Streamers in pulsed positive corona: low and high current regimes

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Streamers are observed with a CCD camera in point-plane and wire-plane configurations. Two pulsed power supplies are compared: a spark-gap switched capacitor (C-supply) and a system with a transmission line transformer (TLT-supply). At 40 kV the C-supply gives ~1 A current and the TLT-supply 60 A, due to better impedance matching in the second case. At low currents the streamers are thin (~0.3 mm) and show a lot of branching. At high current the streamers are thick (~5 mm), nevertheless in both cases the current density is the same in both regimes, ~1 A/mm^2. The influence of dielectric layers and a layer of water above the cathode is also shown.

Keywords: pulsed corona discharge, streamer propagation, ozone creation, water cleaning

1. Introduction

The possibilities of using a low-temperature plasma for environmental application are extensively studied and successfully implemented nowadays [1]. Many recent studies have been focused only on the industrial gas cleaning. The pulsed corona, one of the Advanced Oxidation Techniques (AOT's), is widely used in that field [1]. Recently, attempts to use pulsed corona technique for waste water treatment have been successfully undertaken [2-4]. In those tests corona was created in the liquid phase. The creation of the electrical discharges above the liquid, in the gas phase is a relatively new approach. In such a configuration, the pulsed corona becomes a powerful source for the creation of ozone and other radicals, with high oxidation potential. Species created in the air phase are diffused easily into the thin layer of liquid, where they can react with impurities. The Corona Above Water (CAW) reactor to study the ozone creation and wastewater treatment is available [5-8]. Earlier tests [7] confirmed that the pulsed corona is an efficient ozone source and a promising technique for wastewater cleaning. However, in order to obtain even higher performance a better understanding of the streamer propagation process is needed. Also, changes of the power supply units are necessary to improve the efficiency of the cleaning process.

A comparatively new [9] concept of electrical supply system has been used in this work to study its effect on streamers development and propagation. The integral part of the system is a Transmission Line Transformer. The main functions of TLT are: increase of the output voltage, impedance transformation for faster switching and better matching with corona reactor, and protection of the switch against shortcuts and breakdowns. The streamer formation and propagation in the reactor are observed with an intensified CCD camera.

In the present paper we investigate the influence of physical (electrode configuration, presence of dielectric and liquid) and electrical (TLT presence, pulse energy) parameters on the streamer propagation process.

2. Setups

Two pulsed power supplies are used for the measurements presented here. The first supply uses a capacitor that is discharged via a semiconductor switch or a spark gap (from now on this is called *C-supply*). Voltage and current are measured on the reactor side. A sketch of the supply and typical waveforms of voltage and current are given in [10]. The power supply works at maximal pulse amplitude of up to 45 kV which gives current pulses up to ~1 A and an energy per pulse of up to ~3 mJ.

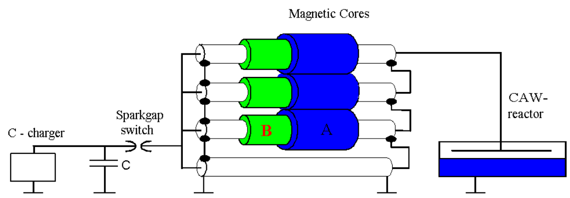


Fig. 1: The pulsed power supply using a sparkgap and a transmission line transformer.

The second pulsed power supply incorporates the Transmission Line Transformer (*TLT-supply*) build from four 50 ohm coaxial cables (Fig. 1). At the generator-side, the lines are connected in parallel, thus providing low discharge impedance for the capacitor (12.5 ohm). At the reactor-side, the lines are connected in series. This output impedance of 200 ohm provides better matching with a corona reactor. In addition, the output voltage is increased by a factor 2. The capacitor C is discharged over the TLT via the spark-gap switch. This setup can operate with a repetition rate up to 25 pps, with the voltage up to 45 kV and the current of 60 A (Fig. 2). The current pulse duration is around 50 ns. The energy per pulse is up to 60 mJ.

