Electrospraying of Water With Streamer Corona Discharge

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Abstract—**The effect of electrospraying of water [electrohydrodynamic atomization (EHDA)] was studied in combination with dc streamer corona discharge as a possible method of biodecontamination of water. This effect was investigated under various voltages and water flow rates. The best conditions when the water spray was localized directly in the relatively stable and intense corona active region were reached at 8 kV and 8.3 μl/s. Images of EHDA with streamer corona discharge are presented.**

Index Terms—**Bio-decontamination of water, streamer corona discharge, water electrospray.**

THE GENERATION of electrical discharges with water is interesting and is a relatively unexplored area because liquids have different physical properties if compared with gases [1]. One of the potential uses of discharges generated in water is decontamination of water from organic and microbial pollutants, which cause the largest contamination of water sources [2], [3].

It is interesting to use the effect of electrohydrodynamic atomization (EHDA) of water in combination with the discharge (e.g., streamer corona). In this mode, water flows directly through the high voltage (HV) needle electrode into the active discharge region. Under these conditions, it is possible to reach high decontamination efficiencies owing to the large active surface of the water droplets treated by plasma [4]. In this regard, it is necessary to better investigate this effect under various conditions.

The electrospraying effect of water depends on the applied voltage on the HV electrode. The surface tension of water decreases when a voltage is applied because positive and negative charges separate inside the liquid. The charges of the same polarity as the HV electrode move toward the drop surface and induce a surface charge density which causes an increase of the electrostatic pressure against the capillarity pressure. When the voltage reaches a critical value, the shape of the drop changes into the Taylor cone. These charges are then accelerated by the electric field, and the electrospraying of water occurs from the top of the Taylor cone. In this process, the size of the droplets can be around tens of nanometers up to hundreds of micrometers [5], [6].

Manuscript received December 1, 2010; revised March 10, 2011; accepted March 14, 2011. Date of publication May 12, 2011; date of current version November 9, 2011. This work was supported in part by the Slovak Grant agency VEGA under Grants 1/0293/08 and 1/0668/11 and in part by the Slovak Research and Development Agency APVV under Grant SK-CZ-0179-09.

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Digital Object Identifier 10.1109/TPS.2011.2134112

Our experimental setup for investigations of similar dc discharges was shown elsewhere [7]. The effect of the EHDA of tap water (typical electrical conductivity of 500 $\mu S \cdot cm^{-1}$) was investigated in the point-to-plane geometry of electrodes with a modified hollow syringe needle anode opposite to the copper plate cathode with the interelectrode space $d = 1$ cm. A dc HV was applied through the ballast resistor R (20 MΩ) onto the needle electrode. The discharge voltage was measured by the HV probe Tektronix P6015A. The discharge current was measured on a 50-Ω resistor. The current and voltage signals were processed by the digitizing oscilloscope Tektronix TDS 2024 (200 MHz). The pictures of electrospraying and discharge were recorded by the digital camera Casio EX-F1. The streamer corona discharge used is characterized by its typical current pulses ($I_{\max} \sim 20$ mA and a pulsewidth of $\sim$50 ns) at constant voltage. Each pulse is followed by a relaxation time of a few tens of microseconds. The process is repetitive with a frequency of $\sim$10 kHz.

In general, water sprayed into the discharge disrupts its formation and stability. Vice versa, the formation of the discharge perturbs the EHDA, normally issuing from the Taylor cone at prebreakdown voltages. With respect to the efficient water treatment, we seek for the stable conditions of electrospraying into the streamer corona discharge region, i.e., at postbreakdown voltage.

We observed differences in the dependence of EHDA on the applied voltage U and water flow rates Q. Fig. 1 shows the comparison of three different flow rates at three different voltages. For each voltage and flow rate, we present a pair of photographs showing the water stream (illuminated) and the discharge region (dark) under the same conditions. Without water, the corona discharge is very stable. Therefore, we expected the best stable spraying conditions at low water flow rates. However, at $Q = 0.83$ μl/s (see upper row in Fig. 1), the streamer corona was relatively intense but not too stable and sometimes was altered from side to side by the flow. Spraying was also unstable; we observed erratic water streams from the needle probably because of the insufficient water supply to create a stable Taylor cone. The best conditions with a good stability and intensity of the streamer corona with a relatively stable electrospraying in its active region were reached for $Q = 8.3$ μl/s. At 6 kV, the Taylor cone issuing the electrospray can be seen on the top of the needle (middle row, first image). With increasing voltage, the dispersion of the spray increased because the water droplets with similar charges stronger repelled one another. At high $Q = 25$ μl/s, the formation of streamer corona

