Investigations of the growth of the vapor-air shell of a gas discharge with a liquid electrolytic cathode of sodium hydroxide solution

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Abstract. Gas discharges with liquid electrodes are widely used in cleaning, polishing, hardening, forming a surface microlief with specified parameters. Burning gas discharge in a number of cases occurs in the vapor-air shell, with film boiling of the electrolyte. The properties of the vapor-air shell strongly influence on the physical processes of the discharge. Investigation of the growth mechanism of the vapor-air shell and the determination of the main factors of influence are relevant for the optimization of applied processes. The structure of the discharge in the vapor-air shell is determined, and the presence of the discharge leader structure is established. Anomalous growth of the vapor-air shell of a gas discharge with a liquid electrolytic cathode was detected.

1. Introduction
The low-temperature plasma produced in gas discharges with liquid electrodes is increasingly used in the field of thermal and chemical treatment of alloys [1], the formation of surface micrelief [2], the formation of functional oxide coatings, the production of metallic micro- and nanoparticles [3], the activation of chemical reactions in polymer solutions [4], generation of shock waves [5], etc. Under the terms of the initiation of discharges in a liquid, it is decided to allocate the following varieties: initiating discharge inside the liquid electrode, the discharge in the gas phase with the liquid electrode, the discharge inside of gas bubbles in the liquid [6]. This process is generally called plasma electrolysis, and depending on the polarity of the metal electrode, add the "anodic" or "cathodic" effect to the name, and in the case of an immersed electrode, call the contact glow discharge electrolysis (CGDE). However, we can’t call this glow discharge, since the nature and mechanism of charge transfer from the electrolyte to the plasma are not well studied.

From the point of view of application, the discharge in the electrolyte is interesting by the possibility of generating active radicals (OH, H2O2, etc.) used to destroy phenols [7] and organic dyes [8]. In this case, the discharge, depending on the shape of the applied voltage, burns either in the vapor-air shell formed around the metal electrode or in the form of separate microdischarges on the surface of the electrode. Researchers Sengupta and Singh [9] found that the discharge ignition voltage in the aqueous solutions of electrolytes on the anode is 420 V, and at the cathode 160 V. At the same
time, the voltage value does not depend on the composition, concentration, temperature and surface tension. This controversial statement, which requires additional research. It is considered to be the reason for the formation of the vapor-air shell overheating of the metal electrode and the appearance of film boiling. The structure of the vapor-air shell remains unexplained, just as the discharge in it is burning. When the discharge burns between a metal anode and an electrolytic cathode, a vapor-air shell 2-3 mm thick is formed. It is of interest to investigate the mechanism of the formation of a vapor-air shell under conditions different from the standard thermal mechanism, when film boiling is observed. The aim of the work was to study the mechanism of the appearance of a vapor-air shell around the metal anode in a solution of sodium hydroxide.

2. Main part

Figure 1 shows the functional diagram of the experimental setup, which consists of an electric power supply system 1, an electrolytic bath - 2, an electrode system - 3, an oscilloscope - 4, an additional resistance - 5, a voltmeter - 6, an ammeter - 7, a thermocouple - 8. Using the electrode system, the distance between the anode and the electrolyte solution was monitored. With the help of an oscilloscope 4, the shape of the applied voltage and current was monitored, the voltmeter and ammeter were used to measure the voltage and discharge current. Two power sources were used in the work: the first is a DC power source with continuously variable voltage, provides regulated rectified voltage of various shapes, consists of a diode bridge (diodes SD 246) and a laboratory autotransformer of adjustment type 1M with a voltage range from 1 to 300V depending on the experimental conditions, a smoothing capacitive filter is connected (C = 1560 μF)). Measurement of voltage and discharge current was carried out using two digital universal measuring devices APPA 305 and APPA 109N, the relative error of measurement is 0.8%.

