Gas discharge between two liquid electrolyte electrodes

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Abstract. A gas discharge between two liquid electrolyte electrodes was studied experimentally in the current range of 0.5–3.5 A. As liquid electrolytes, aqueous solutions of sodium chloride, sodium carbonate, potassium hydroxide and copper sulfate, as well as tap water, were used. The effect of composition of electrolytes on characteristics of discharge was studied at different polarities of connection to the power source.

1. Introduction

Currently, there is an increased interest at gas discharges in gas-liquid systems in which liquid used as electrodes. They are plasma sources with great potential for practical applications. There are successful examples of applications in water disinfection technologies, synthesis of various functional materials, plasma activation of liquid reagents, environmental protection, as well as plasma medicine [1-4].

In most cases, studies are carried out in systems with a single liquid electrode, which serves as cathode or anode. It is difficult to obtain and maintain discharge between two liquids [5, 6]. Some information on discharges between two liquid electrodes is given in [7]. The general spatial structure of the discharges of constant and alternating currents is described. The electrodes used are industrial water and aqueous solution of copper sulfate. Current-voltage characteristics were obtained in current range of 15-1000 mA at atmospheric and low pressures. At atmospheric pressure, discharge between liquid electrodes is ignited inside a quartz tube.

In open air, discharges between two liquids were obtained in [8]. The authors used a system of two grooves as a discharge device, through which tap water flows down. The grooves are made of dielectric material and equipped with metal plates to which the poles of the power source are connected. A discharge was ignited between two streams of water. Studies were conducted with an interelectrode gap of 6 mm. The current was maintained within 60-65 mA. The voltage was ~ 1550 V.

The authors of [9–10] carried out studies in wider range of current variation (0.5–3.5 A). Plasma generators with structural elements made of porous refractory material have been developed. The cathode was liquid that seeped through porous barrier. It has been shown that the use of porous elements enhances the spatial stability of plasma column and allows one to significantly increase interelectrode distance (up to 25 mm when anode is located below and cathode is above). In this work, studies using these plasma generators are continued, and studies with plasma generators in other versions are also carried out.
2. Variants of plasma generators

In figure 1 shows the diagrams of plasma generators in which cathode assembly contains a porous insert.

![Diagram of plasma generators](image)

**Figure 1.** Linear (a) and coaxial (b) plasma generators. 1 - porous cathode insert; 2 - electrolytic bath; 3 - cylindrical current supply of the anode. The photo shows gas discharges created in various modes: (c) – I = 1.25 A, l = 15 mm; (d) – I = 1.5 A, l = 15 mm; (e) – I = 1.0 A. Electrolyte - tap water.

In linear plasma generator (figure 1a), anode is electrolytic bath 2 with capacity of 15 liters. The cathode assembly is located above bath. An electrolyte circulates through it. Part of electrolyte seeps through the porous insert 1. The discharge burns between wet surface of the porous insert and other electrolyte that bath is filled with 2. The porous insert is made of a fireproof dielectric. The binding zone of discharge occupies entire end surface of porous insert (figs. 1c and 1d). Moreover, this zone is heterogeneous, and consists of many separate bright dotted areas. They are clearly visible in mirror image on electrolyte anode. The photographs show that binding zone of discharge to anode is also inhomogeneous and distributed.

In a coaxial plasma generator (figure 1b), the electrolyte is fed into cylindrical current supply of anode 3 tangentially. It flows down, forming a thin film on surface of current lead. The electrolyte serving as cathode seeps through the porous insert 1. The discharge burns in the radial clearance. Gap width \( \Delta = 5 \) mm.

In figure 2 shows another embodiment of plasma generator. The designs of anode and cathode nodes are the same. The output channel 3 of the housing of these nodes is made in form of an extended narrow gap. Its length is 20 cm and its width is 3 mm. Case material - fiberglass. Inside the housings mounted metal current leads.
Figure 2. The plasma generator with two flowing electrolyte electrodes. 1 - body of electrode assembly; 2 - metal current lead; 3 - output channel, 4 and 5 - anode and cathode gas discharge zones. The discharge current is 3 A. The arrows indicate directions of flow of electrolytes. The electrolyte is an aqueous solution of sodium chloride with concentration of 0.5% by weight.

The electrolyte flows out of the gap 3 and flows down, forming a thin film on the surface of the housing. The anode 4 zone is removed from the gap and adjoins this film, while the near-cathode zone 5 starts from the exit edge of the gap (figure 2b).

3. Experiment
The plasma generators were supplied with electric power from three-phase two-half-wave rectifier. As liquid electrolytes, aqueous solutions of sodium chloride, sodium carbonate, potassium hydroxide and copper sulfate were used, as well as tap water.

In figure 3 shows the current-voltage characteristics of coaxial plasma generator obtained with various combinations of electrolytes as anode and cathode.

Figure 3. Current-voltage characteristics of coaxial plasma generator. Liquid electrodes: (a) - identical anodes and different cathodes; (b) - same cathodes and different anodes. Anode: 1, 2, 3 - tap water; 4 - Na₂CO₃ 1.0%. Cathode: 1 - tap water; 2 - NaCl 0.5%; 3, 4 - Na₂CO₃ 1.0%.

At identical anodes, the voltage $U$ largely depends on properties of electrolyte used as cathode (figure 3a). In the case of identical cathodes, the voltage $U$ is practically independent of properties of electrolyte used as anode (figure 3b). The same patterns are observed in the work of other plasma generators.

Liquid electrolyte is exposed to heat and bombardment by high-energy particles. Evaporation and atomization of electrolyte occurs. The electrolyte substance is partially transferred to discharge region. The regularities shown in current-voltage characteristics indicate that the substance is transferred significantly more from cathode side than from anode side.

The cathode is bombarded by heavy particles - ions. The anode is mainly supplied with a stream of light particles - electrons. Therefore, cathode is sprayed more intensely than anode. The sprayed substance is involved in formation of plasma and affects its properties. The photo in figure 2b
illustrates presence of these processes. As can be seen, near-electrode areas are painted in different colors, despite the fact that same electrolytes are used as electrodes. The near-cathode is yellow, and the near-anode is blue. Yellow color is formed due to emission of sodium atoms, which are transferred from electrolyte to plasma. This picture indicates intense receipt of sodium from electrolyte used as cathode.

4. Conclusions
Comparing options for plasma generators with two electrolyte electrodes, following can be noted. The coaxial version and the slotted channel option allow the use of electrolytes in a significantly wide range of concentrations. In this case, the substance is transferred to discharge region mainly from cathode. The plasma properties are almost completely dependent on electrolyte used as cathode.

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