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ELECTROPULSE EROSION OF ELECTRODES IN A LIQUID MEDIUM DURING THE TREATMENT OF GALVANIC WASTEWATER

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Abstract

The high-quality treatment of waste water from galvanic production sites is a recent problem in many fields of production. The electric pulse method is the most acceptable treatment method for this type of waste water.

In the present paper are presents the survey results of the dependence of productivity of the main technological process (metal dispersion) on the energy and technological characteristics of a pulse generator and an electric discharge reactor. The survey results are necessary to determine the optimal operating modes and adequate design of equipment for waste water treatment of aircraft production galvanic areas.

Physical and mathematical model which are presented and experimental data confirm the dependence of the magnitude and nature of the electric pulse erosion of the material on the dispersion conditions.

Results of an experimental investigation of energy technology factors influence on the dispersion of metal in an electroerosive reactor are presented in the paper. A mathematical model of the dependence of the process productivity and specific energy expenditure has been obtained. The results of an experimental investigation of the discharge dimple on a microscope REM 106 for steel electrodes are presented.

Key words: waste water treatment, pulse discharges, dispersion, electrode erosion.

Problem statement

The problem of environmental pollution, including the quality and purity of water resources, is considered very seriously in all countries of the world. Innovative solutions for assessing pollution trends are proposed [1, 2].

Mechanical engineering, the aviation and space industries are characterized by a wide range of complex configuration parts with many internal cavities to be coated. The technology of electroplating coatings using electrolytes is still widespread, despite the fact that new technologies for coating parts of machines, aircraft and vehicle (vacuum spraying, detonation spraying, etc.) are being developed and implemented. In the process of electroplating coatings, it is generated a large amount of waste, especially, sludge and galvanic waste water (GWW). Waste from the galvanic production of aviation enterprises leads to the pollution of the hydrosphere and land resources with toxic substances – heavy metal ions (copper, chromium, cadmium, nickel, etc.). Such a complex composition of pollutants in wastewater does not allow them to be effectively disposed for reuse by existing methods.

The impurities in the wastewater of the electroplating workshops are chemical elements that adversely affect the environment and pose a threat to flora and fauna. It should be noted that heavy metals are potentially toxic to living organisms [3, 4].

Industrial wastewater generated in galvanic plants is one of the most common. Formed as a result of coating, as well as chemical and electrochemical treatment of metals, galvanic wastewater contains salts of heavy metals, acids and alkalis in quantities tens of times higher than the maximum allowable concentrations. Such effluents represent a serious danger to the state of the environment and, in particular, water bodies, which makes it important to develop methods aimed at improving the wastewater treatment of galvanic plants. A wide range of wastewater pollution determines the necessity to develop universal technological processes for integrated disposal of polluted water. Making a choice of the disposal process and its hardware design should be based on a careful analysis of the main technology in order to minimize waste and select the optimal systems for their disposal. The methods of galvanic effluent treatment studied today make it possible to convert toxic substances into sparingly soluble compounds and to neutralize acids and alkalis. At the same time there are losses of valuable raw materials, and also irreparable harm to the environment is inflicted.

An alternative to existing methods of utilization of liquid galvanic waste are physical methods using high temperatures, electric and magnetic fields, electric discharges and currents, UV and ionizing radiation. Among the electrophysical methods should be noted the treatment of water by pulsed discharges in order to purify and disinfect it. This discharge produces a powerful complex effect on the fluid, intensifying the processes in it.

Taking this into account, the task of creating a technology for the processing and disposal of liquid

(waste solutions) and solid (shavings) wastes generated in the process of neutralizing industrial effluents from electroplating industries, as well as waste from metalworking industries, is a relevant objective.

To solve the above-described problem, it is proposed to use the electric pulse method of utilization of GWW. However, the physical and technical processes of electrical impulse dispersion of conductive materials during the disposal of waste from galvanic and machining industries in a one-stage process have been underexplored.