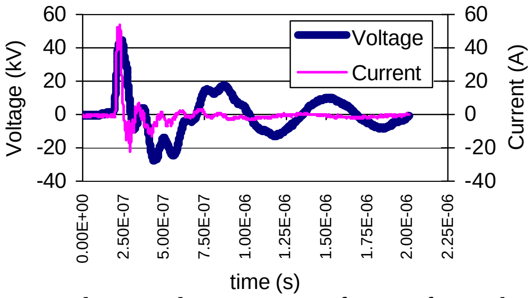


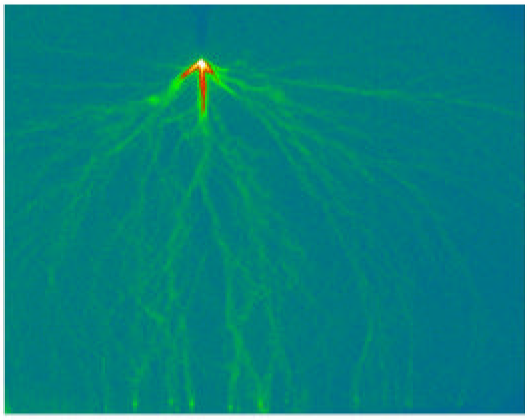
Fig. 2: Voltage and current waveforms of TLT-based pulsed power supply.

Streamer propagation and creation have been studied in two electrode configurations: point-plane and wire-plane. In both cases the effect of the dielectric on streamer propagation has been observed. The gap distance was 4 cm. To observe the streamer distribution in a wire-plane configuration the small-scale model of CAW reactor [8] was used. The length of the wire was 4 cm. An intensified CCD camera is used to photograph the streamer development [10], it operates with a gate of 20 μs.

3. Results

In the first experiment the effect of the applied voltage on the streamer creation has been studied in a point-plane electrode configuration with the C-supply using a spark gap switch. As can be seen in Fig. 3, increasing the voltage from 35 kV to 45 kV leads to the creation of a much larger number of the streamers. However with the use of the TLT-supply, working with the same voltage of 45 kV, the number of streamers created decreases and the diameter of the streamers increases from ≤0.5 mm (see also [10]) up to 5 mm (Fig. 4A).

3A:



3B:

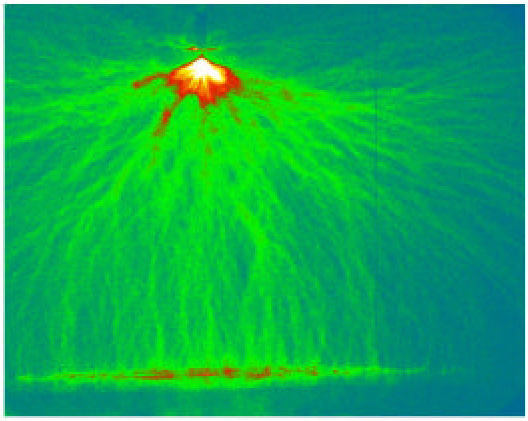
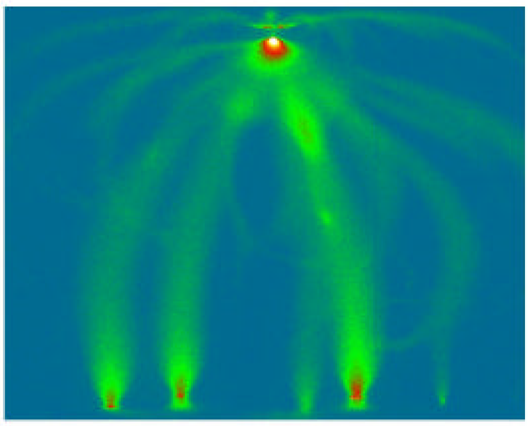


Fig. 3: Streamer propagation in point-plane configuration with the C-supply (3A: 35 kV, 3B: 45 kV).

The presence of a 3 mm plate of dielectric (Perspex) diffuses the streamers and expands the surface discharge area (Fig. 4B). The streamer diameter increases slightly. At the same time the distance between the streamers increases and the discharge area expands. Without dielectric the contact points between streamers and the cathode are narrow. With presence of Perspex the area of the surface discharge is clearly visible.

