Formation of powerful plasma flow from substance of liquid electrolyte cathode

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Abstract. The process of plasma flow formation using an electric discharge with liquid electrolyte cathode in the power range (25–39) kW was experimentally investigated. The discharge was created inside the chamber with walls of refractory material at a distance of 20 cm between electrodes. Sodium chloride aqueous solutions with concentrations of 0.1–0.2 mol·l⁻¹ were used as electrolyte. The optimal conditions are revealed under which the heat losses on the electrodes are reduced. Plasma stream with a mass rate of 1.0–1.7 g·s⁻¹ was obtained.

1. Introduction
The plasma is formed predominantly from a liquid phase substance when using liquid electrolyte as a cathode. Such plasma is promising for creating a high-temperature vapor-gas medium in plasma-chemical reactors designed for energy-intensive plasma technologies. For example, in works [1, 2] the possibility of using gas discharge with liquid electrolyte cathode for processing waste polymeric materials were shown. An experimentally was investigated two-stage process. In the first stage, waste was subjected to thermal destruction, and in the second stage, conversion to synthesis gas was carried out. The power of electric discharge used in second stage of the process was 20–25 kW. The discharge burned in a small vertical gap between the liquid electrolyte and the metal electrode. The gap was formed due to the extrusion of electrolyte from the discharge region. Its height was within 3–4 mm. Such circumstances complicated the introduction of reagents into the discharge area. Therefore, the products of thermal destruction of polymers were fed into the plasma stream at a considerable distance from discharge area. This problem can be significantly simplified by increasing the geometrical dimensions of the discharge area. In this regard, the purpose of this work was to study the processes of formation of a powerful plasma flow when an electric discharge is excited at large interelectrode distances. In the open air, such discharges are obtained and partially investigated in [3–7]. Aqueous solutions of sodium chloride were used as electrolyte. Experimentally identified modes of stable burning in the interelectrode distances up to 20 cm in the current range 5–25 A. the Results obtained in [3–7] considered in the development of the plasma generator in this work.
2. Experiment

In figure 1a shows a plasma generator circuit. Its main elements are the cathode assembly 1, the anode 2 and the discharge chamber consisting of the housing 3 and the lining 4. A detailed description of the cathode assembly is given in [7]. The arrows indicate direction of flow of the electrolyte. Part of electrolyte is sprayed from open surface and is spent on the formation of plasma flow 5. The interelectrode distance \( l \) is 20 cm. The anode is copper rod with diameter of 25 mm. It is cooled by water. Its position is fixed with different projections \( \Delta \) inside the discharge chamber. Housing 3 of discharge chamber is made of asbestos-cement materials, and lining 4 is made of refractory bricks.

Figure 1b shows a photo of plasma generator in action. As seen plasma flow in the form of a glowing flame comes out of generator.

![Figure 1. Plasma generator: scheme (a) and photo (b).](image)

Aqueous solutions of sodium chloride with concentrations in the range of 0.1–0.2 mol\( \cdot \)l\(^{-1} \) were used as a liquid electrolyte cathode. At such concentrations, stable discharge burning is ensured at large interelectrode distances [3, 4]. In the process of burning discharge, the chemical composition of electrolyte changes. The electrolyte loss was compensated by the addition of distilled water during the operation of plasma generator. At the same time, despite change in chemical composition, the specific electrical conductivity \( \sigma \) of electrolyte remained almost unchanged. Therefore, this quantity \( \sigma \) was controlled in experiments.

The power source was a three-phase full-wave rectifier connected to the secondary windings of a step-up transformer. The voltage ripples was smoothed with a C-L-C filter. The current was changed by the stepwise variation of the ballast resistor. It should be noted that the ballast resistor is not a required element in the electrical supply circuit. Plasma generator has an increasing current-voltage characteristic and, therefore, its operating modes were stable with zero electrical resistance of the ballast resistor.

To study the thermal and electrical characteristics of the applied methods described in [5, 7]. The temperature in plasma flow was measured with a platinum-rhodium thermocouple PR-30/6 at different distances \( z \) from the anode. The thermocouple was moved with help of the coordinate device in three mutually perpendicular directions.

3. Experimental results and their analysis

Figure 2 shows oscillograms of current \( I \) and voltage \( U \) at plasma generator at two different flows \( m \) of electrolyte through the zone of reference of discharge to the cathode. It can be seen that both of these parameters are subject to pulsations. Moreover, the ripple current has a significant amplitude. Such pulsations are also characteristic of a discharge that burns in an open atmosphere [7].

