Changes of thermal balance in a plasma-electrolyte system according to the shape of the applied voltage

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Abstract. The work is aimed at studying the changes of the heat balance in the system of the electrode-plasma-gas/vapor-electrolyte in various forms of applied voltage. It was established that in contrast to the voltage, which is obtained after full-wave rectification, film boiling occurs by using a smoothing capacitive filter. This is because in the pulsing mode voltage value has zero value at the beginning and end of the pulse, also at that time takes place cooling of the electrode at the contact with the electrolyte. In this paper describes a heat exchange in two different modes of plasma-electrolytic treatment.

Introduction

Modern materials science has two main lines of development - is changing volume characteristics of the materials or modification of the surface layers. Surface modification is more attractive and necessary to the economic position [1]. One of actively developing methods for surface treatment is a plasma-electrolytic treatment. Interest in this method is caused by wide possibilities of this method (cleaning, hardening, diffusion saturation, formation of microlayer coating, synthesis of nanoparticles etc.) and its environmental performance [2, 3, 4]. The basis of plasma electrolytic treatment is a discharge burning between liquid and solid electrodes. During the processing, occurs the electrochemical reactions, heat impact, the formation of streams of electrons, ions, photons, and their effect on the surface. As known one of the factors, strongly influence on the properties of the materials, is thermal influence [5]. This was the necessity of carrying out works aimed at the research of the heat balance of the system. It should be noted that the heat balance of the system during cleaning, hardening, saturation, and formation of the diffusion surface microlayer would vary. Data processing methods can be divided into two groups, which are classified by the form of the applied voltage. Therefore, the aim of this work was to study the influence of the shape of the applied voltage to the thermal balance of the system electrode-plasma-gas/vapor-electrolyte.

Experimental

The experimental setup is designed for the study of plasma-electrolyte discharge in a range of parameters voltage $U = 0 \div 250$ B, the current $I = 0 \div 50$ A, $pH = 1-12$ and $T = 20-110^\circ$C. Functional schemes of setup is shown in Figure 1. Installation is intended for research of electrical and power...
characteristics of the discharge, including the research of the potential distribution in the electrode gap in the treatment process.

![Functional scheme of the experimental setup plasma-electrolytic treatment](image)

Consider the installation of which is presented in Figure 1. It consists of a current source 1, the electrolytic bath 2, the electrode system 3, the oscilloscope 4, the additional resistance 5, the voltmeter 6, the ammeter 7, thermocouple 8. Power supply 1 supplies a regulated DC voltage to the electrode system 3. The depth of immersion of the anode in an electrolyte solution controlled by using the electrode system. With an oscilloscope 4 was controlled the shape of the applied voltage and current with a voltmeter and an ammeter measures the voltage and current of the discharge.

The magnitude of the contact area of the anode with the electrolyte controlled by applying to the electrode surface of the dielectric protective coating, leaving open on strictly defined part. During the research anode area was $S_A = 0.1 - 0.65 \text{ cm}^2$, cathode area was $S_K = 10 - 34 \text{ cm}^2$. A plasma-electrolytic treatment process takes place, subject to inequality of surface areas of electrodes $S_K > 5 S_A$. In previous studies it was established that at the same areas of the electrodes discharge burns on the cathode. The gradual reduction of the area of the anode relative to the cathode initially leads to the discharge quenching at the cathode, and then to the appearance of micro-discharges at the anode. These data, about the condition of the generation of electrical discharges at the electrodes immersed in the electrolyte, in agreement with the data of [2].

To determine the amount of heat that goes into heating the electrolytic cathode used laboratory mercury thermometer, measuring lab cylinder of 0.25 liters, laboratory flask 1 liter and stopwatch.

Measurements were taken during the discharge by the following procedure:

1) After the ignition of the discharge, the electrolyte circulating through the discharge zone, started to heat up. After 30 seconds, the temperature stops changing and sets the thermal equilibrium.

2) After 40 seconds after ignition of the discharge, began measuring. The drain hose is directed into a laboratory flask (1 liter) to collect the water. Flowing water washes thermometer showing the temperature of the water in real time. The start and the end of water intake recorded stopwatch. The exact amount of water collected in the flask was determined dimensional laboratory cylinder capacity of 0.25 liter.

3) In the workbook recorded values of voltage and current of discharge and obtained at those discharge parameters the thermometer readings, the stopwatch readings and the volume of collected water. Calorimetric measurements for each value of the discharge power were repeated ten times to average the obtained values.

The energy of an electric current, which is inserted into the gas discharge, calculated by the formula:

$$Q_e = U \cdot I \cdot t \ [\text{J}],$$

Where (U) - voltage across the electrodes, (I) - discharge current, (t) - time of current flow.

The amount of heat that spent on the heating of the electrolyte, calculated by the formula:

$$Q_B = c_B \cdot m_B \cdot AT \ [\text{J}],$$
Where $c_p = 4190 \ (J / kg \ °C)$ - specific heat of water, $m_\theta (kg)$ - the mass of water heated in a minute, $\Delta T (°C)$ - the heating temperature of the electrolyte.

The proportion of discharge energy consumed for the heating of the electrolyte is calculated as:

$$\eta = (Q_\theta / Q_e) \times 100\%$$

Experiments have shown, film boiling is observed only when using capacitive smoothing filter. Nature of the electrolyte has a strong influence. For solutions of alkalis film boiling is observed at lower voltages than aqueous solutions of acids and salts. This is due to the higher viscosity of alkali. Consider the release of heat, in this case, there is a four-phase system, which contains a steam-gas shell, in which the discharge is burning and which is separating the anode from the electrolyte. In this shell releases heat under the influence of the electric current. We single out three heat flux: heat flux from the shell in an electrolyte solution, the heat flow which is spent on evaporation of of the electrolyte, the heat flow directed from the anode shell. The volumetric power of the heat source in a conductive shell, we write down with the influence of the space charge on flow of current through the shell in strong electric fields. The current density of anions is equal $j = K \rho E^{1/2}$. Experiments have shown that the gradient of the temperature distribution of cylindrical samples is 5 degrees per 1 mm. Measurement error of 15 degrees. It gives the right to assume that the samples up to 10 mm is homogeneously heated. We neglect the loss of heat by evaporation of the liquid and write heat balance: $jU = Q_A + Q_B$, $Q_A$ and $Q_B$ - the heat flux density at the anode and an electrolyte.

When using film boiling ripple voltage is not observed. This is because in the pulsing mode voltage value at the beginning and the end of the pulse has zero value; at that time there is a cooling of the electrode in contact with the electrolyte. Another distinctive feature is the active dissolution of anode in terms of its passivation of friable film, which constantly forms at all current densities. The appearance of the passivation layer is likely occurs because of interaction between the metal an electrode with oxygen which allocated on the electrode. As a result, take place screening and passivation of the surface of the electrode. In addition, the discharge can be carried out in some of vials. These bubbles are plasma zone with a low electrical resistance. During the discharge volume of the heated bubble due to viscous resistance of the liquid are not rapidly increase and this is leading to a rapid rise of pressure in the vial and its rebound from the electrode surface. Then discharge burns on another favorable location.

**Conclusions**

It was established that in contrast to the voltage, which is obtained after full-wave rectification, film boiling occurs by using a smoothing capacitive filter. This is because in the pulsing mode voltage value has zero value at the beginning and end of the pulse, also at that time takes place cooling of the electrode at the contact with the electrolyte. In this paper describes a heat exchange in two different modes of plasma-electrolytic treatment.

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