Analysis of recent research and publications

The methodology for wastewater treatment is constantly being developed. The aim is to reduce the pollution of water resources and to comply with the legislation. Modern technologies are constantly being modified, new sewage treatment methods are being proposed and introduced to ensure environmental protection and sustainable development. One of the main challenges is the possibility of recovering valuable components, the organization of energy efficient methods, the introduction of waste-free production and environmentally sound technologies [5, 6].

In modern conditions, the development and implementation of technological processes for the utilization of industrial waste with the provision of the regeneration of rare and expensive materials is highlighted [8, 9].

The electrical impulse process of waste utilization of galvanic workshops is based on the combined effect on water of physical and chemical phenomena arising from the implementation of impulse electrical discharges. In this set of physical and chemical influences on the cleaned water is wide enough (presence of electroerosion process allows to obtain highly dispersed materials to conduct activation aqueous suspensions affects the character of the flow of processes when dispersed) [10]. The literature contains limited information of the mechanism of such processes. There is not enough data on the dynamics of the discharge in the layer of material, on the number of circuits that arise between the electrodes in one current pulse, on the mechanism of action of processes that cause material erosion, as applied to the complex of phenomena accompanying electrical erosion in granular material. The data on the formation of the discharge channel and the dynamics of the formation of dimples on the surfaces of the reactor loading elements are decisive when choosing the operating parameters of installations for the implementation of various technological processes. It is associated with the discreteness of mass release from the contact zones of the existence of a spark discharge and the mechanism of post-discharge cooling processes and chemical reactions of erosion products with the environment.

The rate of mass release in the anode and cathode spots of the current-conducting reactor charge depends on the surface temperature of the interacting elements. A preliminary analysis of the phenomenon under study allows us to assert that, in the first approximation, the total energy of the capacitor bank is distributed in equal portions between the anode and cathode.

Technological processes associated with the production and use of a finely dispersed phase of various metals have found wide multipurpose application. One of the ways to obtain a finely dispersed phase is pulsed electric-discharge dispersion of a metal in a liquid or gaseous medium.

The discharge energy is spent on melting the metal surface with its partial evaporation in the discharge binding zone, liquid evaporation in the surface layer of the discharge channel, and on channel expansion. The distribution of energy in the indicated directions is not stationary and is determined by the dynamics of the plasma channel and the physical and chemical characteristics of the medium. In the point of impact there are formed holes filled with molten metal, which, under the influence of the electrodynamic forces of the discharge and the gas-dynamic pressure of the evaporated liquid, is ejected in the form of dispersed drops into the surrounding liquid and the zone of reduced pressure in the discharge channel. The dispersed particles size depends on the energy in the current pulse, heat capacity, surface tension, and other characteristics of the material being processed.

As a result of dispersion in water the suspension is formed. It consists of liquid metal particles and particles condensed from metal vapors. The particles actively interact with water at high local initial temperatures, entering into an oxidation reaction with the formation of metal hydroxide and hydrogen. At the same time, the oxidation of the molten metal remaining on the inner surface of the hole after the ejection of the basic of the metal into the liquid (emission factor 0.6…0.95). Insufficiently complete mathematical description of the complex physical and chemical phenomena occurring in this case complicates the study of the dispersion process.

The observation of the productivity dependence of the main technological process (metal dispersion) on the energy and technological characteristics of a pulse generator and an electric discharge reactor is necessary to determine the optimal operating modes and relevant design of equipment for waste water treatment of galvanic areas of aircraft production.

Statement of the problem and its solution

Whereas that the analytical description of impulse erosion processes is extremely difficult due to space-traveled discharges there an attempt was made to create a simplified model of the process by the method of the mathematical theory of experiment planning. The method allows to represent the process model in the form of an algebraic polynomial reflecting the dependence of the optimized parameter on the specified variables. The model allows to move along the minimal path to the optimum and perform a statistical analysis of the process. The target function Y represents a dependency of the form:

$$Y = F(x_1, x_2, \ldots, x_i, \ldots, x_n), \quad (1)$$

where x_i – energotechnological variables affecting the optimized parameter (dispersible mass); $Y = m$ – dispersible mass.

