Some features of the electric discharge with the anode as a liquid electrolyte flow

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Abstract. An electrical discharge between a liquid electrolyte anode and metal cathode was experimentally investigated. Sodium chloride solutions in distilled water with a mass concentration of 2–10 g l\(^{-1}\) were used as electrolyte. The study was conducted in the range of currents of 0.1–3.5 A. The photo and video methods recorded features in the spatial structure of the electric discharge, which were manifested with an increase in current and variation of the discharge gap geometry. The conditions under which a volume discharge is formed in the diffuse combustion mode are revealed. A threshold current has been established, above which a contracted discharge channel is formed. The emission spectrum of the discharge in the visible region of the spectrum was studied.

1. Introduction
In electric discharges with liquid electrolyte electrodes, many different physicochemical processes occur that can give positive effects for practice. In particular, an electrolyte serving as an anode is subjected to intense electron bombardment. It was shown in works [1, 2] that such impact of electrons is useful for spectral analysis of liquid solutions, because leads to an increase in the intensity of the spectral lines of dissolved substances. The authors of the works [3, 4] noted that electrons coming from discharge to liquid anode, can initiate different chemical reactions. The rate of formation of hydrogen peroxide may increase [5]. Currently, researches are conducted mainly at low currents, measured in tens and hundreds of milliamps. The properties of electric discharges with a liquid anode at high currents have been little studied. In this regard, the aim of the work was to study an electric discharge with flow electrolyte anode at high currents.

2. Getting steady burning modes
In experimental practice, the technical system presented in figure 1a is used to create an electrical discharge with liquid electrode. Depending on the polarity of the connection, the liquid can serve either as cathode [6] or as an anode [7]. In this work, liquid served as an anode.

An electrical discharge was ignited between liquid electrolyte 2, flowing from the tank 1, and metal rod cathode 4. The positive potential to liquid electrolyte was supplied using a metal electrode 3, placed inside the tank 1.
Experiments have shown that in this configuration of electrodes, discharge is stable only at small currents not exceeding 1 A. At the same time, the interelectrode distance should be small (only a few mm). The instability was manifested in the fact that at large interelectrode distances the cathode spot moved up along the lateral surface of cathode, and discharge channel was broken.

The movement of cathode spot in the vertical direction was limited in configuration of electrodes shown in figure 1b. Here metal rod cathode 5 was located horizontally. At large interelectrode distances, another form of instability appeared. It was caused by the movement of anode “spot”. The anode “spot” moved at electrolyte surface. In this case, discharge channel was extended horizontally. Excessive lengthening caused it to disconnection.

In order to limit movement of anode “spot” in horizontal direction, tank 1 was closed with a lid 6 with a narrow slit 7 (figure 1c). The result was been achieved. With such an anode assembly, discharge burned steadily at sufficiently large interelectrode distances in excess of 1 cm.

Thus, technical measures were identified that must be taken to form a stable electrical discharge between liquid anode and metal cathode at large interelectrode distances. First, metal rod cathode must be positioned horizontally. Secondly, it is necessary to organize the flow of a liquid electrolyte through a narrow slit groove that extends along the core of cathode. The discharge device, developed with these technical measures, is presented in figure 2.

The case of anode assembly 1 was made of a dielectric material in the form of an elongated hollow body (figure 2a). Inside the cavity was mounted metal electrode 2 which made of palladium-tungsten alloy. The electrolyte flowed out of a narrow slit 3, made on the case 1. The width of the gap was 3 mm. In this version of discharge device, it was possible to change the relative position of the electrodes not only vertically, but also horizontally. The tubular metal cathode 4 was located coaxially...
with the anode body in different positions: with horizontal displacement ($x \neq 0$) and without displacement ($x = 0$). The cathode was cooled with water.

