High-current gas discharge with a water-solution cathode as a source of plasma flow for gasification of carbon-containing waste

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Abstract. A gas discharge with a water-solution cathode was experimentally studied in the current range 10–25 A. A bulk plasma was obtained in an extended (up to 20 cm) discharge gap. The choice of an aqueous solution of sodium chloride for use as a cathode was justified. The concentration range of an aqueous solution of sodium chloride was established to obtain a homogeneous bulk plasma. A plasma generator has been developed that allows the formation of a powerful plasma flow from the substance of a water-solution cathode. The possibility of supplying gaseous raw materials to an extended discharge gap in a plasma generator has been established. A technical system for the gasification of carbon-containing waste in two stages has been created. In the first stage, the waste was subjected to thermal degradation using an arc plasma, and in the second stage, the volatile components were converted to synthesis gas in a gas-discharge plasma with a water-solution cathode.

1. Introduction
The formation of a huge amount of household and industrial waste is one of the global environmental problems of our time. For the utilization of carbon-containing waste, fire processing - burning is widely used. However, burning produces a huge amount of harmful gas emissions. Plasma sources can significantly reduce the volume of such emissions, because air used as an oxidant is excluded [1, 2]. When using steam-water plasma, harmful emissions can be completely eliminated. In this case, the gaseous products of plasma processing of carbon-containing wastes can be obtained in the form of synthesis gas, which is a mixture of carbon oxide and hydrogen. The aim of this work was to form a steam-water plasma stream from a liquid cathode substance (water solution) and to study the gasification of carbon-containing wastes in such a plasma flow.

2. The results of an experimental study of gas discharge
In high-current combustion modes, electrolyte atomization is enhanced. The working volume of the electrolyte is reduced. In this case, a change in the composition of the electrolyte occurs, because the transfer of its components to plasma occurs through various channels. The dissolved substance is transported mainly by atomized droplets, and the solvent-water is additionally evaporated and decreases due to electrolysis. During prolonged burning of discharge, compensation for the loss of electrolyte is required. How should it be implemented? What should be the composition of added electrolyte? How can task be simplified? To answer of these questions, experimental studies have been performed.
The experiments used the original approach, which was proposed earlier in [3]. Briefly, the essence of experiments with gas discharge was as follows. The discharge was ignited and its combustion was maintained at a constant current \( I = \text{const} \). The decrease in the aqueous solution was compensated by the addition of distilled water (solvent). The working volume of the aqueous solution remained unchanged \( (V_s = \text{const}) \). In a simplified version, the experimental setup is shown in figure 1. Experiments were conducted with solutions of sodium sulfate, sodium chloride, potassium chloride, sodium hydroxide and potassium hydroxide in distilled water.

Over a long burning time of discharge, the volume of added distilled water \( \Delta V \) was comparable with the working volume \( V_s \) of electrolyte. Therefore, it was possible to expect dilution of electrolyte and a significant decrease in its electrical conductivity. The results were mixed. The experiments showed that the addition of distilled water slightly affects the electrical conductivity of weakly concentrated aqueous solutions of alkali metal salts. From the analysis of the results it follows that this property of electrolytes is due to the enrichment of aqueous solution with hydroxyl ions. The electrical conductivity of aqueous solution of sodium chloride changed to the least extent. Therefore, this solution was chosen to create a plasma flow.

In high-current combustion regimes, a significant amount of dissolved substance is carried into the discharge region. Therefore, the essential effect of concentration on the properties of discharge occurs. The result of this effect was clearly manifested in the current-voltage characteristic. In the experiments, the current-voltage characteristics of discharge \( (I - V) \) turned out to be increasing. Moreover, the steepness changed depending on concentration of electrolyte. The lower the concentration, the steeper \( I - V \) was obtained [4]. From a practical point of view, such \( I - V \) characteristic is a very good property of discharge, since the combustion stability increases and the need for a ballast resistor in the electric supply circuit disappears. Accordingly, energy losses are reduced. The experiments showed that the discharge burns steadily at concentrations of 0.2 mol/L or less.

In the case of use of aqueous solutions with low concentrations, the discharge goes into the combustion mode with contracted channels [5]. When such channels appear, the current increases sharply. Again resistor is needed in the power circuit to limit the current. It was experimentally established that in a long interelectrode gap, the discharge burns without spark channels when using aqueous solutions with a concentration above 0.05 mol/L. Thus, for operation without a ballast resistor, the concentration of an aqueous solution of sodium chloride should be within from 0.05 to 0.2 mol/L.