4A:



4B:

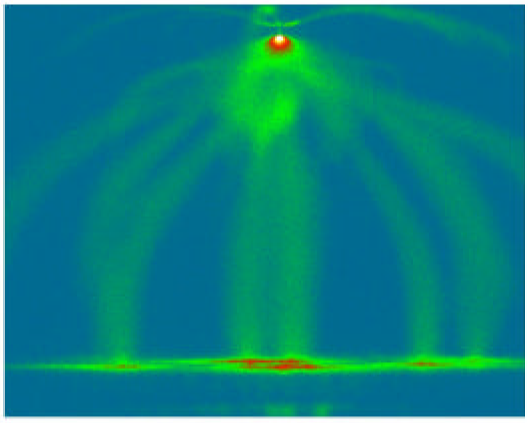


Fig. 4: Streamers in point-plane gap with TLT-supply at 45 kV (4A: metal cathode, 4B: with dielectric).

5B:

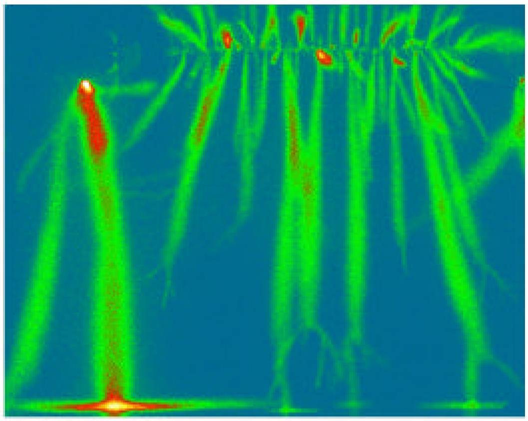
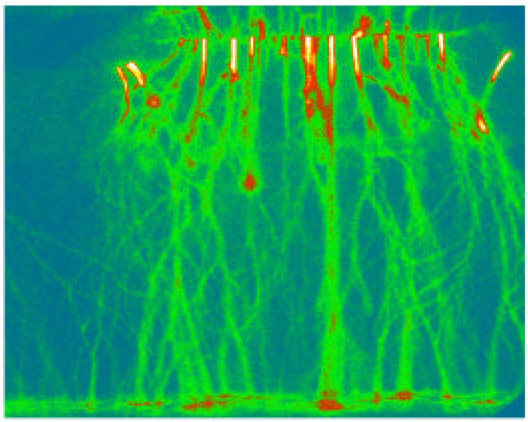


Fig. 5: Streamers in wire-plane configuration at 40 kV (5A: C-supply, 5B: TLT-supply).

As can be seen in Fig. 4 no branching is visible with streamers created using the TLT-supply. Since the discharge gap was the same for two setups and the voltage has been set to the same values, the only difference between those two experiments is the value of the current.

Streamers in the wire-plane configuration using the C-supply are shown in Fig. 5A. The number of streamers going down is ~20 on 4 cm wire, this is close to the value of 6 cm^{-1} as reported in [11]. The diameter of the streamers is similar to those in Fig. 3, branching is also observed, but less pronounced. For fig. 5B the TLT-supply was used, these streamers resemble more fig. 4, but the diameter is smaller. Some of the thick streamers change into thin ones just before the cathode and then show some branching. Probably the pulse duration of 50 ns is just too short for streamers to pass the gap during the high current phase.

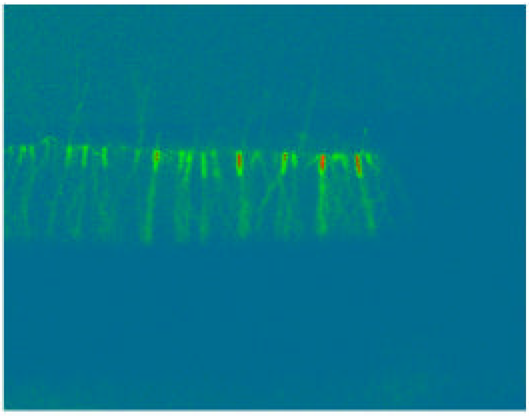
5A:



As can be noticed from Fig. 5 part of the streamers start to propagate opposite to the cathode. They fully disappear after a distance of 1cm.

Fig. 6 shows the development of streamers in presence of deionized water and 1mMol/L phenol solution. For the experiment the semiconductor-switch setup was used, with the voltage of 15 kV and the current of ~1 A. The layer of the liquid is 1.5 cm deep.

