Generalized current-voltage characteristics of electric discharge liquid cathode

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Abstract. The experimental and calculated current-voltage characteristics of the electric discharge between the metal anode and liquid cathode was got. As the liquid electrode process water, copper sulfate solution and various concentrations of sodium chloride were used, a solid cylindrical electrode rods were made of copper, iron and steel of different diameters. The influence of pressure, distance between electrodes, the anode material, electrolyte composition of the cathode on the current-voltage characteristics of the discharge was researched. The current-voltage characteristics are falling, increasing the distance between electrodes raises these curves along the voltage axis. The methods of simulation based on the similarity theory and the dimension formula is obtained for calculating the generalized current-voltage characteristics, taking into account, inter alia, the effect of pressure and electrode spacing.

1. Introduction

Concentrated energy flows is widely used for creating new materials, and to modify the existing [1, 2]. The effectiveness of the implementation of the production depends on the completeness of the research taking place in this process. In particular, for the development process of the plasma treatment of materials and its automation is important to study the characteristics of the current-voltage (CVC) of electrical discharges [3, 4]. It must be borne in mind that the nature of interdependence voltage and discharge current is also affected by the conditions and the implementation of the process, both qualitatively and quantitatively. Therefore, obtaining generalized characteristics, including those conditions, is of particular interest for the understanding of the processes occurring in this case, and for the development process.

The processes taking place under the influence on a substance of the plasma of electric discharges using fluids are the least studied. At the same time, this method is of particular interest because the use of different liquid natures gives opportunities to regulate the properties of modified and synthesized materials [5 – 9]. This makes the calculation of the generalized characteristics of this category to be actual.

2. Experiment

Experimental current-voltage characteristics obtained on the original line of own production [7]. The electrical discharge occurs between the metal anode and liquid cathode. The process water, copper sulfate solution and varying salt concentrations, served as a solid cylindrical electrode rods made of

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copper, iron and steel of different diameter (1 mm to 10 mm) were used as the liquid electrode. Discharge was realized in chamber at different pressures (10^3 Pa to 10^5 Pa). The maximum voltage and the discharge current was 1500 V and 10 A, respectively. Inter-electrode distance was among providing an electrical discharge (maximum 100 mm).

At the experimental line the large number of current-voltage characteristics for different values of variable parameters, such as pressure, electrode spacing, anode material, electrolyte composition of the cathode are received. The current-voltage characteristics are falling, increasing the distance between electrodes raises these curves along the voltage axis. As an example, Figure 1 shows one set of current-voltage characteristics of the discharge between the cathode of the solution (20%) and copper sulfate steel anode under a pressure of 10^3 Pa for different interelectrode distances.

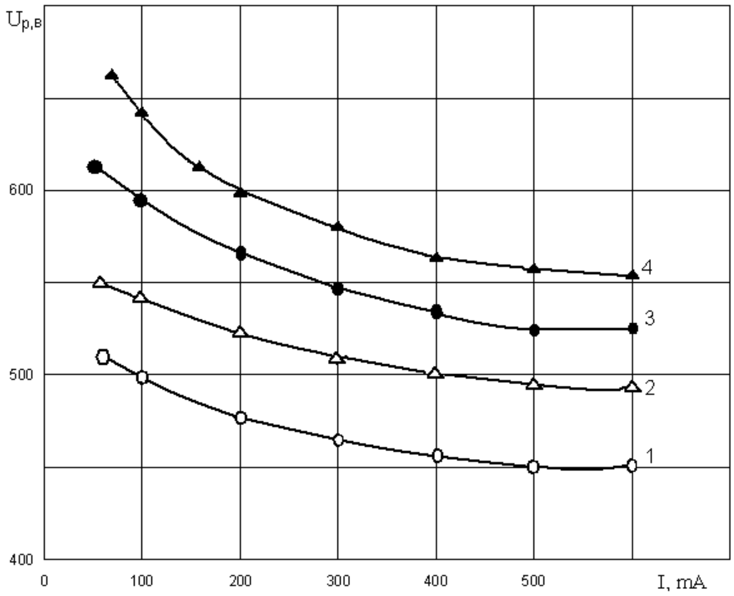

Figure 1. Current-voltage characteristics of the discharge between the solution of copper sulphate and steel for various interelectrode distances (1 – 10 mm; 2 – 20 mm; 3 – 30 mm; 4 – 40 mm).

3. Results and their discussion

Generalized characteristics obtain modeling methods based on the theory of similarity and dimension [10]. For free electric arcs, the main similarity criteria were identified [11]. There are empirical formulas which allow calculating the characteristics of the discharge for the implementation of different arc conditions. Also criterial generalization of the current-voltage characteristics of the negative corona discharge in an argon stream was held. [12] Known generalizations CVC for electric discharges using liquid electrodes was received without taking into account the pressure [13]. Since the pressure was constant and electrode spacing value changes slightly, at this situation the influence of Knudsen on generalized characteristics of the discharge was not revealed.