3. The plasma generator
Based on gas discharge with a water-solution cathode, the plasma generator was developed and created. Its feature is that inside ignites an extended gas discharge. There is the possibility of
constructive solutions for supplying gaseous raw materials to the discharge zone in various ways. The plasma generator circuit is shown in figure 2a.

![Plasma generator circuit](image)

**Figure 2.** Plasma generator circuit (a) and typical current and voltage waveforms (b). 1 - cathode assembly, 2 - anode, 3 - case of the discharge chamber, 4 - lining, 5 - output channel. The arrows indicate the direction of flows of aqueous solution and the mass flow from cathode to plasma. $l = 20$ cm.

The discharge was ignited between cathode assembly 1 and anode 2 inside the chamber, consisting of housing 3 and lining 4. The output channel of discharge chamber was extended by 50 cm and provided with a metal casing 5. The electrolyte was circulated through cathode assembly with a fixed mass velocity $m$. An aqueous solution of sodium chloride with a concentration of 0.2 mol/L was used as electrolyte. Part of electrolyte was sprayed from an open surface and entered in discharge zone. The electrolyte loss was compensated by the addition of distilled water during the operation of plasma generator. The anode was a copper rod with diameter of 25 mm. It was cooled by water. The case 3 of discharge chamber was made of asbestos-cement materials, and lining 4 was made of refractory bricks.

Electrical power was supplied from a three-phase, half-wave rectifier. Voltage ripple was smoothed by a C-L-C filter. The output voltage was 2100 V. Figure 2b shows typical current and voltage oscillograms. As shown, the generator operates stably. In this case, the discharge current is subjected to pulsations. Pulsations are presumably caused by dripping of an aqueous solution into discharge gap.

A ballast resistor was used to ignite discharge, and then its resistance decreased to zero. The power of plasma generator in operating modes was in the range of 25-30 kW. To study the thermal and electrical characteristics, the methods used were described in [6, 7]. Heat losses through the cathode and anode were relatively small. Their total value did not exceed 30% of the power of plasma generator. In this regard, the plasma generator is not inferior to arc plasmatrons.

The effect of gas injection on the characteristics of plasma generator is investigated. In the experiments, compressed air from the compressor was used. Air was supplied to discharge channel at different sites between the cathode and anode. The experiments showed that the most effective is the option of injection from cathode side at an angle to the axis of discharge chamber. It has been established that gas with a mass velocity can be supplied to plasma generator comparable to the flow of water vapor generated during the combustion of discharge.

The amount of electrolyte $G$ spent on creating a stream of water vapor was 1.0-1.7 g/s. It could be adjusted by changing $m$. An increase $m$ led to an enlarge $G$.

### 4. Technical system for plasma gasification

A technical system was developed and created for plasma conversion of carbon-containing wastes into synthesis gas. The basis is a two-stage scheme. Simplified, it is shown in figure 3.
In the first stage, the raw material was subjected to thermal destruction and dispersion under the influence of arc plasma. Volatile products were transported to the discharge chamber of plasma generator with a water-solution cathode. Polyethylene waste was used as raw material. The hydrogen content in the resulting gas was measured by the «AVP-01», hydrogen analyzer, and the carbon monoxide was determined by the «Autotest» gas analyzer.

5. Conclusions
New experimental data on the properties of gas discharge with liquid electrolyte cathode are obtained. In particular, conditions have been identified under which volumetric combustion of a high-current (20–25 A) discharge is ensured at large interelectrode distances (up to 20 cm) without using ballast resistor in the electric power circuit.

An important conclusion of practical interest is that weakly concentrated aqueous solutions of sodium chloride can be used as an electrolyte. The concentration of solutions should be in the range from 0.05 to 0.2 mol/L. The use of such aqueous solutions provides volumetric combustion of discharge at sufficiently large interelectrode distances (up to 20 cm and more). Another important conclusion of practical importance is that when using aqueous solutions of sodium chloride with concentrations within the indicated limits, the discharge burns stably without a ballast resistor in the electric power circuit, i.e. without additional losses of supplied electric energy. The effect of gas injection on characteristics of a plasma generator is investigated. It has been established that gas can be supplied to plasma generator at a mass velocity comparable to the flow of water vapor formed from an aqueous solution substance.

A technical system for plasma gasification of carbon-containing waste was developed and created. In pilot experiments, synthesis gas from polyethylene wastes was obtained.

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