High frequency electric discharge between jet and solid electrodes

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Abstract. The types and forms of combustion of electric discharges of high-frequency (HF) current with liquid and solid electrodes at atmospheric pressure are investigated. The discharge emission spectrum, plasma composition, electron concentration, and temperature of the heavy component are studied. Thermograms on the surface of liquid and solid electrodes during the combustion of the discharge are investigated.

1. Introduction
The physics and application of gas discharge plasma in systems without an electrode and in systems with traditional (solid) electrodes has been studied for a long time. The scientific foundations of these discharges are described in detail in the famous works of Yu.P. Reiser, S.V. Dresvina, V.L. Granovsky and others [1-3].

In the last 30 years, discharges generated in plasma-liquid systems have found increasing interest in research. In plasma-liquid systems, an electrical discharge is ignited in the interelectrode gap, where one or two electrodes are a flowing or non-flowing fluid. As a liquid electrode, as a rule, neutral solutions of salts in industrial, distilled or tap water are used. Plasma-liquid systems are of interest in the field of fundamental and applied research. Today, these systems are successfully used for surface treatment of products of various physical nature, functional coating, and water and air purification.

The scientific works of specialists from Russia are known in this area (Akishev Yu.S., Belkin P.N., Gaysin F.M., Gilmutdinov A.Kh., Duraji V.N., Kashapov N.F., Lazarenko B.R., Lebedev Yu.A., Maksimov A.I., Rybkin V.V., Slovetsky D.I., Son E.E., Titov V.A., Shkolnik S.Sh., and others) and foreign countries (Andre P., Bruggeman P., Faure G., Jedlovsky I., Kaplan V., Krcma F., Kushner M., Leys C., Lefort A., Machula Z., Norberg S., Pongrac B., Vacher D., et al.). However, despite the large stratum of experimental and theoretical work [4 – 17], “white spots” remain in this field of science. For example, the electrical discharges of RF current in systems with flowing and non-flowing liquid electrodes are not sufficiently studied.

The aim of this work is experimental studies of high-frequency jet discharge with liquid and solid electrodes at atmospheric pressure. The results of experimental studies can be used both for constructing various mathematical models for the quantitative or qualitative interpretation of the data obtained, and
for engineering methods for calculating plants and processes for the implementation of plasma-liquid RF discharge systems in a practical plane.

2. Experiment
To solve the tasks set in the work, modern research methods and approaches were used, as well as diagnostic equipment:

1. A study of the forms of electric discharge burning was carried out using high-speed video recording on the Casio EX-F1 aperture, with a video recording speed of 600 and 1200 frames per second. To suppress the intrinsic luminescence of the plasma, a DKSSh-250 arc xenon lamp with a power of 250 W was used.

2. The emission spectrum of the discharge plasma was determined by a PLASUS EC 150201 MC optical fiber spectrometer with a collimator for fixing light rays in the wavelength range from 195 to 1105 nm. The minimum width of single optically thin lines was Δλ_g = 1 nm, which is taken as the hardware width. The radiation under study was collected from the discharge volume, and the composition and components of the plasma were estimated without reference to a specific area. The spectrum was decoded by identifying the lines by comparing the experimental spectrum with the international database of the National Institute of Standards and Technology.

3. The vibrational and rotational temperatures of the molecules were estimated by comparing the experimentally recorded spectrum with the calculation model in the LIFBASE and Specair 2.2.0.0 software packages.

4. Infrared thermography of the electrode surface in the discharge burning zone was carried out with the FLIRA 6500 SC thermal imager, and the ALTAIR v.5.91.010 software was used to process the obtained data.

Some forms of combustion of an electric discharge of an RF current between a jet and solid electrodes at atmospheric pressure are presented in Fig. 1.

![Figure 1 - Combustion of an electric discharge of an RF current between a jet and solid electrodes, at a voltage of U = 1.5 - 2 kV, the diameter of the jet d = 3 mm, jet length l = 30 mm, jet velocity v = 0.15 m/s, pressure p = 10^5 Pa, where the jet is a 7% solution of NaCl in tap water, and the solid electrode is a M1 brand copper plate.](image)

The jet electrode is supplied from an electrolytic cell with a free surface, the flow is pressure less. Depending on the parameters of length, diameter and speed, the jet can flow in the form of a continuous jet or with the corresponding sections of the decay (thinning) of the jet. The region of decay (thinning) of the jet arises regardless of the nature of the current flowing along the jet. With a decrease in the radius of the stream, the current density in the stream increases according to the known dependence \( j = I / (\pi R^2) \), where \( R \) is the radius of the stream. An increase in the current density leads to the heating of the jet to the boiling point with the formation of a gas-vapor bubble. It can be seen from the thermogram (Fig. 2) that the temperature of the medium reaches \( T = 130 ^\circ C \), which corresponds to the high-density gas and temperature region. This leads to a voltage jump with the formation of an electromagnetic field.
pulse. At the interface between the media, a region of intense mixing of the liquid, gas, and RF plasma is formed. 

Figure 2 - Temperature distribution on the surface of the jet electrode during the combustion of an RF discharge at atmospheric pressure.

The radiation spectrum of the RF discharge between the jet and solid electrodes was studied, from which it follows that in the studied plasma region there are atoms (sodium Na I, oxygen O I, potassium K I, calcium Ca I), molecules (hydroxyl OH and molecules N$_2$+) and ions (calcium Ca II) of various names. The electron concentration in the plasma of the RF current discharge with the jet and solid electrode was estimated by analyzing the contour H$_{\alpha}$ and H$_{\beta}$ of the Balmer series hydrogen line and turned out to be $n_e = 4.3 \pm 0.5 \times 10^{16}$ cm$^{-3}$.

The vibrational $T_\nu$ and rotational $T_r$ temperatures were determined by comparing the molecular spectrum with the model one for the N$_2$+ molecule. As a result, the temperature for the molecular band N$_2^+$ turned out to be $T_\nu = T_r = 2600$ K.

3. Conclusion

1. The composition of the plasma is determined by the discharge of the RF current, the electron concentration $n_e = 4.3 \pm 0.5 \times 10^{16}$ cm$^{-3}$, the vibrational and rotational temperatures of the molecular band for N$_2^+$ are $T_\nu = T_r = 2600$ K.
2. The types and forms, as well as the mechanism of ignition and combustion of electrical discharges of the RF current between the jet and solid electrodes at atmospheric pressure, are established.
3. It was found that the temperature of the medium in the region of burning of the RF discharge reaches $T = 130$ °C, which corresponds to the high-density gas and temperature region.

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