Investigation of electrolyte electric discharge characteristics

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Abstract. The most important electrical characteristics of electrolyte electric discharge were investigated. The electric burning discharge was obtained with the help of different electrolytes. The spectral composition of the electric discharge electromagnetic radiation was determined, the plasma temperature was determined. The spectrum of the electric discharge high-frequency oscillations was calculated in the region $\nu=10 \text{ kHz}-80 \text{ MHz}$. The most appropriate modes of the electric burning discharge in different electrolytes were proposed.

1. Introduction
If there are electric discharges in electrolytes, the intensely radiating plasma area, which is situated inside the liquid medium, appears. This results in intensive boiling of electrolyte near the electric discharge and in the formation of liquid flows [1,2]. Electrolyte discharges are used for processing and modification of different metal complex surfaces and in more efficient methods of hydrogen production [1-4]. The burning discharge is caused by broad spectrum of high-frequency oscillations [5,6]. If the discharge plasma is placed in the magnetic field, all the processes of the electric discharge are stabilized. The electrolyte discharge characteristics were investigated in this work and different working mediums were used.

2. The investigation of the electric discharge voltage-current characteristics
Cylindrical and conical chambers were used in these experiments. Chambers were made of plexiglass with volume 120-310 cm$^3$. The experimental setup is shown in figure 1. Electrolytes contained sodium carbonate, sodium hydro carbonate and potassium hydroxide. The discharge supply was implemented with the help of full-wave rectifier: voltage 0-250 V, frequency 100 Hz. Tungsten rods or titanic rods were used as cathodes (diameter 2-3 mm). The plates, made form stainless steel, were used as anodes (plate thickness 0.1-0.2 mm).

Let’s analyze the main patterns of the electrolyte discharge development when the sodium carbonate is used. The concentration of the sodium carbonate Na$_2$CO$_3$ was equal to $C=0.01-1 \text{ M}$ or $m=1.06-10^6 \text{ g}$ in every $10^3 \text{ cm}^3$ of distilled water (1 M – mass of 1 mole of matter in grams). The voltage-current characteristic of the electric discharge is shown in figure 2(a) there the concentration of the sodium carbonate is equal to 0.5 M. At first we have a linear relationship. The cathode arcing and discharge ignition occur near the point 1. After that the plasma area appears around the cathode surface. The color of discharge glow was mainly yellow-red. Previously it was found that the ignition voltage increase occurs as the content of the working medium decreases [5,6]. The cathode region is situated near the cathode surface; this region has the biggest radiating capacity with thickness 1-2 mm.

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The next middle plasma area is rarefied and is surrounded by steam-gas layer with thickness 1-2 cm. The voltage-current relationship becomes smaller in the 1-2 region, because of the medium resistance increase. Then the discharge combustion intensifies and the voltage-current relationship becomes linear in the 2-3 section. The 2-3 section is the main working area, inside of which the discharge combustion is stable and normal. The high electric oscillations occur in the 2-3 section. The gradual decrease of the discharge glow takes place inside the 3-4 section. The discharge combustion ceases in point 4.

Previously it was found that the sodium carbonate content in electrolyte affects the shape of the discharge voltage-current characteristic [6]. The following sodium carbonate concentration values were used for the investigation of this relationship: 1M, 0.75 M, 0.5 M, 0.25, 0.1 M, 0.05 M, 0.01 M. The voltage-current characteristics for 0.5 M и 0.1 M values are shown in figure 2. If the working medium content decreases, the initial linear section of the voltage-current characteristic becomes straighter in figure 2(b). The ignition voltage value increases in point 1. The 1-2 and 2-3 sections also become straighter. The next points 3-4-5 points come nearer to the initial points 3-2-1 section. As a result, the total area of the closed voltage-current characteristics becomes smaller.

![Figure 1. Experimental setup: 1-chamber, 2 – electrolyte, 3 – cathode, 4 – ceramic tube, 5 – anode, 6 – power supply, 7 – electric discharge, 8 – magnetic probe, 9 – frequency analyzer](image)

![Figure 2. The relationships between the electrolyte discharge voltage-current characteristics and the sodium carbonate concentration: (a) the concentration is equal to 0.5 M, (b) the concentration is equal to 0.1 M](image)
If the concentration of the working medium is minimum 0.01 M, the voltage-current characteristic looks like a practically linear section without twists. The voltage-current characteristic shapes for all contents of working medium were investigated in these experiments. If we want to get the optimum shape of the voltage-current characteristic, we need to choose the following concentration of the sodium carbonate: $M=0.5-0.75$.

3. The investigation of electric oscillations

Magnetic probes were used for the investigation of electric oscillations in electrolyte. All signals were recorded with the help of TDS 2024B oscilloscope and processed due to Origin software. The probe signals were also sent to C4-25 analyzer (working range 10 kHz-70 MHz). Magnetic probes are small coils with diameter 2-4 mm and number of coil blocks 80-170. The potassium hydroxide KOH was used as a working medium. The external constant magnetic field $B=200$ Gs was used for stabilization of the burning discharge. The following fundamental oscillation frequencies were determined: $(36\pm2)$ kHz, $(51\pm3)$ kHz, $(203\pm10)$ kHz, $(274\pm13)$ kHz, $(6.4\pm0.3)$ MHz, $(12.3\pm0.5)$ MHz, $(25\pm1)$ MHz, $(32\pm2)$ MHz, $(43\pm2)$ MHz. If we use 190-310 kHz range, the continuous frequency distributions occur. The spectrum of the discharge electric oscillations is shown in figure 3.

