Evolution of electrical discharge channel in isopropyl alcohol solution

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Abstract. Evolution of the spark channel created by the high voltage pulse generator in 15% isopropyl alcohol solution in tap water was investigated experimentally. Fast camera images show the start of spark discharge channel with the anode region glowing, which is due to ionization-overheating instability near the surface of anode electrode. Measured propagation velocity is about 4 m/s and points to thermal process of channel evolution. Partial discharges in gas bubbles near the spark channel were observed. When the channel bridges the gap the cathode flash of lightning occurs which is much brighter than anode glowing and channel one. After destruction of the spark channel the cathode glowing stays for a longer period than anode one.

1. Introduction

Underwater arc discharges are of interest for various applications such as water purification, underwater welding, electrohydraulic and electrodynamic fragmentation, high power switchers [1]. Arc discharge in liquids always starts with the formation of gas region where electron avalanches, slow (primary) and fast (secondary) streamers may occur [2–4]. The same situation is observed for wet sand [5], where sand grains play the role of dielectric inclusions. On the next stage if conductivity is quite high it takes some time for hot plasma channel to reach opposite electrode. On the final stage spark channel bridges the electrode gap. A number of papers on low-density regions (microbubbles etc.) importance for discharge initiation have been published for the last decades. Their reviews are given in [6, 7] as well. Some of them deal with pre-existed microbubbles [8, 9], while others report on microbubbles generation during initial stages of streamers propagation. In this paper, we describe experimental observations connected with the propagation of pulse discharge in 15% isopropyl alcohol (IPA) solution in tap water.

2. Experimental set-up and diagnostics

The main parts of the experimental setup are the pulse generator and the discharge cell. Full scheme is shown in figure 1. The pulse generator consists of dc high voltage power source, high voltage oil-filled storage capacitor C which is discharged by a triggered spark gap switch. The value of capacity is 1.6 μF.

The discharge voltage could be varied in the range of 0–40 kV and has a positive polarity. A rise time could be varied in the range of 10–40 μs. The half amplitude pulse duration was

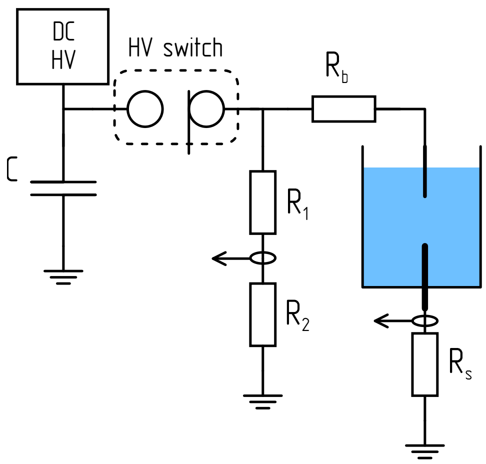

Figure 1. Experimental setup.

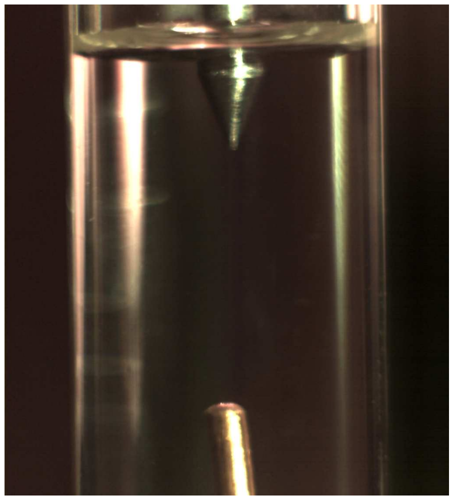

Figure 2. Electrode system: the anode at the top and the cathode at the bottom.

typically 10 ms. The ballast resistance R_b limits current in the range of (1–5) A. The applied voltage was measured by a Tektronix P6015 probe with additional resistive divider (R_1–R_2), the current was measured by means of the 2 Ω current shunt R_s at the cathode side. Both signals were recorded with Tektronix DPO7054C oscilloscope. The conductivity σ of the solution was about 300 μS/cm. The high-speed images were taken with CMOS Redlake MotionPro X3 camera, which was synchronized with applied voltage pulse.

The experiments were performed in the pin-to-pin geometry in the closed volume. The quartz tube with 16.6-mm-inner-diameter is used as the closed volume to be able to carry out OES diagnostic in future. The electrodes alignment is shown in figure 2. The quartz tube was vertically oriented. The bottom cathode side is sealed with elastic dielectric plug. The anode is made of copper and inserted from the top side. The anode is of conical shape with an apex angle of 20°, a cone basis diameter of 3 mm, and a 100 μm radius hemispherical tip. The cathode is made of 2.5-mm-diameter copper wire with rounded borders, so it also has a hemispherical tip and placed at the center of the elastic plug. The inter-electrode gap is 15 mm. The resistance to direct current of the inter-electrode volume was about 4.5 kΩ. During the experiments, the water was replaced after each breakdown and had the same chemical composition.

