Gas discharge with liquid electrolyte cathode in the mode of occurrence of the constricted channels

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Abstract. Gas discharge between liquid electrolyte and a copper electrode at capacities that make up tens of kilowatts is experimentally investigated. As the liquid electrolyte we used the aqueous solution of sodium chloride. Identification of conditions of occurrence of the constricted channels. The electrical and spectral characteristics of the discharge in such conditions were studied.

1. Introduction
When using a liquid electrolyte as the cathode plasma is formed mainly of liquid-phase substance. Plasma properties and characteristics of the gas discharge is directly dependent on the chemical composition of the electrolyte, which is confirmed by a number of experimental studies conducted with various electrolytes in a wide range of current, interelectrode spacing, and other parameters [1-6]. By varying the electrolyte composition can be obtained plasma containing different chemically active components. The aim of this work was to study the characteristics of the gas discharge with liquid electrolyte cathode at occurrence a constricted channels that serve as additional sources of chemically active species, such as excited atoms, ions and electrons.

2. Experiment
The experimental setup is shown in figure 1. As the electrolyte were used saline solutions in distilled water. The electrolyte is flowed from the tank 1 in the form of a cylinder of diameter D = 75 mm in the vertical upward direction (figure 1). The current-carrying element was a graphite plate 2 placed inside the cylinder. Discharge was burning between the electrolyte 3 and the copper anode 4, cooled with tap water. The length l of the discharge gap was set in the range of 30 to 60 mm. On graphite plate and an anode was applied voltage from three-phase full-wave rectifier with an output voltage 3200 V. The pulsations voltage was smoothed with using LC-filter. Current regulation the discharge was carried by a stepwise change of the ballast resistor in the circuit of the electric power.

The concentration C and the electrical conductivity \( \sigma \) of the electrolyte was measured with conductivity meter ANION 4150. The current \( I \) and the voltage \( U \), applied to the plate 2 and the anode 4, were recorded with the oscilloscope AKIP-15/1. Instant images of the discharge were photographed with high-speed camera VIDEOSCAN-415.

The emission spectra were recorded using high-speed fiber-optic spectrometer AvaSpec-3648 in the wavelength range 484-708 nm with a resolution of 0.15 nm (diffraction grating 1200 lines / mm, the input optical gap of 10 microns). The image of the plasma column using converging lens \( L \)
projected entirely on the input fiber optic cable. High-speed video camera 5 and spectrometer 6 were operable associated with computers 7 and 8.

3. Results and their discussion

Emergence constricted channels in the discharge region contribute to reducing the concentration (respectively, conductivity) of the electrolyte. Figure 2 shows photographs taken at the time of occurrence of such channels.

Figure 2. General view of a gas discharge (left photo) and constricted channels: \( I = 12 \pm 0.5 \) A, \( l = 5 \) cm, \( \sigma = 2.0 \pm 0.1 \) mS/cm \( (C = 1.0 \pm 0.1 \) g/l), the exposure of 196 \( \mu \)s (the top row of the right) and 3 \( \mu \)s (bottom row of the right).

On the general form of a gas discharge, which was photographed with the maximum aperture, constricted channel stands out as a bright area (figure 2, left photo). Shots taken with the closed
diaphragm, have revealed the range of light images. As can be seen, unlike a yellow background radiation generated by sodium, constricted channels are allocated in a light-colored red (figure 2, the top row of the right). The image of the constricted channel is obtained in the form of complex, sinuous shapes with branches resting on the surface of the electrolyte. In the footage with less exposure, observed the same color throughout the length of the constricted channel. From the monotony of color implies that in the channel are numerically dominated by the excited particles of one kind. The most likely candidates for the role of such particles are hydrogen atoms because hydrogen gas is released at the cathode electrolysis processes and flows into the discharge region.

The photographs shown on the middle and lower ranks of figure 2, made with different exposure more than 60 times. Comparing them, we can conclude that the complex intricate images constricted channels (frames with a larger exposure) were formed with of stacking simple shapes (frames with less exposure).

The presence of radiating of hydrogen atoms have confirmed by spectral studies. In the emission spectrum of the gas discharge are the Balmer lines of hydrogen H\(_\alpha\) and H\(_\beta\), and at the moment of appearance of the constricted channels line H\(_\alpha\) acquired much more intense yellow D-line of sodium (figure 3).

![Figure 3. The emission spectrum of the gas discharge.](image)

Since the appearance and disappearance constricted channels occurs almost instantaneously, spectra were recorded without averaging with a minimum integration time in maximum performance mode spectrometer. In particular, for the spectrum shown in the figure 3 as an example, the integration time was 0.25 ms.

![Figure 4. Oscilloscope traces of currents and voltages:](image)
As follows from the oscillograms, parameters constricted channels vary significantly with decreasing ballast resistance. They occur more frequently and the maximum current through a single channel increases. At the same time in the change \( \Delta \tau \) any patterns not explicitly detected. In the moments of occurrence of the constricted channels voltage \( U \), registered between the anode and the current-carrying graphite plate is reduced.

An increase in current occurs because in case of constricted channel decreases the electrical resistance of the discharge region, respectively, and the total resistance of the circuit. For the same reason, i.e. because of the reduction in the total electrical resistance increases the maximum current in the constricted channel while reducing ballast \( R_{\text{ballast}} \). The presence of the emission spectrum of the hydrogen Balmer lines allows us to estimate the electron temperature \( T_e \) of the plasma in the constricted channel. As an example, the table shows the values of \( T_e \) calculated by the method of relative intensities. The emission spectrum of gas discharge used under the conditions: \( l = 5 \, \text{cm}, \sigma = 2,4 \pm 0,1 \, \text{mS/cm} \) \( (C = 1,2 \pm 0,1 \, \text{g/l}) \).

| \( \tau_{\text{int}}, \text{ms} \) | \( T_e, \text{K} \) |
|---|---|
|  | 1 | 2 | 3 | 4 | 5 |
| 0,12 | 4926 | 4980 | 5039 | 5178 | 5468 |
| 0,25 | 4209 | 4500 | 5091 | 5367 | 5677 |
| 0,50 | 4993 | 5039 | 5340 | 5747 | 6282 |
| 1,00 | 4298 | 5059 | 5607 | 5835 | 6451 |

Calculated values \( T_e \) fluctuate in considerably wide range. Apparently, the reason for such a wide difference in the \( T_e \) is that the signal integration spectrometer does not always coincide in time with the time of point of maximum discharge current. According to the calculated data the maximum current in the constricted channel is within the 5500 - 6500 K.

4. Conclusions

The experiments showed that the gas discharge burns in the mode of occurrence of the constricted channels continuously without time limitations. The power released in the discharge is in the range of tens of kilowatts. Thus, from the experiments it follows that the gas discharge in the combustion mode with constricted channels may serve as a plasma source for energy-intensive technologies.

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