On figures 2b and 2c shows instant photo and oscillograms of current and voltage of one of the discharge burning regimes with at nonzero horizontal displacement of electrodes. As can be seen from the photo, the discharge area occupies a sufficiently large volume like a glow discharge. Under the influence of Archimedean force, the heated gas rises. The discharge channel bends and takes the form of an arc. In the flow of heated gas, the geometrical dimensions of discharge channel are continuously changing. Such changes cause voltage and current pulsations (figure 2c).

The volume burning of discharge was observed at currents up to 1.0–1.2 A. Further increase current leads to the appearance of bright contracted channel (figure 3). In this case, the voltage and current pulsations intensified.

![Figure 3](image)

**Figure 3.** Instant photos of discharge in the burning mode with a contracted channel. A tubular metal cathode is in the background. Its outlines on frame 1 are indicated by white lines. Diameter of a tube is 14 mm. The discharge current is 2.4 A. $x = 12$ mm.

High-speed video recorded the chaotic movement of discharge channel along the electrodes. In this case, the geometry of discharge area changed with lightning speed. However, despite this, discharge burned without interruption.

3. **Visible radiation of discharge**

In the visible region, gas discharge radiation was studied using an AvaSpec-3648 high-speed spectrometer with a resolution of 0.15 nm (a diffraction grating of 1200 lines$\cdot$mm$^{-1}$, an entrance optical gap of 10 $\mu$m). Spectral studies have shown that the Balmer lines of hydrogen $H\alpha$ and $H\beta$ (figure 4).

![Figure 4](image)

**Figure 4.** Profiles of Balmer hydrogen lines. Current discharge 3.5 A.

The spectral lines of hydrogen $H\alpha$ and $H\beta$ were used to calculate the electron temperature $T_e$ and the electron concentration $n_e$. The half-width of $H\alpha$ spectral line in spectrum of TBC-15 hydrogen lamp, in
which a glow discharge was ignited at low pressure, was taken as the apparatus half-width of spectrometer. The average value of the measurements was 0.35 nm.

Table 1 shows, as an example, the results of calculations obtained via three successively recorded spectra. Discharge burned in regime with a contracted channel at current of 3.5 A. The duration of the integration of the spectra was 5 ms, and time interval between them was 0.1 s.

Table 1. Temperature and concentration of electron gas.

|   | $T_e$ (K) | $\Delta \lambda/2 (\text{H}_\alpha)$ (nm) | $\Delta \lambda/2 (\text{H}_\beta)$ (nm) | $n_e(\text{H}_\alpha)$ ($10^{15}\text{cm}^{-3}$) | $n_e(\text{H}_\beta)$ ($10^{15}\text{cm}^{-3}$) |
|---|---|---|---|---|---|
| 1 | 3560 | 0.487 | 0.622 | 2.7 | 1.2 |
| 2 | 4280 | 0.427 | 0.687 | 1.3 | 2.1 |
| 3 | 3590 | 0.455 | 0.750 | 2.0 | 2.8 |

The electronic temperature $T_e$ was calculated by method of relative intensities. Required data for the calculation were taken from [8]. The concentration of electron gas $n_e$ was determined using the graphical data given in [9]. The results of computing $n_e$ is close to the values of concentration of electron gas in the nitrogen arc at atmospheric pressure [10]. This fact indicates the similarity of properties of the investigated discharge and electric arc. Signs of arc appears in the combustion mode of contracted channel. Relatively low values of $T_e$ also indicate presence of signs of arc discharge.

4. Conclusions

In the range of currents of 0.1–3.5 A, two regimes of electric discharge burning are observed between liquid electrolyte anode and metal cathode: 1) volumetric diffuse; 2) mode with a contracted channel. The volumetric diffuse mode is realized at currents up to 1.0–1.2 A. At higher currents, contracted channel appears and discharge becomes unstable. Stable combustion can be accomplished using a special electrode system. The results obtained can be useful in the development of plasma-liquid systems in which there is plasma contact with a liquid medium.

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