3. Experimental results

The experimental results are shown in series of images and set of waveforms on discharge in 15% IPA solution in tap water. The images in figure 3 show the evolution of spark channel. At the very beginning when the voltage is applied the anode the surrounding liquid are cold and do not show light emission. After the switch is triggered the voltage has a constant value near the applied one for a short period of time 300–600 μs. A pre-breakdown current is quite large due to large conductivity of tap water and decreases while the capacitor discharges. The stored energy is spent on Joule heating of the liquid and the anode tip. After some threshold energy is deposited (about 40 J in our case) the anode and the near region glowing (figure 3a) appears typically in 300–600 μs after voltage applying due to ionization-overheating instability near the surface of anode. It corresponds to the point (a) on figure 4 where nonlinear growth of the current starts. Figure 3b shows channel developing from the anode region and denote the end of the first nonlinear part of current waveform, figure 4, point (b). Partial discharges (figures 3b–3e, A, B) are observed in the near region along the whole channel during its evolution.

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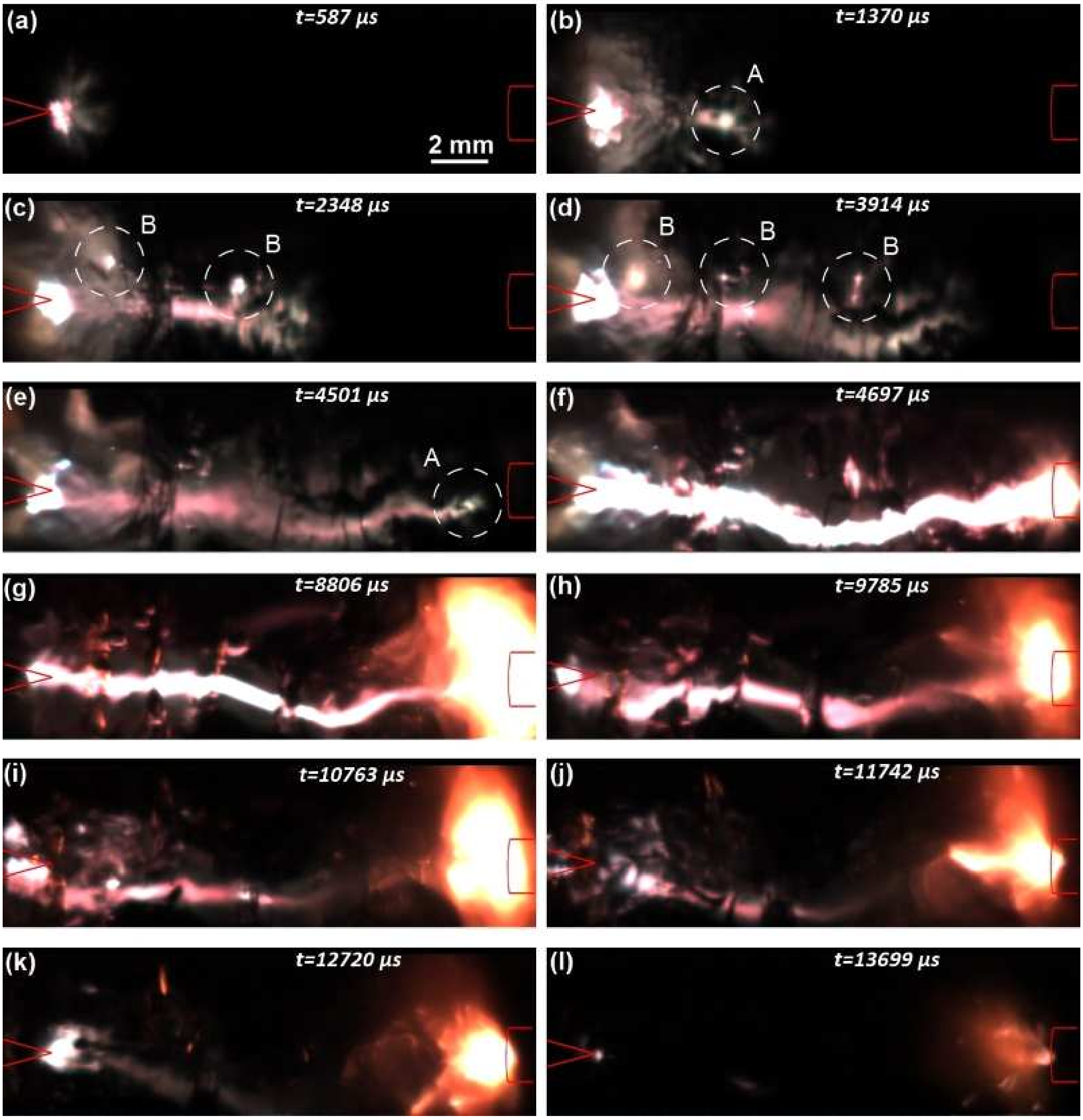

Figure 3. The evolution of spark channel in 15% IPA in tap water. Anode is at the left and cathode is at the right. Images are obtained with RedLake MotionPro X3, 5000 fps, exposure 300 μs.

