Electric arc in plasma flow of gas discharge with a liquid electrolyte

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Abstract. The properties of an electric arc ignited in a gas discharge plasma flow with a liquid electrolyte cathode are experimentally investigated. Aqueous solutions of sodium chloride with a specific electrical conductivity of 10⁻¹⁵ mS/cm were used as a liquid electrolyte. The distance between the anode and the liquid electrolyte cathode was set in the range of 5-60 mm, and the distance between the anode and the metal cathode was varied in the range of 2-30 mm. The current of gas discharge with a liquid electrolyte cathode was set in the range of 5-10 A, and the arc current varied in the range of 1-10 A. The conditions under which the arc burns with the formation of a contracted channel are revealed.

1. Introduction
A distinctive feature of a gas discharge with a liquid electrolyte cathode is multichannel in the region of binding to the electrolyte. Such channels are observed visually and are recorded on photographs [1-5]. As the current increases, the discharge channels become larger. In the ranges of currents of amperes and tens of amperes, they are clearly recorded in high-speed video frames [6-8]. Under certain conditions, a contracted channel is formed in the discharge gap [9, 10]. At the same time, the overall multichannel is preserved. The contracted channel appears and disappears randomly. In this work, the possibility of the formation of a contracted channel in a controlled mode is investigated.

2. Experiment
The experiments were carried out in different versions of the arrangement of electrodes in space. Figure 1 shows one of the options. In this embodiment, the anode is oriented vertically. The gas discharge was ignited between the metal anode 1 and the liquid electrolyte 2, which flowed out of vessel 3 in the form of glass (figure 1). A graphite plate 4 was located inside the vessel for supplying a negative potential from a power source. The electric arc was ignited between the metal anode 1 and the cathode 5. The current was regulated by a step change in the ballast resistors 6 and 7. The power source was a three-phase full-wave rectifier with an output voltage of 1200-1700 V.

Anode 1 and cathode 5 were made of copper. The distance \( l_1 \) between the anode 1 and the liquid electrolyte cathode 5 was set in the range of 5-60 mm, and the distance \( l_2 \) between the anode 1 and the metal cathode 5 was varied in the range of 2-30 mm. In this case, the position of the metal cathode was...
changed in height relative to that of the liquid electrolyte cathode. In the version of the horizontal anode, the metal cathode was located both above and below the anode.

Figure 1. Schematic of the experimental setup.

The gas discharge current $I_1$ with a liquid electrolyte cathode was set in the range of 5-10 A, and the arc current $I_2$ varied in the range of 1-10 A. Currents $I_1$ and $I_2$ were recorded by an ACIP-15/1 double-beam digital memory oscilloscope with a bandwidth of 25 MHz.

An aqueous solution of sodium chloride with a specific electrical conductivity $\sigma$ in the range of 10-15 mS/cm was used as a liquid electrolyte cathode. The concentration and specific electrical conductivity of the electrolyte were measured with ANION 4150 conductometer.

Instantaneous discharge images were photographed with a high-speed camera VIDEOCKAN-415. Regulation of the radiation flux using a diaphragm made it possible to obtain images of the arc channel against the background of a gas discharge with a liquid electrolyte cathode.

3. Experimental results
Figure 2 shows the video frames obtained in the version of the vertical orientation of the anode at small interelectrode distances. The metal cathode is located on the side of the anode. Oscillograms of currents are also presented here.

Figure 2. Instant photographs of discharges and oscillograms of currents in the vertical orientation of the anode. Exposure 0.2 ms. $l_1 = 20$ mm. $l_2 = 5$ mm. 1 – discharge with a liquid electrolyte cathode, 2 – arc.

The arc is in continuous motion. The arc lengthens under the influence of the plasma flow and the Archimedean force. The anode spot rises upward. In its lowest position, the arc burns to form a short contracted canal (figure 2 (a)). With lengthening, the structure of the arc changes. The contracted channel remains only near the anode. In the rest, diffuse arc burning is observed. Changes in arc length and structure result in ripples of current (figure 2 (d)).
Figure 3 shows the video frames obtained in the version of the vertical anode, when the metal cathode is in the discharge gap between the anode and the liquid electrolyte cathode. In most frames, the contracted arc canal is clearly distinguished.

![Figure 3](image1)

**Figure 3.** A sequence of video frames. A metal cathode is located between the anode and the liquid electrolyte cathode. $l_1 = 40$ mm. $l_2 = 5$ mm. $I_1 = 8$ A; $I_2 = 10$ A.

With an increase in the distance between the metal electrodes, the arc burning mode changes. In the video frames, the contracted channel appears and disappears (figure 4). Thus, in the version of the vertical anode, the contracted channel is most stable when the metal cathode is located in the discharge gap between the anode and the liquid electrolyte cathode.

![Figure 4](image2)

**Figure 4.** Instant photographs of discharges at large interelectrode distances. Exposition 0.2 ms. $l_1 = 60$ mm. $l_2 = 20$ mm. $I_1 = 8$ A; $I_2 = 10$ A.

In the case of a horizontally oriented anode, the experiments were carried out in different versions of the location of the cathode in space. In one embodiment, the cathode was perpendicular to the anode. In this version, the arc burned unstable. The anode spot was displaced, the arc lengthened and ended.

![Figure 5](image3)

**Figure 5.** Instant photos and waveform of the arc current in the open air. The anode is on left, the cathode is on right.

Figure 5 shows video frames and an oscillogram of the free arc current between horizontal copper rod electrodes oriented parallel to each other. The arc burns in diffuse mode. It bends and stretches
vertically. The arc geometry is continuously changing, and therefore large-scale ripples of current occur.

In a plasma flow, the picture changes significantly (figure 6). A contracted channel is formed near the anode. The arc length is shortened. The ripples of current are becoming weaker.

Figure 6. Instant photographs of discharges and oscillograms of currents with a horizontal orientation of the anode. The metal cathode is located above the anode. Exposure 0.2 ms. $l_1 = 60$ mm, $l_2 = 30$ mm. 1 – discharge with a liquid electrolyte cathode, 2 – arc.

When approaching the metal electrodes at a distance of less than 10 mm the arc burns to form only a constricted channel without portion diffuse. The ripples of the current became even weaker.

4. Conclusions
Thus, the plasma flow contributes to the formation of a constricted channel in a low-current arc in the range of 1-10 A. The formation of a stable constricted channel is observed in the case of a horizontally oriented anode. The arc goes completely into a contracted combustion mode when the electrodes approach each other at a distance of less than 10 mm.

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