Formation of a powerful flow of steam-water plasma in a gas discharge with an aqueous solution cathode

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Abstract. A powerful flow of steam-water plasma was created using a gas discharge with an aqueous solution cathode. For this purpose, plasma generators with a power in the range of 25-40 kW were developed and created. The problems of choosing the composition of an aqueous solution and its concentration were solved. The energy characteristics of plasma generators were investigated. It is shown that the thermal protection of the walls of discharge chamber can be carried out by supplying gas to the interelectrode gap.

1. Introduction
Gas discharges with liquid electrolyte electrodes have great potential for practical applications [1-6]. Many successful applications have been made with low-current discharges. In high-current modes, a significant amount of substance from liquid cathode enters the plasma column [7-11]. The discharge burns in a vapor-gas environment. It becomes possible to create a plasma flow that is acceptable for energy-intensive technologies, in particular, for gasification of waste polymer materials [12, 13]. However, the methods of forming powerful plasma flows in gas discharges with liquid electrolyte electrodes are still far from perfect. There are questions related to the choice of electrolyte, the design of the plasma generator, the introduction of reagents into the plasma, etc. Experimental studies in this work were aimed at solving these problems.

2. The choice of composition of the aqueous solution
With prolonged burning of discharge, the aqueous solution used as a liquid electrolyte cathode is decreases. An additional amount of aqueous solution is required. In the simplest version, distilled water can be added instead of a solution. This option was studied experimentally. The essence of the experiments was as follows. In the hydraulic system, the volume of aqueous solution was kept constant. Distilled water was added continuously during the burning of discharge. After adding a certain amount of water, a sample was taken for analysis. Changes in the physicochemical properties of aqueous solution were recorded. In particular, the electrical conductivity was measured. In figure 1 shows the results obtained for various aqueous solutions. They were prepared with the same concentration. Relative values are plotted along the axes. Horizontal - the ratio of amount of distilled water to the total volume of aqueous solution. Vertical - the ratio of electrical conductivity to its original value. As can be seen, this ratio varies differently for different aqueous solutions. For some it decreases, and for others it increases. In the case of an aqueous solution of sodium chloride, it changes slightly. Based on this, an aqueous solution of sodium chloride was chosen as the electrolyte.
3. Choice of concentration of aqueous solution

Figure 2 schematically shows a gas-discharge device and presents its current-voltage characteristics (I–V curve). It can be seen from the results obtained that the slope of the I–V curve decreases when using aqueous solutions with a higher specific electrical conductivity, respectively, with a higher concentration. However, in this case, as experiments have shown, the discharge becomes unstable. For stable combustion of discharge, a ballast resistor is required in the power supply circuit. It was experimentally found that for operation without a ballast resistor, the concentration of an aqueous solution of sodium chloride should be no more than 0.3 mol/L.

When using aqueous solutions of sodium chloride with concentrations less than 0.02 mol/L, the discharge also became unstable. Ionization instability has appeared. Contracted channels formed in the discharge gap. At these moments, the current increased sharply. To limit the current, it was again required to include a ballast resistor in the power supply circuit. Thus, it was found that the discharge burns stably without a ballast resistor when using aqueous solutions of sodium chloride with concentrations in the range of 0.02–0.3 mol/L. To obtain a volumetric homogeneous plasma column, it is necessary to use aqueous solutions of sodium chloride with concentrations from 0.05 to 0.2 mol/L.

4. Plasma generators

In figure 3 shows a diagram of one of the variants of plasma generator and oscillograms of current and voltage in the operating mode.
The plasma generator was powered by a three-phase two-half-period rectifier. The voltage ripples were smoothed out by a capacitive induction filter. The voltage at the terminals of plasma generator is practically equal to the output voltage of rectifier. As seen, it is smoothed (figure 3b). In this case, regular current fluctuations with a sufficiently large amplitude are recorded. Small-scale pulsations are superimposed on these oscillations. It should be noted that the presence of current pulsations in the megahertz range is a characteristic feature of gas discharge with a liquid electrolyte cathode [14, 15].

In the experiments, a decrease in the amplitude of current oscillations was observed with an increase in the flow of electrolyte flowing through cathode assembly. However, this increased heat losses through liquid cathode. Therefore, the optimal regimes of electrolyte circulation through cathode assembly were determined experimentally. In the power range of 25-30 kW, the optimal electrolyte flow was in the range of 15-17 g/s. In this case, heat losses through the cathode did not exceed 18% of the input power. In general, despite the presence of current fluctuations, the plasma generator operates stably in operating modes.

During long-term operation of plasma generator, the walls of its discharge chamber were heated. The area near anode was heated to greatest extent. The surface of the refractory material of lining was melted. The problem was solved as follows. A new version of plasma generator was developed. It is shown schematically in figure 4a. A channel is made in the wall of discharge chamber at an angle to the axis. Through this channel, gas was supplied to the anode zone. Air was used in the experiments. The gas flow displaced the anode spot from wall to the center of discharge chamber. Only the end part of anode was in the high-temperature flow. At the same time, another positive effect was obtained.
Heat losses through the anode are significantly reduced. They made up only 3-4% of the input power.

5. Plasma flow
In figure 4b shows a photo of plasma flow at the exit from plasma generator. The temperature in plasma flow was measured with a platinum-rhodium thermocouple. It was quite high at a considerable distance from plasma generator outlet and exceeded 1600 °C at a distance of 0.5 m from anode (figure 4b). The mass flow rate of plasma flow was determined by measuring the decrease in aqueous solution in the hydraulic system. In the operating modes of plasma generators, the aqueous solution decreased at a mass rate of 1.5–2.0 g/s. It was considered that all loss of aqueous solution goes to formation of plasma flow.

6. Conclusion
Experimental studies have been carried out using aqueous solutions of alkalis and salts of alkali metals as a liquid cathode. Based on the results obtained, an aqueous solution of sodium chloride was selected as the most suitable for practical use. It was found experimentally that the concentration of an aqueous solution of sodium chloride should be in the range from 0.05 to 0.2 mol/L. Plasma generators were developed and their characteristics were investigated in the power range of 25-35 kW. A steam-water plasma flow was obtained using aqueous solutions of sodium chloride with concentrations of 0.1-0.2 mol/L. The mass flow rate of plasma flow reached up to 2 g/s. The temperature in plasma flow exceeded 1600 °C at a distance of 0.5 m from anode of plasma generator.

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