![Figure 3. The spectrum of the electrolyte discharge high-frequency oscillations](image)

Let’s analyze all possible oscillation processes which can occur in the discharge plasma of the electrolyte. If we have an external constant magnetic field, cyclotron frequencies can appear. If the field magnetic induction is equal $B=200$ Gs, we will have the following cyclotron frequencies: $\omega_{Bi}=eB/m_p=1.92\cdot10^9$ s$^{-1}$ and $\omega_{Be}=eB/m_e=3.52\cdot10^9$ s$^{-1}$. These frequencies can correspond with ion-cyclotron plasma waves or electron-cyclotron plasma waves. The wave lengths for different frequencies of electric oscillations were calculated in accordance with dispersion relation for low-frequency waves, which occur in plasma [7]: if the frequency is $\nu=205$ kHz, the wave length is $\lambda=5$ cm; if the frequency is $\nu=35$ kHz, the wave length is $\lambda=2$ mm [5,6]. These wave lengths are practically equal to the characteristic of anode and cathode, which are used in the discharge system.

Debye radius as the parameter of the plasma screening was $r_d=5\cdot10^{-6}$ cm at all standard characteristics of plasma. This value is much smaller than standard Debye radius of plasma structures ($l=10^{-3}$-10$^{-2}$ cm), which occur during the electrolyte discharge.

The spectra of the electrolyte discharge electromagnetic radiation were investigated by the concentration $M=0.5$ of the sodium hydroxide KOH. The following lines had the most intensive radiation: K I 770 nm, K II 394 nm, Na I 589.5 nm, Na I 588.9 nm. The sodium atoms were used as electrolyte impurities. The following lines had the less intensive radiation: K II 423 nm, K I 404 nm, Hα 656 nm, Hβ 486 nm, Hγ 434 nm. The plasma temperature inside the cathode region with the help of the method of relative intensities [8] due to lines of atomic hydrogen $H_a$ and $H_b$ was calculated: $T=2400\pm200$ K. The working range was used by the current: $I=1.25\pm0.15$ A. We also calculated the
plasma concentration for the same current with the help of Stark broadening of H\textalpha, H\beta lines: 

\[ n_e = (2.8 \pm 0.2) \times 10^{15} \text{ cm}^{-3} \]

The oscillation processes in the region 4-7 kHz were recorded for time dependencies of hydrogen line intensity.

4. The investigation of the electrolyte working medium characteristics

Earlier experiments with composites showed that if we fill crystalline cells with electrolyte, the voltage occurs in these cells are up to 1.5 V [9]. We investigated the change of the discharge characteristics after the addition of crystalline powders to the electrolyte. One electrode the aluminum plate with thickness 0.1-0.2 mm and total area 80-120 cm\textsuperscript{2} was placed inside the plexiglass vessel. The calcite fine-dispersed powder CaCO\textsubscript{3} was placed on the vessel bottom (medium size of each granule 1-5 μm). The electrolyte contains distilled water and sodium carbonate Na\textsubscript{2}CO\textsubscript{3} with concentration 0.5 M. The thickness of electrolyte layer inside the vessel was bigger that the thickness of the powder layer. The second electrode - copper rod with diameter 3-4 mm was vertically fixed in the center of the vessel. This electrode was fixed at the distance from the vessel bottom and contacted the calcite powder. The voltage and the current were measured with the help of micro volt meter (measurement accuracy: \( \Delta U = \pm 1 \mu\text{V}, \Delta I = \pm 0.1 \mu\text{A} \)) after the discharge ceasing. The thickness of the calcite powder layer inside the vessel was equal to \( h_1 = 3-40 \text{ mm} \). The negative potential was recorded on the aluminum electrode; the positive potential was recorded on the central copper electrode. Let’s analyze the measurement results for the following cylindrical vessel: diameter \( d = 40 \text{ mm} \), height \( h_3 = 50 \text{ mm} \), the depth of the central electrode submersion \( h_2 = 40 \text{ mm} \). The relationship between the electrode voltage and the thickness of the calcite layer is shown in figure 4.

![Figure 4. The relationship between the electrode voltage and the thickness of the calcite layer](image)

If the range of the load was 100 kΩ -300 kΩ, the current was equal to 45 μA-10 μA. If the calcite layer thickness and its volume increase, the voltage increases too. This phenomenon is apparently caused by the increase of the number of charge carriers in calcite medium and in the electrolyte medium. Such phenomena in new materials can be represented as plasmon waves, which occur in near-surface layer of the medium [10]. This means that additional potentials can appear in the medium, which contains electrolyte and fine-crystalline component.

5. Conclusion

The following results were obtained during the course of this work. The main patterns of the voltage-current characteristic shape change in accordance with the working medium content in the electrolyte were investigated. If the working medium content increases, the total area of the voltage-current characteristic also increases. The optimum concentration of sodium carbonate, which is used as the working medium, is \( M = 0.5-0.75 \).

The fundamental oscillation frequencies for \( \nu = 10 \text{ kHz-80 MHz} \) working range were obtained during the investigation of the discharge oscillation processes, so the potassium hydroxide KOH was
used as a working medium. Our calculations showed that ion-cyclotron plasma waves and electron-cyclotron plasma waves can occur in such discharge.

The electrolyte elemental composition and the presence of impurities in the electrolyte were calculated with the help of spectral methods. The electrolyte, which contains potassium hydroxide, has the intensive lines of potassium ions and potassium atoms. The plasma temperature inside the cathode region of the discharge was calculated: \( T = (2400 \pm 200) \) K.

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