Investigation of the influence of energotechnological parameters on the productivity of metal dispersion.

On a pulsed electric discharge in water, when the dispersed metal interacts with water there are a number of factors arise that accompany the discharge – high temperatures and pressures, high-intensity alternating magnetic fields, ultraviolet radiation, powerful shock waves, water activation, etc.

The discharge energy is spent on melting the metal surface with its partial evaporation at the points of discharge attachment and on liquid evaporation near the surface layer of the discharge channel. In this case, in the discharge channel reached a high temperature $0.2 \cdot 10^4 \ldots 2 \cdot 10^4$ °C and pressure to $3 \cdot 10^8 \ldots 8 \cdot 10^8$ Pa.

Energy distribution along the discharge channel is unsteady and is determined by the dynamics of the plasma channel and the physical and chemical characteristics of the medium.

Under the influence of the electrodynamic forces of the discharge and pressure, the evaporated part of the metal and liquid, the molten and evaporated metal is thrown into the surrounding liquid.

The size of the dispersed particles depends on the energy introduced into the discharge and the rate of its input, heat capacity, surface tension, the number of crystallization centers, and other characteristics of the metal. As a result of dispersion in water, a suspension is formed of relative coarse (10…60 μm), medium (1.0…10 μm) and micronized (0.1…1.0 μm) metal particles from the melt and condensed from metal vapors.

The dielectric metal hydroxide formed on the surface of the hole and in the interelectrode gap sharply increases the electrical resistance of the circuit and the discharge switches to another section of the metal surface. In the future, this can lead, after the removal of the reaction products by the water flow, both to the excitation of electrical erosion of the area under consideration, and to its movement over the surface.

Preliminary analysis showed that the main factors affecting the specific performance of dispersion m, kg/h and energy expenditure $E = P/m$, kW·h/kg are the pulse energy J, determined by the capacity of the working (discharge) capacitor C, μF, voltage in it U_0, V, discharge duration τ_{imp}, s, the elevation of the metal layer in the electric discharge reactor H, cm, electrode area S, cm^2 and flow rate of pumped water V, l/h; current pulse frequency f, s^{-1}, which determines the pulse energy at a given voltage U_0.

As the main influence at τ_{imp} is exerted by the inductance of the discharge circuit; to reduce the inductance of the discharge circuit, the distance between the discharge capacity and the reactor was reduced to a minimum determined by the design capabilities of the installation and was equal to 25…30 cm.

To determine the mass of the dispersed material in each individual experiment, a given volume (the same in all cases) of an aqueous suspension of the dispersed material was accumulated, which settled for the same time, after which it was separated from the water by filtration. The wet sediment was dried in the drying chamber SSh-200 at a temperature of 50 °C. The mass of dispersed metal was determined by weighing on an A-3 analytical balance with an accuracy of 0.1 mg. The value of the mass of the dispersed material that precipitated out at fixed values of the factors was determined as a result of three independent experiments.

As a backfill materials in the aerospace industry widely were used: structural and alloy steels and aluminum alloys. Therefore, iron pellets were used to fill the reactor (pellet diameter – 6...8 mm), steel shavings (steel 5, steel 10, steel 20, steel 45, etc.). All measurements were performed at a voltage in the capacitor bank U = 600 V.

Experimental results (mass of dispersed material m, kg/h, and specific energy expenditures E, kW·h/kg) for materials based on iron are presented in the form of graphical dependencies are shown at the Fig. 1.