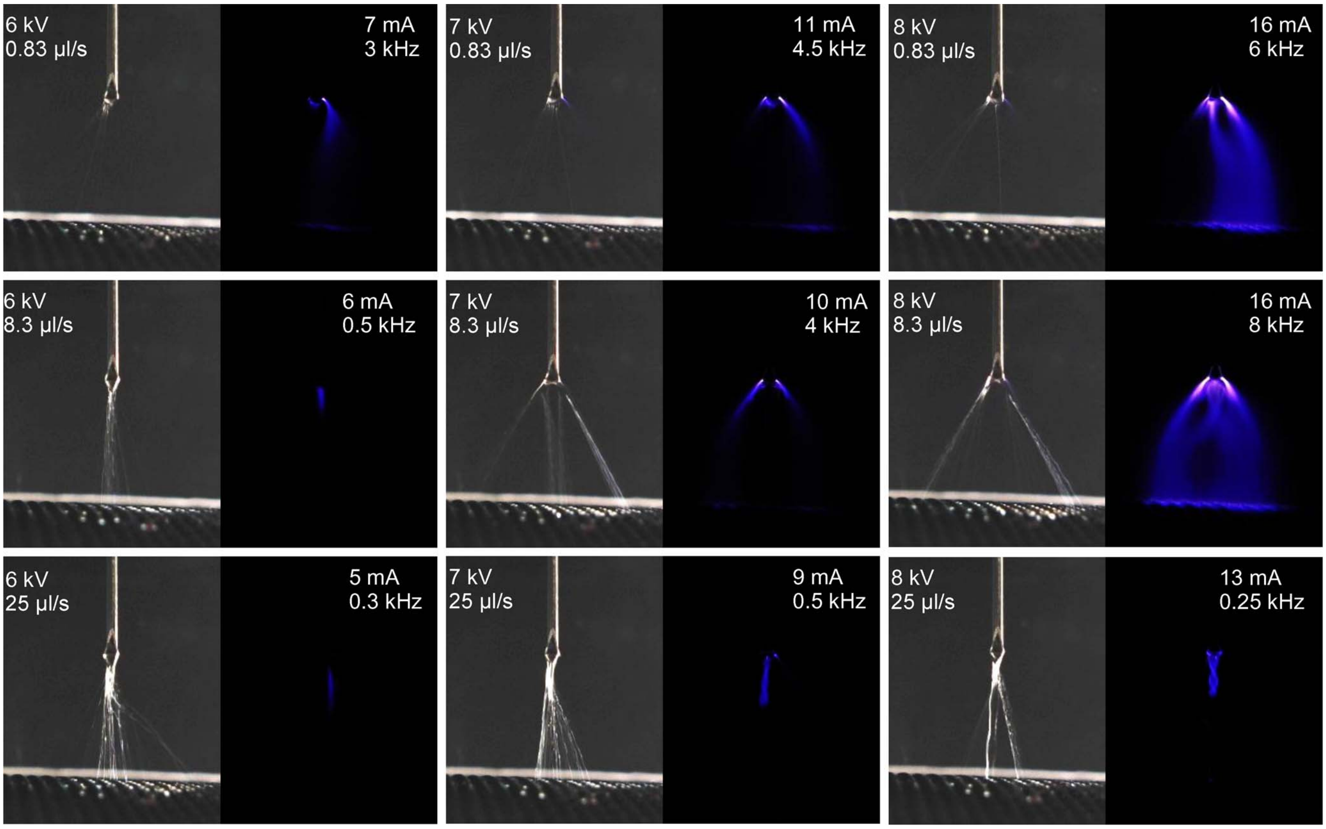

Fig. 1. Electrospraying effect with streamer corona discharge depending on the voltage and the water flow rate with the typical current amplitudes and frequencies ($d = 1$ cm, f/2.7). Exposure time was 1/15 s for illuminated pictures showing water streams and 4 s for dark pictures showing discharge regions under the same conditions.

was too much disrupted and eventually quenched by the water flow. In addition, the electrical breakdown occurred at lower voltage than at lower flow rates.

The results show that the effect of the EHDA of water in combination with streamer corona discharge depends both on the applied voltage and the flow rate. This is an interesting and important conclusion for the next research and water decontamination applications.

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