The combustion of a gas discharge occurs between a metal electrode made of copper and a liquid electrolyte. As an electrolytic cathode, aqueous solutions of sodium hydroxide with a concentration of 1 to 5% by weight were used. In the experiments, a copper anode and a cathode of 0.65 cm² and 34 cm², respectively, were used. The electrode system 3 allows, by rotating the side screw, to vertically and horizontally move the anode electrode to the surface of the electrolyte or the wall of the discharge chamber. In the experiments, two positions were used, when the anode was immersed in the electrolyte and was above it. Figure 2 shows images of discharge burning on a metal anode in a vapor-air shell. Figure A shows a uniform luminescence of the entire surface of the electrode, the intensity of the glow decreases from the bottom up. At the initial moment of formation of the vapor-air shell, the
intensity of the glow is minimal and increases with increasing applied voltage. With the formation of a steam-air shell, there is a sharp drop in current from 8 A to 1 A and an increase in voltage by 15-20 V. When the electrode was moved horizontally to the surface of the observation window, the presence of a lead structure of the discharge was detected (Figure 2B). There are many discharge channels starting from the tip of the metal anode and propagating along the surface of the electrolytic cathode. In this case, intensive vaporization of the electrolyte is observed. This allows us to say that the discharge in the vapor-air shell burns between the tip of the metal electrode and the electrolyte of the vapor-gas shell. The discharge channels run parallel to the surface of the metal electrode over the surface of the liquid cathode, and not between the surfaces of the electrode and the electrolyte.

In the second case, when the metal anode was vertically immersed in the electrolyte, the formation of the discharge leader structure was observed at the initial moment of contact (Figure 3A). At a voltage of 80-100 V, electrolyte accumulation can occur on the surface of the electrode above the combustion zone of the discharge. The electrolyte is accumulated by spattering the electrolytic cathode with a discharge. At voltages above 150 V, the electrolyte does not become hot, since the evaporation process occurs due to the anode heating. Figure 3B shows the increase in the size of the accumulated electrolyte above the discharge. Further immersion of the metal anode results in a displacement behind the tip of the electrode of the discharge leader structure. In this case, intensive foaming of the electrolyte over the discharge zone is observed (Figure 3C).

Continued immersion of the electrode leads to a situation where discharge channels propagate from the tip of the anode between the main electrolyte layer and the expanded electrolyte located above the discharge zone. In this case, one can observe a clear glow boundary separating the foamed vapor-air shell. Gradually, the foamed shell grows, its rotation around the metal anode is observed, but the center remains stationary and attached to the tip of the anode. Figure 4 shows the growth pattern of the shell. It consists of the following stages: A - splashing and formation of an electrolyte droplet, B - further immersion of the anode, foaming and dripping of the drop to the tip of the electrode into the discharge zone, C - formation of a foamed shell with the center of the discharge burning at the tip of the anode, D - growth of the foamed-vapor-air shell.

Figure 2. The image of the steam-air shell in the electrolyte. A – the electrode is surrounded by electrolyte. B – section of vapor-air shell.
Figure 3. Formation of the vapor-air shell during smooth immersion of the electrode.

Figure 4. Schematic diagram of anomalous growth of a vapor-air shell in NaOH solution.

It is established that for the plasma electrolyte process in NaOH solutions with a smoothed voltage obtained after full-wave rectification and using a 450 μF capacitive filter, a vapor-air envelope is observed: for 1% solution at 97 V, 3% solution for 93 V, 5% solution - 81 V. The “foamed” shell gradually grows and fills the entire space between the metal electrodes. The decisive factor is the applied voltage.

3. Conclusions
The structure of a gas discharge with an electrolytic cathode inside a vapor-air shell is determined. The discharge has a multitude of channels emanating from the tip of the anode and propagating along the surface of the electrolyte.

The leader structure of the discharge is determined by slow immersion of the anode in the electrolyte. The conditions for the anomalous growth of the steam-air shell were determined: for a 1% solution at 97 V, a 3% solution for 93 V, and a 5% solution for 81 V. The discharge was initiated when the metal anode was in contact with the electrolyte surface.

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