Construction and validation of predictive models

To determine the mass of the dispersed material in each individual experiment, a given volume of an aqueous suspension of the dispersed material was accumulated, which was then settled for a certain time, after which the precipitate was separated from the water by filtration. The wet sediment was dried in the drying chamber SSh-200 at a temperature of 50 °C. The mass of dispersed metal was determined by weighing on an A-3 analytical balance with an accuracy of 0.1 mg. The value of dispersed material (coagulant) mass at each experimental point was determined as a result of three independent experiments.

Based on the analysis of the experimental results there were obtained five significant factors and have been identified their affect the specific performance of dispersion, kg/h, i.e. by the amount of the obtained coagulant, and energy expenditure, kW·h/kg: current pulse frequency f, s^{-1}, capacity of the working (discharge) capacitor C, μF, which determines the pulse energy at a given voltage U_0, metal layer height in the electric discharge reactor H, cm, area of electrodes S, cm^2 and flow rate of water pumped through the reactor V, l/h.

For these factors, the approximating or model function of the target is taken in the form of an incomplete polynomial of the second degree:

$$\begin{aligned} y = {} & a_0 + a_1 \cdot f + a_2 \cdot C + a_3 \cdot H + \\ & + a_4 \cdot S + a_5 \cdot V + a_6 \cdot f^2 + a_7 \cdot C^2 + \\ & + a_8 \cdot H^2 + a_9 \cdot S^2 + a_{10} \cdot V^2 + \\ & + a_{11} \cdot f \cdot C + a_{12} \cdot f \cdot S + a_{13} \cdot C \cdot S, \end{aligned} \quad (2)$$

where f, C, H, S, V – factors affecting the performance of the dispersion process m.

After comparing the influence of each of the listed factors on the value of the dispersed mass m, it was found that three five more factors, namely the frequency f, the capacity of the discharge battery C_0, the area of the electrodes S, are decisive, since their change leads to more significant weight change (variation of parameters f = 400…1000 Hz, C = 5…20 μF, S = 5…40 cm^2 leads to an average change in mass for 400…440 %; variation of H = 1…7 cm, V = 70…400 l/h leads to an average change in mass for 100…120 %).