6A:



6B:

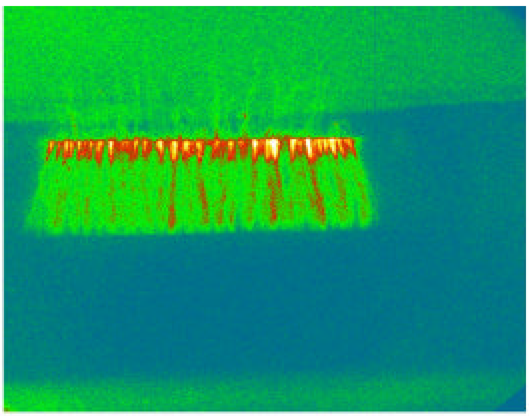
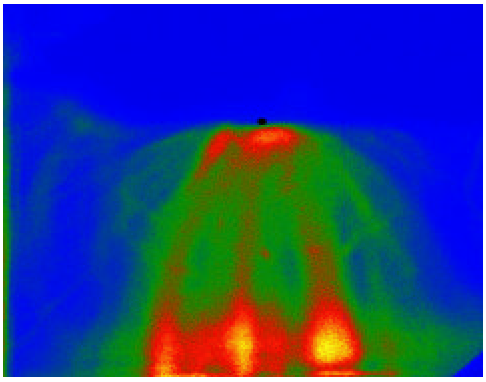


Fig.6: Streamers propagation above: deionized water (6A) and phenol solution (6B).

It is clearly visible that the presence of a more conductive liquid influences the streamer development. The amount of streamers created above the phenol solution is higher compared to deionized water.

7A:



7B:

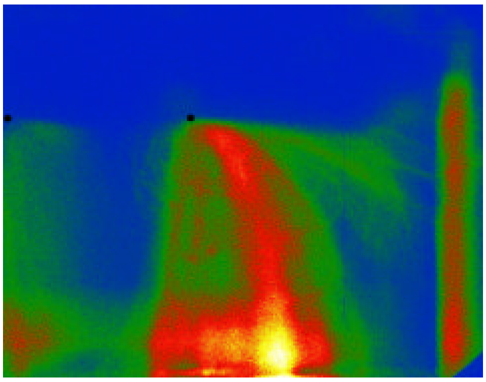


Fig. 7. View along the wires (40 kV, TLT-supply). 7A: one wire, 7B: two wires. The black dots indicate the position of the wire.

Fig. 7 shows the effect of the number of wires on the streamer distribution. The streamer development was observed along the wires with TLT-supply at 40 kV and a current of 60 A.

The presence of additional wires affects the shape of the discharge area. With one wire the discharge area is wider. With two and more wires present, the discharges from the separate wires start to influence each other causing the streamer area to be narrower. The attaching of the streamers to the wall is also visible.

4. Conclusions

Obtained results showed the big influence of the electrical system on the discharge structure. Streamers created with TLT-supply operating at 40 kV and 60 A, with ~60 mJ per pulse energy, are thicker (up to 5 mm) than those created by the C-supply (~0.3 mm) [10], operated at 40 kV and 0.8 A with energy of ~3 mJ. Previous experiments [6-8] confirmed high ozone yields obtained with the TLT-supply, which indicates that from the ozone creation point of view it is better to create streamers carrying more energy in a large diameter.

A rough estimate from figs. 3B and 4A shows that the current density in both types of streamers is similar, ~1 A/mm^2. Streamers obtained with TLT-supply sometimes change to a small diameter close to the cathode when the current from the supply drops. This indicates that the thick streamers have approximately the same speed as the thin ones. These thick streamers resemble the ones reported in [12].

Streamers starting from the wire also propagate opposite to the cathode. A layer of deionized water reduces this effect. With the presence of a more conductive, phenol solution, a larger amount of high intensive streamers starts from wire. Presence of dielectric affects the discharge area, expanding it and diffusing the streamers. Streamers are easily attached to the walls.

The presence of more than one wire affects the shape of the discharge, creating the streamer-free gaps between the discharge areas.

To fully understand the effect of TLT presence on the streamer development more tests are needed with a larger range of applied voltages. A new setup for these measurements is being prepared.

Acknowledgement

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5. References

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