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Installation for studying the interaction of electric discharge plasma with the surface of solutions

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The paper presents an installation for studying the interaction of electric discharge plasma with the surface of aqueous solutions. The installation implements an original system for maintaining an adjustable liquid level in a flow discharge cell. The special case when the solution level coincides with the edge of the discharge cell is most interesting for optical studies of the discharge. It is shown that in this case it is possible to obtain photographs of the plasma interaction area with the liquid surface that are not distorted by the superposition of plasma radiation reflected from this surface. The installation can be used for a wide range of studies of the interaction of electric discharge plasma with the surface of liquids, including using optical methods and emission spectroscopy methods.

Keywords: liquid level, liquid electrode, plasma, surface, electric discharge, high-speed photography, emission spectroscopy.

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Over the last two decades, there has been considerable interest in the study of the electrodischarge plasma interaction with the liquid surface, in particular with the surface of aqueous solutions. This interest is associated primarily with the prospects of practical application of such interaction. The areas of practical application of plasma interaction with liquid surface include water purification from organic compounds, spectral-emission analysis of metal ions in aqueous solutions, synthesis and polymerization of organic compounds in solutions, sterilization of aqueous solutions under the action of active particles and UV-radiation of electrodischarge plasma, synthesis of nanoparticles under the action of discharges in liquid, surface modification of polymeric materials in aqueous solutions, etc. [1–3].

The prospects of possible applications prompt the investigation of various aspects of plasma interaction with aqueous solutions [4–9]. Since aqueous solutions are electrically conductive, the most effective way to arrange the electrodischarge plasma interaction with the surface of the solution is to create an electric discharge, in which this solution acts as one of the electrodes. From the point of view of the study, the most convenient is a pin-to-plate system, i.e., the system in which the electric discharge is created between a rod metal electrode and a flat surface of the liquid [10]. In this case, any discharge areas are readily accessible for optical studies.

A specific feature of studying the interaction of plasma with aqueous solutions is the need to maintain the constant composition and temperature of the aqueous solution during the experiment. To do this, the experiments usually use flow tanks in which the solution is constantly renewed. At the same time, the setup should be organized so that the level of the solution in the area of interaction with the plasma remains unchanged. The usual system for maintaining the solution level, which represents the current scientific practice, is based on free pouring of the liquid supplied to the vessel over its edge [10].

However, this way of arranging the installation has several obvious disadvantages. First, such a system is inconvenient, because it requires a special vessel to collect the liquid overflowing over the edge. Secondly, the overflow of liquid over the edge is unstable and strongly depends on a slight change in the vessel inclination. Thirdly, the level of the solution is tied to the level of the edge of the vessel and cannot be adjusted in any way.

A less obvious but more important problem is that the surface of the solution is not flat everywhere in this arrangement. Near the edge of the vessel it is strongly curved, and since the surface of the solution at small incident angles of radiation has a high reflectance coefficient, this results in the formation of a rather bright reflected image of the discharge when imaging along the surface of the solution [4,10]. As a result, any optical measurements of the discharge area near the solution surface, whether for velocity imaging or spectral studies, are distorted because of the reflected image being superimposed on this area.

In order to overcome these problems, we have developed and experimentally tested a setup based on a completely different principle of maintaining the solution level. In the installation we have created, the solution was fed into a flowing tank with a free surface through one tube, and it was pumped out of this tank through another tube by a pump capable of pumping both liquid and gas. In this case, the pumping speed provided by the pump was higher than

