Study of the binding zone of electrical discharge to the liquid cathode by high-speed visualization

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Abstract. This work is devoted to the experimental study of the properties of the binding zone of gas discharge to the liquid electrolyte cathode. Detailed description of the processes on the border "plasma-liquid" was analysis by of high-speed shooting. Were installed the regularities of phenomena of transfer substance and electric charges from the liquid electrolyte in the plasma column.

1. Introduction
In recent years, electrical discharges tied to the liquid attract the attention of researchers due their great potential for practical applications [1-5]. In the presence of fluid in the near areas of electrode occur are quite complex processes. This work is devoted to a detailed study of these processes using high-speed video.

2. Experiment
In experimental practice, different electrode systems are used to creating a gas discharge with liquid electrolyte cathode. In the open air at atmospheric pressure, typically, the electrolyte is pour in a container with a large geometric volume and circulates through it, or is expire from the tube.
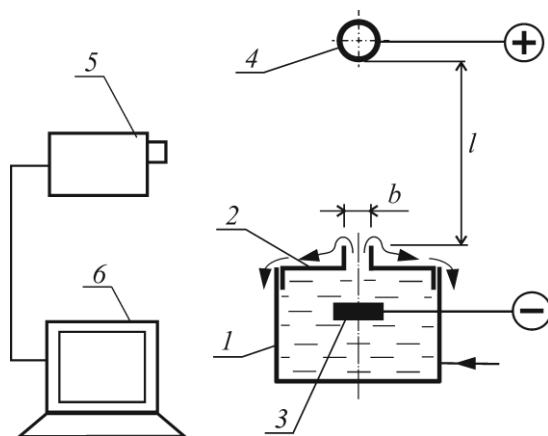

Figure 1. Experimental setup (electric discharge unit).

In such embodiments, a discharge formed in the form of a body of cylindrical shape. Near its axis, figuratively speaking, the discharge is "thickens", and spatial structure is "smeared". In this work, the electrolyte is flowing out from a slit gap. The discharge formed as a vertical glowing wall and relatively small thickness. Thereby, made possible study of its spatial structure more detailed.

The experimental set-up used to generate and study of electrical discharge, which schematically depicted in figure 1.

Liquid electrolyte fed into the cylindrical container *1*. It closed by a cover *2*, which had a slit gap of width b = 2.5 mm. Length of slit gap was 35 mm. On the edges of the gap was done shoulder of height of 5 mm. Sodium chloride solution in distilled water as electrolyte was used. It was prepared with a concentration of 0.55% by mass. Specific electric conductivity was in the range of 10.00 ± 0.20 mSm/cm. The mass flow rate m of electrolyte through the gap was 5-6 g/s. Inside of the container was mounted graphite plate *3*, which was connected to the negative pole of the power source. The discharge was burning between the electrolyte and the water-cooled metallic anode 4. The anode was made in the form of a long tube. It was oriented along the slit and located above it at a distance of l = 4 cm. The power supply was a three-phase full-wave rectifier. Voltage ripple was smoothed out by C-L-C-filter.

High-speed videography was filmed by camera Photron FASTCAM SA4. Its technical characteristics allow to study in detail processes in the system with the liquid medium [6]. Accumulated in the camcorder *5* information was being transferred to the computer *6*.

3. The results of the experiments and their analysis.

In figure 2 shows the video footage obtained under the regime of 10000 frames per second. As seen, closer to cathode the glowing column is split into multiple channels. These channels rest against on the surface of the electrolyte, forming a small luminous cathode spots.
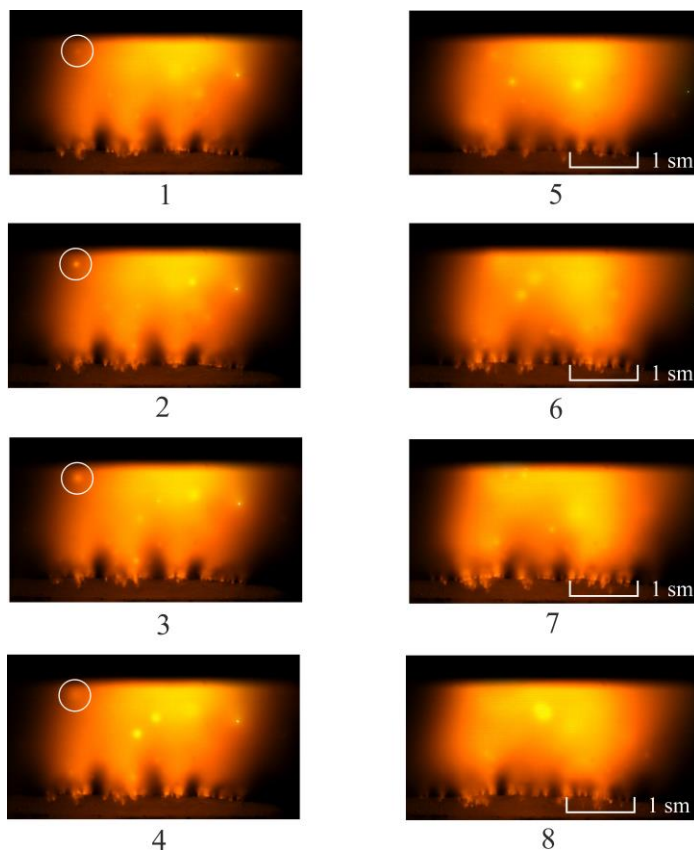

Figure 2. Video frames. The cathode at the bottom, the anode at the top and it covered with an opaque plate. Current 1.3 A; the terminal voltage 1100 V. 1, 2, 3, 4 - interval between the frames 10^{-4} s; 5, 6, 7, 8 – 10^{-3} s. One of many outbreaks isolated with white circle.

