6 s for the entire process. The results show a 6.8 $\log_{10}$ reduction for *E. coli*, 5.1 $\log_{10}$ for *A. brasiliensis* and 6.7 $\log_{10}$ for *S. aureus*.

Conclusion

The special kind of the decontamination task is as manifold as the plasma sources. The varying plasma parameters and therefore the different composition of antimicrobial components in combination with complex microbial test methods using different microorganisms and procedures leads to an inhomogeneous picture. In consequence, each antimicrobial plasma treatment has to be carefully adapted to the specific task. This seems to be the reason for the limited utilization of plasma decontamination processes in industrial applications up to now. Currently, only few systems for very specific applications are commercially available. Another problem is that existing chemical disinfection and sterilization processes are cheap and effective. So plasma processes have to be even more time and cost efficient or have to occupy niches such as sterilization of endoscope channels. To overcome these difficulties more interdisciplinary research especially between physicist and biologist is needed. Due to the required high amount of reliability the involvement of engineers is desired.

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