Plasma-assisted inactivation of bacterial biofilms in polymeric tubes using a water-based surface DBD system

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Atmospheric-pressure surface dielectric barrier discharges (SDBDs) employing a liquid electrode represent a promising plasma technology for medical applications requiring efficient and uniform treatment of complex and confined geometries, such as medical catheters. In this work, we present a water-based SDBD reactor developed for the antimicrobial treatment of hollow polymeric structures, with direct relevance to the decontamination of medical devices such as catheters and tubing [1,2].

The proposed plasma system operates at atmospheric pressure and uses water as an active electrode, forming a stable plasma ring at the plasma–solid–liquid interface. The controlled movement of the plasma ring along the inner or outer surface of tubular objects ensures uniform treatment, which is crucial for applications involving complex geometries, such as catheters.

The antimicrobial efficacy of the plasma system was investigated using multiple bacterial strains under controlled experimental conditions. Planktonic bacteria suspended in aqueous solutions were exposed to the plasma to evaluate bactericidal activity as a function of discharge power and treatment duration. In addition, the effectiveness of the plasma system was tested against 48-hour biofilms formed on the inner surfaces of polymeric tubes mimicking contamination of medical tubing. Biofilm inactivation and removal were achieved through direct plasma treatment, as well as through plasma activated water generated under well-defined operating conditions.

Bacterial inactivation was quantified using standard microbiological plate-counting methods to determine viable cell reduction, complemented by flow cytometry assays to evaluate membrane integrity and the fraction of dead cells. These methods provided a comprehensive assessment of the antimicrobial efficacy relevant to medical sterilization. By systematically varying discharge power, treatment duration, and plasma ring velocity, the treatment parameters could be optimized for maximal antimicrobial efficacy while maintaining uniform exposure. The results demonstrate up to 6-log reduction of planktonic bacteria, indicating strong bactericidal activity in liquid environments. For biofilm-covered surfaces, complete biofilm destruction was achieved under optimized plasma conditions.

To better understand plasma-induced surface modifications, polytetrafluoroethylene (PTFE) tubes were analyzed before and after plasma treatment. Surface characterization was performed using water contact angle measurements, scanning electron microscopy, confocal laser scanning microscopy, and X-ray photoelectron spectroscopy. These analyses revealed increased surface hydrophilicity, chemical functionalization, and surface integrity.

In summary, this study demonstrates the strong potential of water-based SDBD plasma systems for plasma medicine applications, particularly for the decontamination and functionalization of the inner surfaces of medical tubing and catheters. The combination of uniform plasma delivery, atmospheric-pressure operation, and high antimicrobial efficiency positions this approach as a promising tool for advanced plasma-assisted sterilization and infection control in medical device processing.

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