High-speed shooting is allowed for trace the movement of cathode spots and reveal some of their properties.

1. Separately taken cathode spots existed not long. Some of them appeared and quickly disappeared, others lasted a little longer. Minimum lifetime τ was ~ 1 ms. The maximum value τ was difficult to determine. It was more than 10 ms. During this time, the cathode spots grouped and merge with others, i.e. becomes difficult to discriminate in the video frame.

2. During the time τ brightness of the cathode spot was varied. In the moment of maximum brightness of the spot expanded to the largest size. The maximum value of the spot diameter was in the range of 0.15-0.25 mm.

3. The number of cathode spots with the maximum brightness was constantly changing. This happened due to the fact that the spots appeared and disappeared, and as well "merged". However, in each frame they could be counted with some error. In particular, at a current of 1.3 A the number was 35-50 pieces.

4. There is a continuous movement of the cathode spots on the surface of the electrolyte. Moreover, the cathode spots moved much faster than electrolyte flow, which could be seen visually and it confirmed by calculations. The average speed of the cathode spots was ~ 1m/s.

The results of observations were used to estimate the current density on the liquid electrolyte cathode by the formula $j_k = I/(N \cdot S)$, where N − is the number of cathode spots, S − sectional area of individual cathode spot. It was found that j is in the range of A/sm^2. This is several orders of magnitude smaller than the current density on the metallic cathode during combustion of electric arc [7]. However, in the case of the gas discharge with liquid electrolyte cathode is a relatively large value in comparison with the known data [8-10]. Traditionally, the current density on the liquid cathode is measured as the ratio of the amperage to the area of the luminous region on the surface of the liquid. For small currents not exceeding ten milliamps, this method is acceptable because the nonuniformity of the binding zone is not observed, at least, cannot be detected by visual inspection. The numerical value of j_k is obtained ~ 1 A/sm^2 [9]. At currents over 1 A nonuniformity binding zone of discharge to the liquid cathode becomes apparent. It is noteworthy that in these conditions the calculation according to the traditional methods gives the same result. [10]

Another property of electric charge, which is clearly evident in studies of high-speed shooting is the appearance of outbreaks. In the videos they allocated in the form of bright circles with different diameters (figure 2). They are increased and become less noticeable. The duration of their existence was a few tenths of a millisecond.
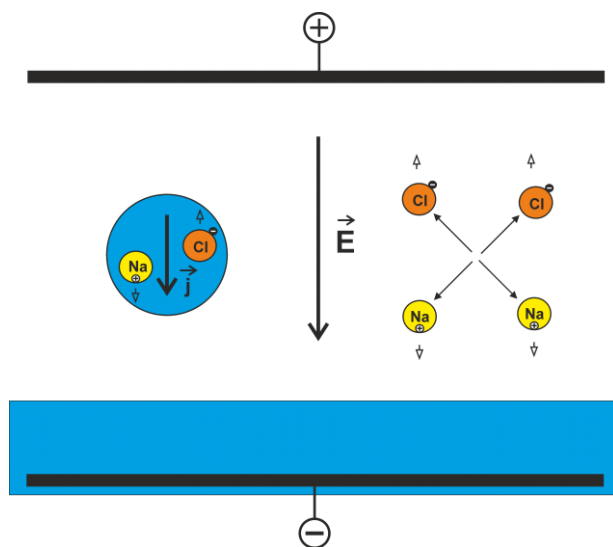

Figure 3. A drop of the electrolyte in the electric field of the plasma column before and after the explosion.

We can assume that microbursts electrolyte droplet happening in the plasma column. At the site of the explosion concentration of atoms is much larger than in its environment. Accordingly, radiation emitted from atoms observed in the form of bursts.

Droplets of electrolyte contain ions. After the explosion, they scatter. Further, under the influence of an electric field, they drift to the electrodes, creating a diffuse electric current. This can explain the formation of significant volume of the plasma column above the liquid electrolyte.

The electric field creates directional movement of ions inside the drop. The positive sodium ions move towards the cathode, and the negative chlorine ions - to the anode (figure 3). Thus is arises ionic current. Probably the Joule heat generated during the flow of ion current resulting to an explosion of drop. It is possible that an explosion occurs in a different way. However, what would not have been an mechanism of explosion, the ion current plays a role in this process.

4. Conclusions

Binding zone of electrical discharge to the liquid electrolyte cathode is composed of a lot small cathode spots, with dimensions constituting a few tenths of a millimeter. The current density in the cathode spots is large and reaches a value up to 100 A/sm^2.

The liquid cathode is spray into the cathode spots. Small droplets getting in discharge area is heat, vaporize and explode. Ions carried out from the liquid cathode by electrolyte droplets fly away. Diffuse ion current is formed the plasma column.

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