Electrophysical and thermal characteristics of gas-vapor discharge with liquid electrodes

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Abstract. Within this work the results of experimental studies of low temperature plasma of gas-vapor discharge frequency (RF) and direct current with the liquid electrodes in the range pressures \( p = 10^5 – 10^2 \) Pa are presented. Current oscillations and combined-discharge voltage are set. Estimates on distribution of temperature fields at the limits of division of mediums in the zone of formation of the vapor-gas discharge are given.

1. Introduction
With studies gas discharges with metal electrodes a great interest for specialists is gas-vapor discharge, lighted in the electrode gap with one or between two liquid electrodes. Steam-gas discharges with one electrode liquid have been known for a long time, while the steam-gas discharge, lighted between two liquid (non-metallic) electrodes began to be explored rather recently. However, the steam-gas discharge from the liquid electrodes may be used successfully for various processing solutions and socially significant problems. In industry steam-gas discharge can be successfully used for forming a microrelief outer and inner surfaces of products of different physical natures, the application of functional coatings or to obtain fine metal powders. In ecology and the health care the steam-gas discharge may be used as a source of charged particles for skin disinfection, water and air purification.

2. Experimental plant
Investigation of the plasma gas-vapor discharge RF and DC currents with decreasing pressure was carried out in the experimental plant (Figure 1) to the gas-discharge chamber (Figure 1b), where: 1 - the power source; 2 - a vacuum chamber; 3 - VTI vacuum gauge marks 1218; 4 - valve for air injection; 5 - the working area to the discharge chamber; 6 - rotary vane pump mark "5DM-2NVR"; 6 - the electrolyte solution; 7 - stream of liquid; 8 - a metal plate for the supply potential in the electrolyte; 9 - tube jet discharge liquid. As a power source for lighting the gas-vapor discharge RF current applied RF generator mark "VCHG8-60 / 13" tuned to a frequency \( f = 13,56 \) MHz controlled voltage to 10 kV. For gas-vapor discharge lighting a DC constant current generator is used that supplies the regulated DC voltage to 4 kV at rated current to 10 A. The lighting and gas-vapor plasma discharges study RF and DC current was carried out with established parameters: tension \( U = 0,1 – 5 \) kV pressure \( p = 10^5 – 10^2 \) Pa, jet flow speed \( v = 0,05 – 0,6 \) m/s, jet length \( l = 10 – 25 \) mm and diameter of the jet \( d = 3 – 5 \) mm between the jet liquid and the electrodes.
To achieve the objectives modern complex diagnostic equipment and techniques are applied:

1. To study the distribution medium temperature fields in the plasma discharge vapor-gas combustion zone imager brand «FLIRA6500SC» was applied. Software «ALTAIR v5.91.010» was used for data processing.

2. Investigation of oscillations of current and voltage by a vapor-gas discharge was carried out by digital oscilloscopes brand «GDS - 806S» and «AKTAKOM ASK-2067” with a high frequency voltage divider mark “Electronics R6015A”. Measurement of the potential $\phi$ was made by using the electrostatic voltmeter C50.

3. The discussion of the results
The analysis of waveforms of current and voltage fluctuations in the vapor-gas discharge DC (Figure 2) shows that the discharge $U = 700$ V is generated in the form of current pulses in the range of $I \approx 1 - 2.5$ A with a frequency $v = 50 - 100$ Hz and voltage drop to 600 V, where the pulse width $\tau \approx 4 - 6$ ms is corresponded to the lifetime of the discharge in the expanding vapor-gas bubble (Figure 2a).
Figure 2. Fluctuations in current and discharge voltage between the gas-steam jet anode and liquid cathode (a, b) and between the liquid jet cathode and anode (c, d): $\Delta U = 700$ V, $\Delta I = 2$ A, $\Delta t = 10$ ms

With setting it increases $I \approx 0.8 - 1.0$ A decreases $\nu = 40 - 70$ Hz, the current pulse width changes slightly (Figure 2b). Deposited in a combined-cycle discharge capacity is $P \approx 1 - 4$ kW.

In the second variant of the generation of steam and gas discharge DC liquid electrodes have their own characteristics of combustion discharge. Depending on the parameters of the jet electrode the discharge can burn as the first variant of the electrode configuration in two zones of the system. With the plant $U = 600$ V of a breakdown occurs with the combustion discharge $I \approx 0.5 - 2.0$ A, $\nu = 100 - 200$ Hz, increases to 30 ms (Figure 2c). When illuminated with $I \approx 0.8 - 1.0$ A, $\nu = 40 - 70$ Hz capacity put in discharge is $P \approx 1 - 4$ kW.

From the analysis of waveforms of current and voltage fluctuations in the vapor-gas discharge RF current (Figure 3) is followed that with $l_c \approx 23$ mm and $p = 10^5$ Pa the amplitude of the current $I_{\text{max}} \approx 19$ A and voltage $U_{\text{max}} \approx 850$ V in areas corresponding to discharge combustion (Figure 3a), current values of current $I = 13$ A and voltage $U = 601$ V respectively.

Since the pressure lowered $p = 10^3$ Pa with the same parameters of length $l_c$, diameter $d_c$ and flow rate $v_c$ of the jet of the electrode amplitude values of current $I_{\text{max}} \approx 14$ A and voltage $U_{\text{max}} = 700$ V (Figure 5b) of the current $I = 10$ A and voltage RMS values $U = 495$ V respectively. Taking into account the phase difference between current and voltage at an angle $\phi \approx 60^\circ$ invested in combined-cycle power RF discharge current is in the range $P \approx 2.5 - 3.9$ kW.

Figure 4 shows photographs of the temperature distribution along the liquid fields electrode. With the development of combined cycle DC discharge between the electrodes of the liquid jet and the
temperature at the boundary between the jet and stagnant liquid electrodes varies in a range $T = 39 - 104 \, ^\circ C$ (Figure 4a).

Figure 4b shows the temperature distribution of the field along the vapor-gas bubble generated before the breakdown and the development of steam and gas discharge from the jet break, the temperature varies $T = 83 - 102 \, ^\circ C$. On Figure 4c representation of the temperature along the gap of the interelectrode gap and after the break of the jet is seen that the surface temperature of the jets $T = 100 \, ^\circ C$. Figure 4d shows the distribution along the jet temperature fields along the jet electrode. In the case of vapor-gas jet along the discharge $T = 63 - 109 \, ^\circ C$.

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**References**
[1] Gysin F M and Son E E 1989 Electrical discharges processes in solid and liquid electrodes (Sverdlovsk: in Uralsk. University Press) 432 p.
[2] Gysin Al F, Son E E, Petryakov S Y 2017 The high frequency capacitive discharge electrodes with flowing liquid at low pressure *Plasma Physics* 43 7 pp 625-633
[3] Akishev Yu S, Grushin M E, Karalnik V B, Monich A E, Pan'kin M V, Trushkin N I, Kholodenko V P, Chugunov V A, Zhirkova N A, Irkhina I A and Kobzev E N 2006 Creating a nonequilibrium plasma in environments heterophase gas-liquid at atmospheric pressure and demonstrating its ability to sterilize *Plasma Physics* 32 12 p 1142