Combined electric discharge “arc + discharge with liquid electrolyte cathode”

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Abstract. A combination of an electric arc and discharge with a liquid electrolyte cathode in a single discharge gap has been created. The plasma column of discharge with liquid electrolyte cathode formed a "hollow cylinder". The electric arc was burned in a vapor-gas environment inside the "hollow cylinder". The gas discharge current with liquid electrolyte cathode was set in the range of 5-10 A, and the arc current varied in the range of 1-10 A. Aqueous solutions of sodium chloride with a specific electrical conductivity of 10-15 mS/cm were used as a liquid electrolyte. Spectral studies have been carried out in the visible range of radiation. In the experiments, copper and duralumin metal cathodes were used.

1. Introduction
A gas discharge with a liquid electrolyte cathode is one of the sources of non-equilibrium atmospheric pressure plasma. Plasma is formed therein, which contains a large number of reactive components: hydroxyl ions, atomic hydrogen, etc. This plasma has great potential for application in the synthesis of metal nanoparticles, the production of oxide powders, and the gasification of polymer waste [1-4]. From a practical point of view, the volumetric combustion of discharge is attractive. By changing the geometry of the cathode zone on the electrolyte surface, it is possible to give to the plasma column various shapes, in particular, it is possible to form a "flat wall" [5, 6]. The presence of a large volume favors the placement of additional electrodes in the discharge gap. The aim of this work was to study the possibility of igniting an electric arc inside the plasma column of discharge with a liquid electrolyte cathode using an additional metal cathode.

2. Experiment
In this work, a device has been developed that allows to create plasma column in form of "hollow cylinder". It contains one anode 1 and two cathodes: metal 2 and electrolyte 3 (figure 1). The electrolyte flows out of annular channel 4 with dielectric walls. A negative potential is fed to the graphite ring 5 mounted inside the channel. The discharge between electrolyte cathode 2 and metal anode 1 is volumetric and forms a "hollow cylinder". The arc burns between metal electrodes 1 and 2 inside the "hollow cylinder". Electrical power is supplied from a single source. The currents flowing in the device are regulated by two ballast resistors 6 and 7.
Anode 1 was made of copper. Copper and duralumin rods 10 mm in diameter served as metal cathode 2. The distance l between anode 1 and metal cathode 2 was set within 2-10 mm. Metal cathode 2 was located above electrolyte cathode 3 by 2-5 mm.

Figure 1. Schematic of the experimental setup.

The gas discharge current \( I_1 \) with liquid electrolyte cathode was set in the range of 5-10 A, and arc current \( I_2 \) varied in the range of 1-10 A. Currents \( I_1 \) and \( I_2 \) were recorded by AKIP-15/1 double-beam digital memory oscilloscope with a bandwidth of 25 MHz. A three-phase full-wave rectifier connected to the secondary windings of step-up transformer served as electric power source. The voltage ripple was smoothed out with C-L-C filter. The voltage applied to the electrodes varied between 1200-1700 V.

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

The emission spectrum of gas discharge was studied using a fiber optic spectrometer AvaSpec-3648 in the wavelength range of 484-724 nm with a resolution of 0.15 nm (diffraction grating 1200 lines/mm, entrance optical gap 10 μm).

3. Experimental results
Figure 2 shows the video frames obtained at low discharge currents.

Figure 2. Instant photos of the arc channel. Exposure is 0.2 ms. Cathode material: (a) – copper, (b) – duralumin. \( I_1 = 5 \) A, \( I_2 = 2 \) A.
There are views of channel arcs for two variants of the metallic cathode. In the first variant, the cathode material is copper (figure 2a), and in the second - duralumin (figure 2b). As shown in both versions, arc channel is colored in scarlet light. This color is characteristic of radiation of atomic hydrogen. As is known, the Balmer line $H_\alpha$ emits a scarlet light emission. The presence of scarlet color means that in both cases the arc burns in the water vapor environment.

In the second version, a blue background (figure 3) is observed near duralumin cathode. This background is created by the radiation of aluminum. Under the influence of the arc, the duralumin cathode is sprayed. Erosion products partially enter the arc channel. With increasing current, the process of destruction of the duralumin cathode is intensifies. Blue light becomes brighter (figure 3). On video frames, images of bright particles appear, which scatter from cathode.

![Figure 3](image)

**Figure 3.** Instant photos of the arc channel at increased currents. Exposure 0.2 ms. Cathode material is duralumin. $I_1 = 7\ A$, $I_2 = 9\ A$.

Figure 4 shows the oscillograms of currents. There is a clear difference in the properties of arc and discharge with liquid electrolyte cathode. In discharge with liquid electrolyte cathode, high-frequency pulsations of current are present, while in arc there are no such pulsations. The pattern is identical for both metal cathodes (figures 4a and 4b). The presence of high-frequency current ripples in the megahertz range is a characteristic property of discharge with the liquid electrolyte cathode [7].

![Figure 4](image)

**Figure 4.** Oscillograms of currents. Cathode material: (a) copper, (b) duralumin.

Figure 5 shows a panoramic spectrum of radiation in the visible region. As can be seen, the most intense are the spectral lines of sodium and hydrogen. Sodium is carried out into the discharge area from an aqueous solution used as a liquid electrolyte cathode. Hydrogen is formed as a result of the dissociation of water molecules in an electric arc. There are also copper spectral lines of copper, because the material of the electrodes is sprayed.
The Balmer hydrogen line \( H_\alpha \) (656.3 nm) corresponds to a radiative transition from level with an excitation potential of 12.088 eV [8]. Therefore, the presence of \( H_\alpha \) line in spectra suggests the presence of high-energy electrons in the arc, capable of transferring hydrogen atoms from the ground state to an excited state.

**Figure 5.** Panoramic spectrum of radiation. The cathode material is duralumin. \( I_1 = 6 \ A \), \( I_2 = 9 \ A \).

4. **Conclusions**

The possibility of creating a combination of an electric arc and discharge with a liquid electrolyte cathode in a single discharge gap has been shown experimentally. In such a combination, plasma is formed, enriched with a chemically active component - hydrogen. The placement of metal electrodes in the discharge region is also attractive from a practical point of view.

**References**

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