The influence of the method of cooling liquid electrolyte cathode on the energy balance in the gas discharge

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Abstract. Experimentally investigated the energy balance in a gas discharge between a flowing electrolyte cathode and a metal anode at an power of tens of kilowatts. The discharge was burning in the air in the electrode gap with a height of 10 cm. The electrolyte was a solution of salt in distilled water. The concentration of the solution by weight was 5.5 g/l. The regularities of the influence of electrolyte mass flow through the flowing cathode on the energy characteristics of the discharge were studied. The modes of the discharge, whereby the energy balance of the portion of heat losses for heating of the electrolyte reaches a minimum were identified.

1. Introduction
Gas discharges with liquid electrolytic electrodes have a sufficient range for practical applications. They are promising for use in such processes as bacteriological water purification [1], the treatment of textiles in aqueous solutions [2], plasma-electrolytic processing of materials [3], the receipt of ferromagnetic powders [4]. In the power ranges that comprise tens of kilowatts, the gas discharge with liquid electrolyte cathode may serve as a source of energy in the plasma technologies for processing wastes [5].

With a large contribution to energy in the gas discharge liquid electrolyte it is heated and there is a need for cooling. Heating occurs due to the Joule heat within the electrolyte and the energy input from the gas-discharge plasma. The heat exchange between the electrolyte and the plasma takes place in difficult conditions. The electrolyte is evaporated and subjected to sputtering. In these conditions the cooling effect of the electrolyte significantly affects the energy characteristics of a gas discharge, which was experimentally found in [6] at currents of 7-22 A and the power of 8-33 kW. In particular, a reduction in thermal losses in flow of the cathode with decreasing mass flow rate of the electrolyte was shown. In this paper, we continued the study with a smaller flow of electrolyte in the zone of contact with the discharge.

2. Experiment
The experiments were performed on the installation, which was used in [6]. Part of constructive changes has been made in the gas-discharge unit. The cylindrical vessel 1, which implies the electrolyte was divided into horizontal partition 2 into two parts (figure 1). Such modernization is
allowed to carry out experiments in the maximum permissible conditions under which the electrolyte flows from the neck of a cylindrical vessel with a temperature very close to 100 °C.

![Figure 1. Gas-discharge unit. 1 - cylindrical vessel, 2 - partition, 3 - liquid electrolyte, 4 - current lead, 5 - anode, 6 - thermocouple, 7, 8, 9 - collecting tank.](image)

Joule heat generated inside the electrolyte, was calculated by the formula

\[ Q_j = I \cdot \Delta U_k, \]

where \( \Delta U_k \) – the voltage drop within the electrolyte, measured with a probe technique.

The calculations of heat loss from the heat capacity of the electrolyte was taken as that of water. Mass flow through the upper and lower portions of the cylindrical vessel, respectively \( m_1 \) and \( m_2 \), were measured and monitored by a float rotameter. The numerical values of thermal losses in heating the electrolyte escaping through the neck of the cylindrical vessel, calculated by the formula

\[ Q_{k1} = c \cdot (m_1 - G) \cdot \Delta t_1, \]

where \( G \) – is the mass loss rate of the electrolyte under the influence of a gas discharge, \( \Delta t_1 \) – the difference between the temperature which detected by a thermocouple, one of which is installed at the entrance of the cylindrical vessel and the other in the collecting tank 10 (figure 1), which receives the electrolyte.

3. The results of experiments, their processing and discussion

In figure 2 presented the diagram characterizing the energy balance in a gas discharge with different values of mass flow rate \( m_1 \).

![Figure 2. Heat losses at the electrolyte cathode in the energy balance of the gas discharge. The total flow of electrolyte \( m = 30 \text{ g/s} \). (a) – according to [6]; (b) \( m_1 = 10 \text{ g/s} \); (c) – 5. Discharge current: (a) \( <I> = 21.5 \text{ A} \); (b) – 18.1; (c) – 8.6.](image)
The diagrams are built on experimental data obtained at zero value of the ballast resistor. In this case in addition to gas discharge devices the power source had no other external loads. Therefore, in all considered cases, the terminal voltage of discharge device was the same.

As can be seen from the diagrams, with decreasing mass flow of the flowing electrolyte, the portion of heat losses in the energy balance does not changing monotonically. At first it decreases and then increases slightly.

Part of the heat losses is Joule heat $Q_j$, which are generated within the electrolyte. In the presented diagrams there is a decrease in its share the energy balance. This situation is quite natural, since in these embodiments, a decrease in the mass flow of the electrolyte is accompanied by a decrease in the discharge current.

Changing the current by varying the mass flow rate of the electrolyte takes place at a constant voltage applied to the terminals of a gas discharge device. It can therefore be clearly confirm, that the discharge current is affected substantially by thermal phenomena on the electrolyte cathode.

At higher currents the electrolyte heats up and comes to a boil. The bubbles of steam which escaping to the surface is tearing discharge of the electrolyte. The area of contact of the discharge with the electrolyte in a liquid state is reduced. Apparently, due to such phenomena, there is a current limitation.

Boiling of the electrolyte leads to a complete break of current channels, and the discharge is extinguished when the current reaches some limit value. Thus, the smaller the mass flow rate of the electrolyte, the lower the value of current limit.

![Figure 3. Waveforms of the currents and voltages. $m = 30$ g/s. (a) $- m_1 = 10$ g/s; (b) $- 5$.](image)

The occurrence of instability of the burning discharge at low mass flow rate of the electrolyte was recorded on the waveforms of currents and voltages. In figure 3 shows waveforms obtained at two different mass flow rates of the electrolyte. As can be seen, with less consumption of electrolyte, vibration amplitude current and voltage is increasing.

The appearance of instability of combustion of a gas discharge at low flow rates of electrolyte was recorded on snapshots. In figure 4 is showed photos taken at two different mass flow rates of the electrolyte. As can be seen, at low flow rate of the electrolyte contact of the discharge with the electrolyte drastically changes its geometry and is moved across the surface of the electrolyte.

Thus, the mass flow rate of the electrolyte can be reduced only to a certain limit. At the same time measures should be taken to prevent boiling of the electrolyte in the binding zone of discharge.
4. Conclusions

The energy balance in the gas discharge with flowing electrolyte cathode essentially depends on the mass flow of the electrolyte. By varying the mass flow rate of the electrolyte can reduce heat loss at the cathode and reduce their share in the energy mix to 10 - 15% at the same time maintaining stable operation of the discharge.

References
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Figure 4. Snapshots of the gas discharge. The exposition is 200 µs. The interval between frames 125 ms. $m = 30$ g/s. (a), (b) $m_1 = 10$ g/s and $<I> = 18.1$ A; (c), (d) $5$ and $8.6$. 