They often correlate with small current peaks on the raw waveforms without smoothing. These discharges most likely occur in gas bubbles. Their formation due to vaporization during the Joule heating of highly volatile fraction with conduction currents was observed in subsidiary experiment without electrical breakdown of the electrode gap.

Bubble breakdowns are observed both in front of channel tip and on the side. Bubble breakdowns in front of the channel tip are showed in figures 3b and 3e (A). Side discharges (B) are presented in figures 3c and 3d. The full set of images shows that generated bubbles can lead to additional side channels developing. Their propagation is stopped by side bubbles.

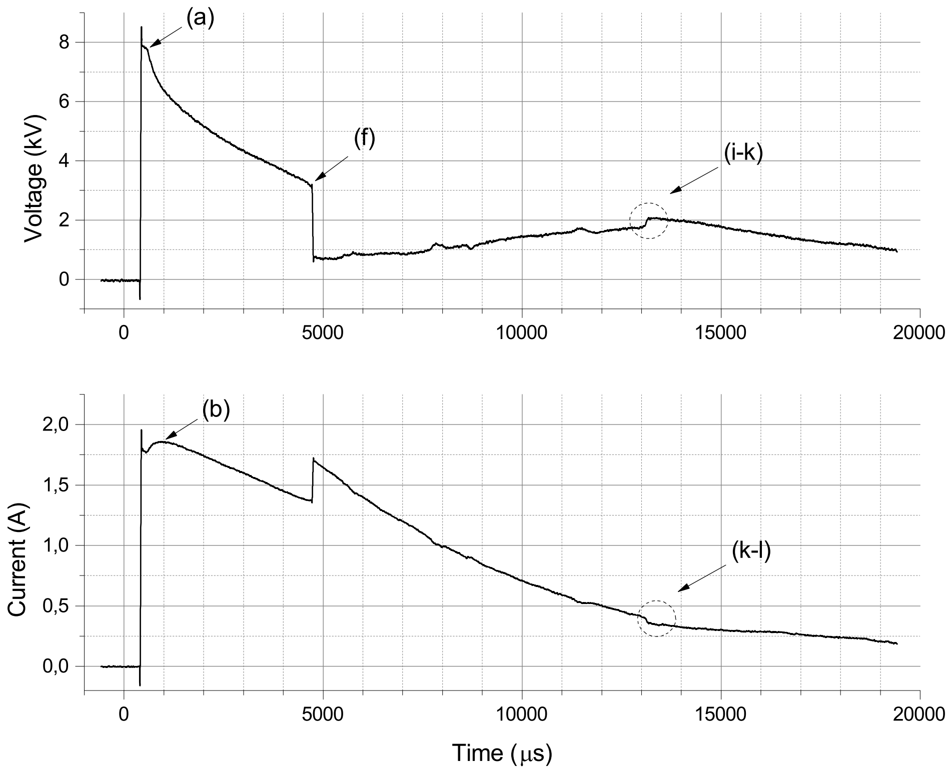

Figure 4. Current and voltage of the electrical discharge in 15% IPA solution in tap water.

Even the main discharge channel can change its propagation towards the bubbles. The flash of lightning (figure 3f) bridges the electrode gap in 4 ms after the anode glowing appearance. The propagation velocity is about 4 m/s. After the gap is bridged, the discharge channel heats up. During the next 4 ms the most of energy deposits in the cathode region, intensive cathode heating occur which leads to growing of the cathode spot (figure 3g). Images in figures 3h–3j show dehomogenization of the discharge channel and decrease in glowing intensity. The hydrodynamic destruction of spark channel takes about 2 ms. After the discharge current drops anode glowing almost disappears in contrast to cathode glowing with additional 4–5 ms life-time (figures 3j–3l).

4. Conclusion

High-speed images of discharge channel evolution in 15% IPA solution recorded by a CMOS fast camera and set of waveforms are presented. The spark channel develops due to ionization-overheating instability near the surface of anode. Partial discharges in bubbles occur in the near region along the whole channel during its evolution. The generated bubbles lead to additional side channels developing. The main discharge channel can change its propagation towards the bubbles. The cathode glowing disappears much later than anode one after the destruction of the channel. The most part of energy during discharge deposits in the cathode region.

Acknowledgments

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