About the conditions of volumetric combustion of the gas discharge with water-solution cathode in an extended discharge gap at atmospheric pressure

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Abstract. A gas discharge between liquid electrolyte cathode and copper anode was studied experimentally. Water solutions of sodium chloride were used as liquid electrolyte. The discharge was ignited in an open air atmosphere in the current range of 2-5 A at distances of 3-18 cm between the electrodes. The conditions for the formation of volumetric plasma column in discharge gap were revealed.

1. Introduction
Gas discharges excited in contact with liquid electrolytes have great potential for practical application [1-7]. One of the properties of discharge that is of practical interest is volumetric combustion. There are such regimes in which plasma column of rather large dimensions is formed. For example, in [8], discharge with a length of up to 0.5 m was obtained. Ignition of discharge at large interelectrode distances is possible at high voltages. However, this method does not always lead to the desired result. The spatial structure of plasma column is disrupted. Contracted channels appears in discharge gap [9]. The aim of this work was a more detailed study of conditions affecting to volumetric combustion of discharge between water-solution cathode and metal anode.

2. Experiment
The experimental setup is shown schematically in figure 1. The photograph shows the gas discharge device that was used in the experiments. The body 1 of cathode assembly was made of dielectric. A graphite plate 2, was mounted inside it. A negative potential was supplied to this plate from power source. Electrolyte 3 flowed out of cathode assembly in vertical direction upward and flowed into working vessel 4. Sodium chloride solutions in distilled water were used as electrolyte. Anode 5 was located above cathode assembly. It was made of copper in the form of a disk with diameter of 90 mm and was cooled with water. The experiments were carried out with different mutual positions of cathode assembly and anode. The length l of discharge gap was set in the range from 3 to 20 cm.

To cool electrolyte, a water-cooled heat exchanger 6, was used. The electrolyte was circulated by means of a hydraulic pump 7. The mass flow rate of electrolyte varied in the range of 5-30 g/s. The electrolyte temperature was measured by chromel-alumel thermocouples installed at the inlet and outlet of cathode assembly.

The concentration C and the specific electrical conductivity s of electrolyte were measured with an ANION 4150 conductometer. To measure the current I an M2015 pointer instrument of accuracy class
0.2 was used. The voltage $U$ between the graphite plate 2 and anode 5 was measured with the same accuracy class with an M2016 device, to which an additional resistance was connected. The instantaneous images of discharge were photographed with VIDEOSKAN-415 high-speed camera. Information from speed camera 8 was transmitted to computer 9.

Figure 1. Schematic of experimental setup.

Electric power was supplied from a power source based on an inverter converter. The choice was due to the fact that power supplies of this type provide high stability of the current mode. Current stabilisation errors do not exceed 1%.

3. Experimental results and their analysis
In figure 2 shows video frames obtained with a small discharge current. Continuous frame sequences for two interelectrode distances are represented here.

Figure 2. Video frames of gas discharge. Duration of shooting is 1 min. Exposure 0.2 ms. $I = 1.8$ A. (a) - $l = 5$ cm; (b) - $l = 7$. $C = 5$ g/s.
In the first sequence of frames (figure 2a), combustion modes are observed, which differ in the filling of interelectrode gap with plasma. In the very first frame, plasma occupies entire space between electrodes. In the next frame, volumetric plasma is recorded only in the lower part near cathode. The alternation of such situations in video frames was observed for a long time. The situation did not change upon repeated ignition of discharge.

There is no complete filling of interelectrode space with a uniform bright glow in the second sequence of frames (figure 2b). A narrow discharge channel with less bright glow extends from anode side from top to bottom. Thus, at low currents at large interelectrode distances, volume combustion of discharge occurs only near cathode. At interelectrode distances of more than 7 cm, discharge burned unstable.

In figure 3 shows instant photographs of discharge at an increased current at various interelectrode distances. As can be seen, the volumetric glow fills discharge gap, which has a rather large length (figure 3a and 3b). However, the distance l between cathode and anode could only be increased up to a certain limit. At the interelectrode distances close to the limiting one, the homogeneous spatial structure of discharge was disturbed. From time to time, a narrow discharge channel appeared near anode, which was surrounded by a weak glow region (figure 3c). Thus, an increase in current ensured volumetric combustion of discharge at sufficiently large interelectrode distances. At a current of 5 A, a homogeneous volumetric plasma column was formed at distances of up to 13 cm.

![Image](a) ![Image](b) ![Image](c)

**Figure 3.** Instant photos of discharge. Exposure 0.2 ms. I = 5.0 A. (a) - l = 5 cm; (b) – 7; (c) – 13. C = 5 g/s. (σ = 10.80 mS/cm).

The discharge glow pattern changed when water solutions of sodium chloride with different concentrations were used as the electrolyte (figure 4).

![Image](a)

**Figure 4.** Sequences of video frames. Exposure 0.2 ms. I = 3.0 A. l = 6 cm. (a) - C = 3.5 g/s; (b) – 5.
In the case with a lower electrolyte concentration, volumetric discharge combustion was not observed (figure 4a). Under the same conditions, the use of an electrolyte with a higher concentration led to appearance of frames in which a homogeneous glow of interelectrode space was recorded (figure 4b).

In figure 5 shows photographs of plasma column in an extended discharge gap at various electrolyte flow rates through cathode assembly. At high flow rates, electrolyte was heated to a lesser extent. In this case, a violation of homogeneity of plasma column was observed (figure 5a). At low flow rates, electrolyte was heated to film boiling in zone of contact with plasma. Under these conditions, volumetric discharge combustion took place (figure 5b).

Figure 5. Photographs of plasma column of discharge on an extended discharge gap. Exposure 0.2 ms. \(I = 5.0\, A, l = 18\, cm, C = 5\, g/s\); Electrolyte temperature at outlet of cathode assembly: (a) \(- 40\, ^\circ C\); (b) \(- 54\, ^\circ C\).

4. Conclusion
The factors influencing formation of plasma column between water-solution cathode and metal anode were revealed. The regimes of volumetric combustion of discharge in open air at interelectrode gaps with a length of up to 18 cm were established.

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