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Bio-Decontamination by Transient Spark and Corona Discharges with Electro-Spray

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Abstract

DC electrical discharges in atmospheric air - streamer corona and transient spark - were tested for bio-decontamination of bacteria in water solution. Two set-ups for the treatment of flowing contaminated water were compared. In transient spark, high decontamination efficiencies were achieved in short treatment times. Streamer corona was efficient when the treated medium flew through the active corona region where the electro-spray effect enhanced the efficiency and lead to very short *D-values* and low energy costs of the process. The bacteria and spores were handled evaluated by standard microbiology cultivation procedures.

Introduction

Sterilization and bio-decontamination by atmospheric pressure plasmas generated various types of electrical discharges, plasma jets and afterglows have been extensively studied in the last decade, in various gases, both in direct and remote exposure to plasma, with various microbes (bacteria, spores, fungi, viruses), reaching from disinfection (1-2 log reduction of microbial population) up to complete sterilization [1].

We have been investigating three types of DC atmospheric discharges and testing their bio-decontamination effects on selected bacteria in water solutions, and spores on plastic and paper surfaces [2]. We have also been identifying the dominant mechanisms involved in the process by comparing the electrical characteristics of the investigated discharges, their emission spectra, and bio-decontamination effects. We are also applying the TBARS method that quantifies the interaction of the reactive oxygen species generated in the plasma with the biological membrane of cells. The results obtained so far indicate the major role of radicals and other reactive oxygen species [2]. Here we report on bio-decontamination by transient spark and corona discharges in the flowing regime. The method of electrostatic spraying of the treated water seems to be very promising for enhancing their contact with the plasma and so improving the process efficiency.

Experiment

Two types of self-pulsed DC discharges of both polarities operating in atmospheric air with water were investigated: a well-known streamer corona, and relatively novel transient spark. These non-equilibrium plasma discharges were described in detail in our previous works [3].

The experimental setup for investigations of the DC discharges was shown elsewhere. [2] The bio-decontamination effects were tested in two flowing set-ups. Fig. 1 shows the setup for the continual flowing water treatment. Five parallel discharges were operated in a transparent discharge tube. The stressed high voltage electrodes were hollow needles, opposite to the copper or stainless steel plate electrode submersed in a water stream, with the typical needle-water distance of 4-6 mm.

The second flowing regime arrangement was developed to increase the efficiency of the corona discharge, although transient spark was tested there as well. The contaminated water flows directly through the high voltage needle electrode, and so through the corona active region in its proximity. The effect of electrostatic spraying occurs when the high voltage is applied on the needle electrode. Fig. 2 shows the set-up and demonstrates the water spraying effect through the corona active zone. The water flow rates, and thus the residence times in the discharge, were varied.

The discharge voltage was measured by a high voltage probe Tektronix P6015A. The discharge current was measured on a 50 Ω or 1 Ω resistor or by a Rogowski current monitor PEARSON 2877. The current and voltage signals were processed by a digitizing oscilloscope Tektronix TDS 2024 (200 MHz).

Bio-decontamination was tested on *Salmonella typhimurium* (Gram-negative bacterium, pathogen causing typhus diseases) in water solution. The bacterial inactivation was examined by standard cultivation methods of a thermostatic growth on agar in Petri dishes, and statistically evaluated.

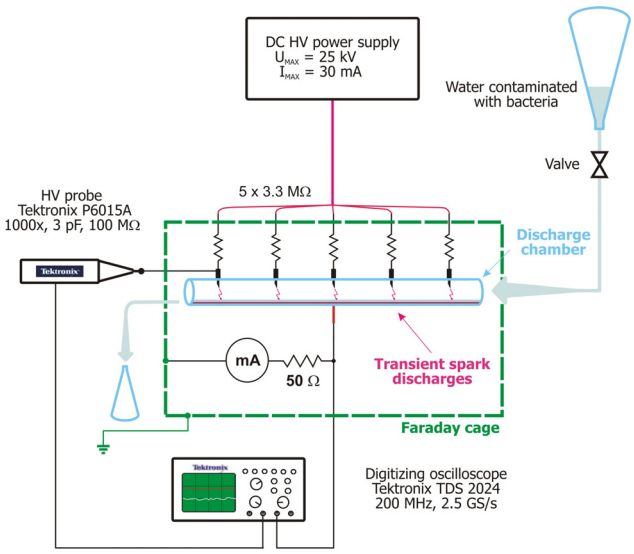

Fig. 1: Experimental set-up and a tube with 5 parallel discharges for flowing regime water treatment.

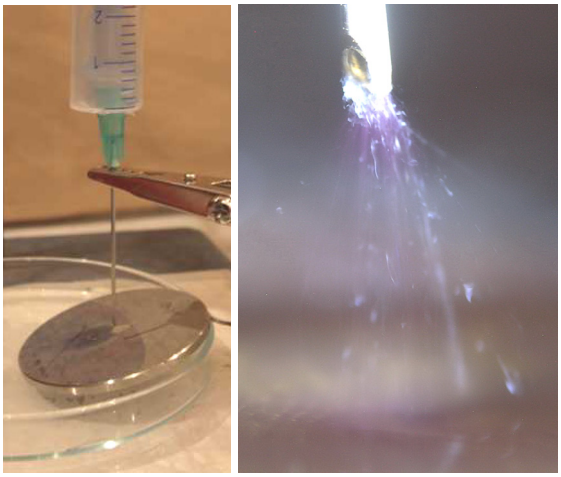

Fig. 2: Flowing the contaminated water through the high voltage needle electrode and electro-spray effect in the corona discharge.

Results and discussion

In bio-decontamination by positive transient spark in the 5-discharge tube we treated a fixed volume 0.1 l of the contaminated water and varied the treatment times (15-28 min), i.e. flow rates (3-6 ml/min). The typical discharge parameters were: total mean current 5 mA, U_d = 7 kV, f = 6 kHz. The decontamination efficiencies reached 99.25-99.99% (up to 4.1 log reduction). The corresponding *D-values* (time required to reduce the microbial population by one log) were short (2.8-8.1 s). We introduce a new parameter: *E-value* [Joule per treated volume and one log reduction] to express the energy requirements of the process. The obtained *E-values* were 92-600 J/ml.log.

With the transient spark, we explored the effect of the pulse shape and amplitude. The bio-decontamination tests showed that substantially higher efficiencies were obtained with strong and short current pulses (~8 A, ~50 ns). Such pulses result in strong plasma nonequilibrium and generation of radicals and other active species, and low energy losses by gas heating.

In the set-up where the treated water flowed directly through the high voltage needle electrode, the electrostatic spaying of the water to micrometric droplets occurred. These passed through the active plasma zone resulting in the improved efficiency of decontamination due to much larger contact surface of the water with the plasma.

Positive streamer corona with electro-spray resulted in efficiencies up to 93 %, very short *D-values* (0.13-0.54 s) and very low energy costs (*E-values*: 0.7-37 J/ml.log). In negative corona, 79 % efficiencies were reached, with corresponding *D-value*=0.43 s and *E-value*=43 J/ml.log. Positive transient spark in the same set-up gave up to 96.6 %, *D-value*=0.2 s and *E-value*=109 J/ml.log. Negative transient spark, similar to negative corona, was less efficient (70-79%) but required lower energy (32-49 J/ml.log).

In all these studied cases, despite the bio-decontamination by several logs was not reached, the process was very fast thanks to the electro-spraying effect: the *D-values* were below 0.6 s and the energy costs were also low. These experiments have shown that both transient spark and streamer corona with electro-spray are potentially interesting for applications.

Acknowledgements

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