Generalized discharge CVC with a liquid cathode obtain solid anodes from a particular material, and take them geometrically similar. If the velocity of the gas is a certain parameter, the Reynolds number is not a determining criterion. Then, in a first approximation, the dimensionless integral characteristics of the discharge ψ are functions of defining similarity criteria and have the form

$$\Psi = f_1\left(\frac{I^2}{l^{1,5}g^{0,5}\chi_R T_R}, \frac{l\mathrm{PQ}_{ll}}{\mathrm{KT_R}}\right), \quad (1)$$

here I - discharge current, P - pressure, l - electrode spacing, χ_R - thermal conductivity of the feed gas at a temperature T_R, K - Boltzmann constant, g - acceleration due to gravity, Q_l - sectional electron-molecule collision.

Distribution of dimensionless parameters ψ1 discharge will be described by criterion equation

$$\Psi = \left(\frac{I^2}{l^{1,5} g^{0,5} \chi_R T_R}, \frac{l\mathrm{P}\mathrm{Q}_{la}}{\mathrm{K}\mathrm{T}_\mathrm{R}}, \frac{\tau}{l}, \frac{y}{l} \right), \tag{2}$$

where τ and y are the distance to a given point, respectively, from the axis of the discharge liquid and the surface of the cathode. Local dimensionless discharge characteristics depend on the dimensionless coordinates

$$\bar{\tau} = \frac{\tau}{l}, \bar{y} = \frac{y}{l}.$$

For generalizations of discharge voltage characteristics between the liquid and solid electrodes, as well as the open arcs the similarity criterion was adopted [11, 14]

$$\frac{I^2}{l^{1,5} g^{0,5} \chi_R T_R}.$$

If the mean of free path of an electron is determined by the formula

$$\lambda_l = \frac{1}{n_a Q_{al}} = \frac{kT_R}{PQ_{la}},$$

then the inverse of the Knudsen number for electrons is a similarity criterion

$$\frac{lPQ_{la}}{KT_R}.$$

In our experiments, the Knudsen number varied by several orders of magnitude, which allowed to establish its role in the generalized characteristics.

Let's define a non-dimensional voltage

$$\bar{U} = \frac{U_p l^{0,5} g^{0,5}}{I}. \tag{3}$$

If the value of g, χ_R, T_R, $Q_{\ell a}$ for our case are assumed to be constant, from (1) and (3) you can get a simple equation

$$\frac{U_p l^{0,5}}{I} = f_2\left(\frac{I^2}{l^{1,5}}, Pl \right). \tag{4}$$

The accepted range of current I (from 0.1 A to 0.6 A), the pressure P (from 10^3 to 10^5 Pa), and the interelectrode distance l (from 2 mm to 40 mm) of the discharge current-voltage characteristics of a generalized view of dependence on parameters Pl will be described by the formula:

$$\frac{U_p l^{0,5}}{I} = a_3 \left(\frac{I}{l^{0,75}}\right)^{-1,1} \cdot (Pl)^{0,42}, a_3 = 430 A^{0,1} \cdot B \cdot \text{Па}^{-0,42} \cdot \text{м}^{-0,745}. \tag{5}$$

The calculation shows that the standard deviation of the calculated values U_p from experimental values does not exceed 10%. Figure 2 shows a generalized current-voltage characteristics of the discharge of liquid electrodes made of process water.

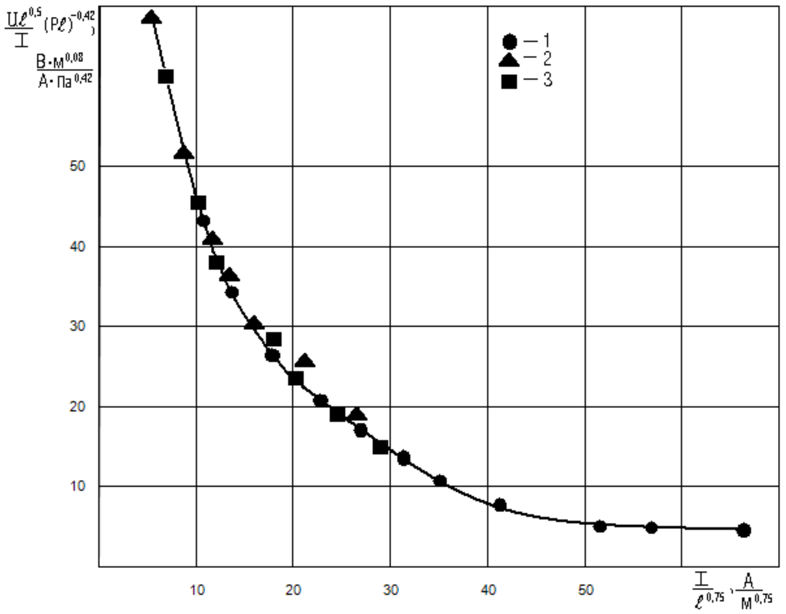

Figure 2. Generalized discharge current-voltage characteristics for different inter-electrode distances and pressures (1 – 2 mm; 10^5 Pa; 2 – 7 mm; $8 \cdot 10^3$ Pa; 3 – 15 mm; $2.5 \cdot 10^3$ Pa).

4. Conclusion

The slight value of the standard deviation calculated from the experimental values allows us to recommend a generalized formula of the current-voltage characteristics for use in the development of plasma electrothermal line with liquid electrode and the design of appropriate processes.

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