Experiments have shown that with increasing current the amplitude of its pulsations was decreases. The same pattern was observed when the flow \( m \) of electrolyte increased through zone of binding of
discharge to cathode. Thus, an increase in current $I$ and electrolyte flow $m$ contribute to an increase in the stability of the process of plasma flow formation.

Figure 2. Current and voltage oscillograms. $\sigma = 8.8 \text{ mS-cm}^{-1}$. (a) – $m = 10 \text{ g-s}^{-1}$; (b) – 17.

In the operation modes of the plasma generator with zero electrical resistance of the ballast resistor, another regularity was revealed. By increasing the flow of electrolyte $m$ flowing through the zone of binding discharge to cathode, there is an increase of current (figure 3a). In practice, this pattern can be used to control the current at a constant voltage at the terminals of plasma generator. On the other hand, the presence of such a pattern imposes rather stringent requirements on the electrolyte supply system to the cathode assembly. Measures should be taken to exclude abrupt changes in the flow $m$ of electrolyte through the binding zone of discharge to the cathode.

Figure 3. Dependencies of the discharge current (a) and the mass rate of electrolyte loss (b) on the electrolyte flow flowing through the discharge binding zone to cathode. $I = s = 10 \text{ mS-cm}^{-1}$; $2 – 16$.

One of the main parameters affecting the formation of plasma stream is the consumption of the plasma-forming substance. In this variation, plasma is formed from an electrolyte substance. Its mass flow rate is equal to the loss of electrolyte in the hydraulic system of the experimental setup. The experiments showed that the mass loss rate of $G$ depends on the flow of electrolyte $m$ through discharge binding zone to cathode (figure 3b). The presence of such a dependence is due to the interaction of plasma and electrolyte. This is one of the features of the formation of a plasma stream using plasma generator with a liquid electrolyte cathode.

Inside the electrolyte at the cathode Joule heat is released. The electrolyte heats up. Part of the energy supplied to cathode from plasma also goes to the heating of electrolyte. This is how heat loss at the cathode is formed. They can be reduced by reducing the electrolyte flow $m$ through the binding zone of discharge to cathode [7]. This method was used in this work. However, reducing heat loss at the cathode to a minimum is impractical because it leads to modes with high current pulsations. Experimentally established stable modes in which the power of heat loss $Q_k$ at the cathode is in the range of 12–15% of the electric power supplied to the plasma generator.
The heat loss at the anode was reduced by shortening the protrusion \( \Delta \). However, when using short anodes \((\Delta < 30\;\text{mm})\) the discharge was unstable. In stable operation modes of the plasma generator, the heat loss power \( Q_A \) at the anode was 7–10% of the electrical power supplied to the plasma generator. Thus, thermal efficiency the plasma generator excluding heat losses through the walls of the discharge chamber was in the range of 0.75–0.80.

According to the results of spectral studies, the gas in an electric discharge with a liquid electrolyte cathode is heated to 2300±100 K. Such temperatures exceed the limits of measurement of a platinum-rhodium thermocouple. For this reason, temperature measurements using a thermocouple were possible at a considerable distance from the output of the plasma generator. In the investigated power range (25–39 kW), the temperature was within 1900±100 K at a distance of \( z = 45\;\text{cm} \).

4. Conclusions
Plasma flow from liquid electrolyte substance was obtained. The process was implemented under the following conditions: 1) liquid electrolyte – an aqueous solution of sodium chloride with a concentration of 0.1–0.2 mol\textsuperscript{-1}; 2) flow of electrolyte through the binding zone of discharge to the cathode was 10–20 g\textsuperscript{s\textsuperscript{-1}}; 3) interelectrode distance 20 cm; 4) power supply – full-wave rectifier with step-up transformer; 4) voltage applied to electrodes 1780±20 V; 5) discharge current 14–22 A.

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References
[1] Fridland S V, Tazmeev A Kh, Miftakhov M N and Tazmeev Kh K 2006 *Vestnik mashinostroeniya* 77 72
[2] Gibadullina G R, Tazmeev A H and Tazmeeva R N 2015 *International Journal of Applied Engineering Research* 10 (24) 45015
[3] Tazmeev Kh K, Arslanov I M and Tazmeev G Kh 2013 *Prikladnaya Fizika* 4 33
[4] Tazmeev Kh K, Arslanov I M and Tazmeev G Kh 2014 *Izvestija VUZov. Fizika* 57(3–2) 227
[5] Tazmeev Kh K, Arslanov I M and Tazmeev G Kh 2014 *J. Phys.: Conf. Ser.* 567 012001
[6] Tazmeeva R N and Tazmeev B K 2014 *Prikladnaya Fizika* 1 35
[7] Tazmeev K K, Arslanov I M and Tazmeev G K 2016 *J. Phys.: Conf. Ser.* 669 012058