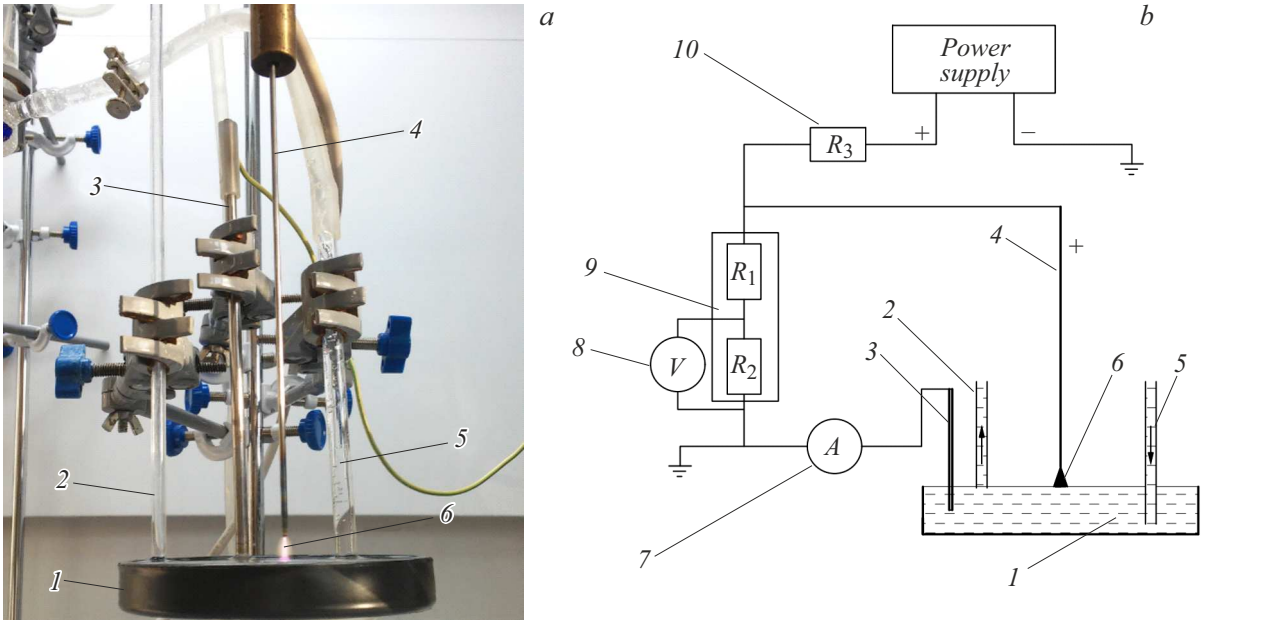

Figure 1. Experimental setup. *a* — photograph of the discharge part, *b* — diagram of the discharge part. *1* — flowing discharge cell, *2* — tube for feeding solution into the discharge cell, *3* — cathode, *4* — anode, *5* — tube for pumping solution out of the discharge cell, *6* — discharge, *7* — ammeter, *8* — voltmeter, *9* — voltage divider, *10* —ballast resistance.

the solution supply speed. As a result, the solution level in the flow tank was maintained exactly at the level of the solution suction tube tip. Changing the position of the tip of the solution suction tube allowed adjusting the position of the solution level in the tank with high accuracy (Fig. 1).

In our setup, the solution was supplied to the vessel by a peristaltic pump Lead Fluid BT601S, which allowed adjusting the feed rate within a wide range. In order to eliminate pulsations in the flow rate, at the outlet of the peristaltic pump two standard dampers of flow pulsations were placed in series. The solution was pumped out by a KNF Flodos NF 30 KPE diaphragm pump with a non-adjustable speed. The maximum pumping speed of the pump was 420 ml/min. It has been shown that the unit can maintain a stable solution level at pumping rates from 50 to 350 ml/min. In this case, neither the solution supply nor its pumping does not create noticeable perturbations on the liquid surface. It has been demonstrated that, at a given solution feed rate, the level of the solution in the flow-through container can be regulated with high precision by vertically adjusting the tip of the suction tube. When conducting discharge surveys, one of the electrodes of which was a solution (DC discharge with a liquid cathode), the solution surface in the discharge cell was placed at the level of the discharge cell edge so that the liquid surface remained flat throughout (Fig. 1, *a*).

A glass cylindrical vessel with a height of 14 mm and a volume of 100 ml was used as the discharge cell. The pumping rate of the solution was 330 ml/min, and the solution in the discharge cell was completely renewed in 18 s.

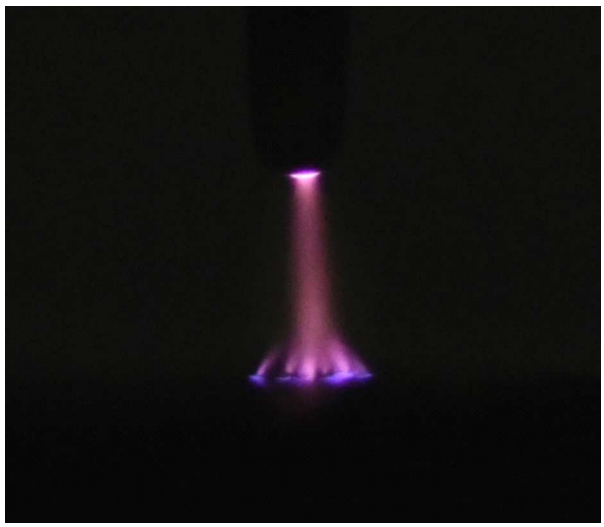

Figure 2. Photograph of the discharge with a liquid cathode. Discharge current 20 mA, discharge gap 4 mm, NaOH solution with electrical conductivity of 300 μS/cm. Exposure 125 μs.

The tungsten rod electrode with a diameter of 2 mm was located above the solution surface. Its position was adjusted by a micrometer screw. A constant positive voltage from a stabilized power supply was applied to this electrode through a ballast resistor. The second (grounded) stainless steel electrode was immersed in the solution (Fig. 1, *b*).

Rapid color photography of the discharge was carried out at a discharge current of 20 mA and a distance between the electrode and the solution surface of 4 mm. The shooting

was carried out along the surface of the solution using a Nikon D500 camera. The exposure time of one frame was 125 μs. The distance from the cathode spot on the solution surface to the discharge cell wall was about 10 mm. The wall of the discharge cell was darkened to avoid illumination from over-reflection of the discharge radiation inside the discharge cell (Fig. 1, *a*). NaOH solution in deionized water with a conductivity of 300 μS/cm was used for the experiment. The temperature of the solution at the inlet of the discharge cell was 14 ± 2°C. The result of high-speed photography of the discharge channel is shown in Fig. 2.

As the data of high-speed photography showed, the method used allowed obtaining a complete photograph of the discharge, including the area near the solution surface, with virtually no image reflected from the solution surface (Fig. 2). The photographs obtained by this method allow studying the interaction of the plasma with the solution surface (in particular, in a discharge with a liquid cathode, the features of filamentation of the discharge channel near the solution surface, as well as cathode spots directly on its surface).

Since, as the high-speed discharge photography shows, the reflection from the solution surface in this method of imaging is virtually absent, the described setup allows conducting studies of the emission properties of the electrodischarge plasma near the solution surface without distortions related to the reflection from the solution surface.

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Conflict of interest

The authors declare that they have no conflict of interest.

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