The influence of the mass flow rate of the electrolyte through the following cathode on the energy characteristics of the gas discharge

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Abstract. Experimentally investigated the energy characteristics of the gas discharge between the flowing electrolyte cathode and a metal anode at a current 7 – 22 A and capacities 8 to 33 kW. It is found that when changing the mass flow rate of the electrolyte through the flowing cathode, it is possible to adjust the combustion mode of the discharge and to receive a stream of steam plasma with average mass temperature of about 3000 K.

1. Introduction
Gas discharge with liquid electrolyte cathode is of practical interest as a source of nonequilibrium atmospheric pressure plasma. Such a plasma can be promising for the creation of high-temperature vapor-gas medium in the plasma-chemical reactors designed for energy-intensive plasma technologies, in particular for the conversion of hydrocarbons into synthesis gas [1, 2]. For rational use of gas discharge in practice it requires detailed energy characteristics and laws of their change in technologically acceptable intervals power. The aim of this work was to obtain a gas discharge with electrolyte cathode in such capacity and study the influence of the mass flow rate of the electrolyte on its energy characteristics.

2. Experiment
The flowing cathode consisted of a cylindrical vessel 1, from which flowed the electrolyte 2. The outer diameter of the vessel 1 was 75 mm and inside it was mounted graphite plate 3 for the supply current. The experimental setup is shown in figure 1.

The discharge was ignited between the liquid electrolyte 2 and the metal anode 4. The distance l between them was 10 cm. Power supply was served from a three-phase full-wave rectifier connected to the secondary winding step-up transformer. The pulsations of voltage were smoothed with using C-L-C filter. The current is changed stepwise variation of the ballast resistor R. To measure the electrical parameters used equipment and methods, are described in detail in work [3].

The electrolyte used was a solution of sodium chloride in distilled water with a mass concentration of 5.5 g/l. This concentration of electrolyte required to ensure the sustainability of the discharge at
high currents. Due to alkalization of the electrolyte due to the electrolysis process, was made adjustments to its electric conductivity $\sigma$ is the before beginning each experience. Measurements $\sigma$ were carried out on conductometer ANION 4150. The duration of the experiments were chosen so that the increase $\sigma$ shall not exceed 5 percent of its original value, which was 10 mS/cm. To reduce $\sigma$ was added distilled water.

![Figure 1. The experimental facility.](image1)

Heat $Q_h$ spent on heating of the electrolyte was determined by calorimetric method. The electrolyte temperature was measured chromel-alumel thermocouples 5 and 6, one of which was mounted at the upstream end of the cylindrical vessel 1 and the other on the small tank 7 located underneath. The electrolyte flowing out of the cylindrical vessel 1 almost fully fall into this small container 7, and then drained into the reservoir 8. Removal of heat from the electrolyte was carried out by passing it through a heat exchanger 9, water-cooled. A frequency converter 11 changed the number of revolutions of the motor M of the hydraulic pump 10. In this way ensured the continuity of mass flow rate electrolyte $m$ through the flowing cathode. Pre experimentally was obtained the dependence $m$ from frequency of rotation via frequency converter.

The amount of electrolyte was carried away from the circulation system during the combustion of the gas discharge, but was offset by the addition of distilled water from the feed tank 12. The flow rate of valve 13 was set so that the level of electrolyte in the tank 8 was on the same height. The consumption of distilled water was determined according to the testimony of the float flowmeter 14 and it was adopted for the mass flow rate of the gas mixture $G$ entering in the discharge region between the cathode and the anode.

3. Results and their discussion

![Figure 2. Oscillograms of current and voltage. $m = 20$ g/s; $R = 0$.](image2)
Figure 2 shows oscillograms of the discharge current $I$ and voltage $U$, which were supplied to the terminals of the cathode and anode. It is seen that both of these parameters are exposed to pulsations. As was established in [4], such low-frequency pulsations with significant amplitudes caused by the change of the shape and size of the plasma column open discharge. Due to the presence of pulsations in the graphical representations of experimental results were used average values of the parameters. In the figures and in the text they were denoted with common signs in the form of angle brackets.

![Figure 2](image)

Figure 3. Dependencies on the discharge current, the voltage at the terminals of the electrodes ($a$) power consumption ($b$), the heat losses at the cathode ($c$), the proportion of thermal losses at the cathode in the energy balance ($d$), the increment of temperature of the electrolyte ($e$) and the mass velocity loss of electrolyte ($f$). $m = 10 \text{ g/s}$ (bright circles) and $m = 30 \text{ g/s}$ (dark circles).

The voltage measured at the terminals of the cathode and the anode consists of a voltage drop in the electrolyte $\Delta U_k$ and voltage in the discharge gap. The values of the $\Delta U_k$, measured with different $m$, practically coincided (figure 3a). Therefore, from the comparison of the graphs of the dependence of $<U>$ and $<I>$ clearly showed that reducing the mass flow of the electrolyte leads to an increase of the
voltage in the discharge gap. The total power consumed in the discharge gap and the inside of the electrolyte (Joule heat) increases slightly (figure 3b). The change in m has virtually no effect on the power Joule heat dissipation \( Q_j \) inside of the electrolyte (figure 3c), and thermal losses at the cathode \( Q_k \) significantly reduced with decreasing \( m \). This means that at a small mass flow of electrolyte takes less heat from the discharge zone. The cost of heating of the electrolyte reduces and their share in the energy balance decreases (figure 3d). Previously, this pattern was identified in \[5\], which studied gas discharge generated under other conditions differ substantially from conditions in this work. It is noteworthy that with decreasing \( m \), the proportion of heat losses in the energy balance becomes almost the same as the arc water-steam plasmatron [6].

As expected, for small \( m \), the electrolyte is heated to higher temperatures (figure 3e). This significantly increases the amount of electrolyte carried away from the circulation system, ie, increased mass flow rate of electrolyte loss \( G \) (figure 3f). Basically, the decline is due to the electrolyte spraying and evaporation under the influence of the gas discharge in the area of its binding to the cathode. Therefore, the value \( G \) may be considered as a stream of plasma-forming substance. In this embodiment, to simplify the enthalpy of the medium in the plasma column above the electrolyte can be calculated from the formula:

\[
i = (<N> - Q_i)/G.
\]

Because the electrolyte is weakly concentrated (mass fraction \( \sim 0.055\% \)), we can assume that the as plasma-forming substance is used mainly water vapor and calculation results \( i \) can be attributed to the water vapor plasma. Comparison of calculated values of \( i \) with data presented in [7] for steam plasma, allowed us to estimate the mass-average temperature in the plasma column between the cathode and the anode. Its maximum value was within 3000-3200 K.

4. Conclusions
Reducing the mass flow of the electrolyte through the flowing cathode can reduce heat loss and increase the efficiency of electrical energy to create a plasma.

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