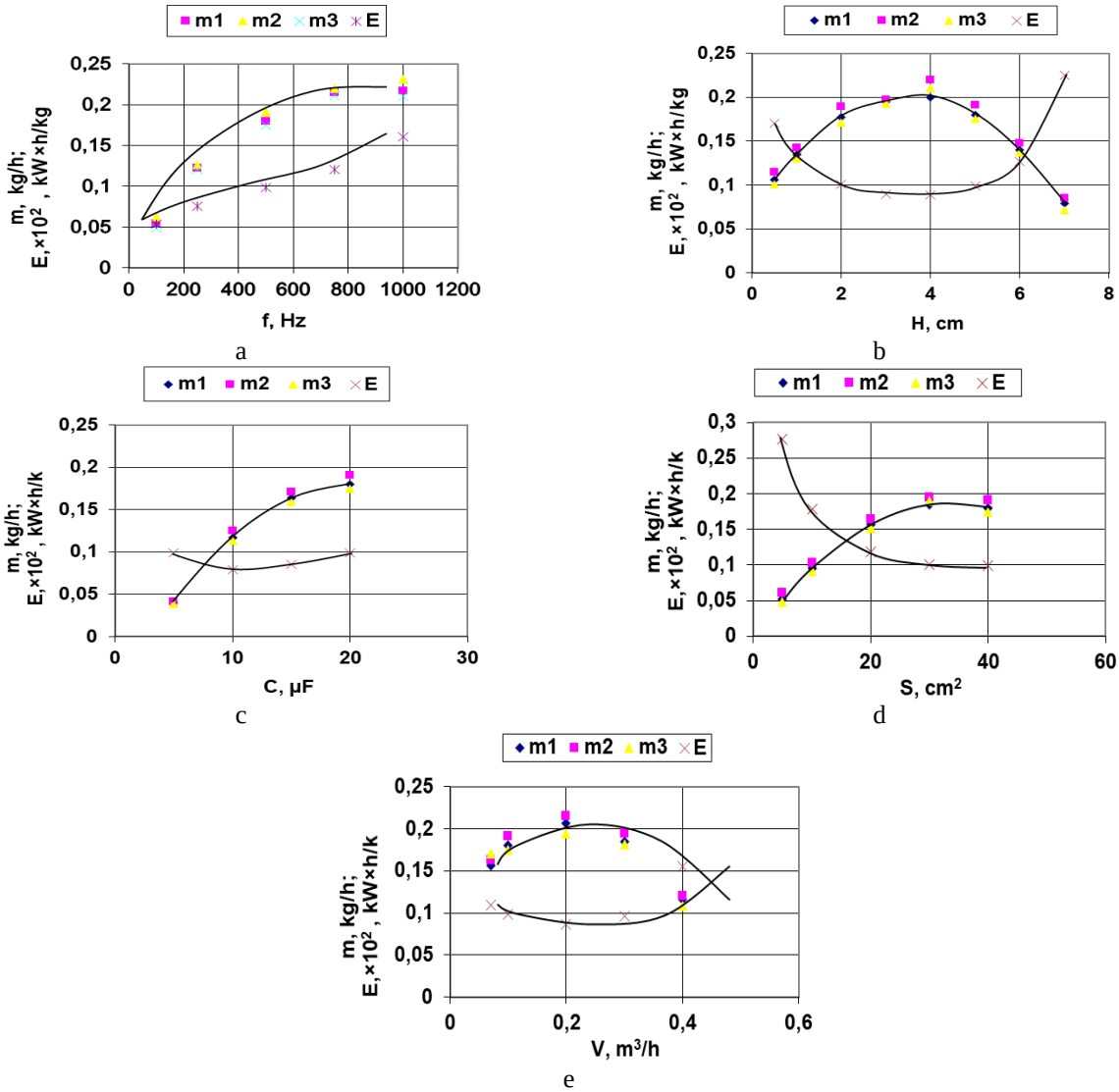


Fig. 1. Dispersed material m, kg/h and specific energy expenditures E, kW·h/kg diagrams to technological parameters for steel 20:
a – current pulse frequency f, Hz; b – backfill layer height H, cm; c – discharge capacitor capacitance C, μF; d – area of electrodes S, cm^2; e – water flow through the reactor V, m^3/h

Thus, to describe the process of metal dispersion can be used a quadratic function, which depends on five variables (factors), three of which are the most significant (f, C, S). To determine the unknown parameters a_i of such a mathematical model, a fractional factorial plan was used $N = 3^{5-2}$, in which each of the selected factors changes at three levels. Such a design of the experiment, supplemented by the results of preliminary observations, is at the same time D-optimal.

Experimental studies on the influence of factors (each factor varied at three levels) on the dispersion of the metal, the results of which are given in Table 1.

The experimental data were processed using the least square adjustment method. The calculated values of the model parameters are presented in Table 2.

Since the value of the dispersion for the model function is unknown, and the variance of the observation errors S_d was used as its estimate, the significance of the model coefficients a_i was estimated using the Student's t distribution at the significance level $\alpha = 0.05$:

$$|a_i| > t_{cr} S_i , \quad (3)$$

where t_{cr} – argument t of the distribution corresponding to $\alpha = 0.05$ and $\varphi = 44 - 14 = 30$ degrees of freedom; $S_i^2 = C_{ii} S^2$ – dispersion model parameter estimates a_i; C_{ii} – diagonal elements of the dispersion matrix, see Table 3; S – diagonal estimate errors of observation, which is calculated according to the formula (4):

$$S^2 = \sum_{i=1}^{N} \frac{(y_{av_i} - y_i)^2}{\varphi} , \quad (4)$$

where y_{av_i} – average experimental values of dispersed mass; y_i – dispersed mass value calculated by the model at the i-th point of the experiment.

Comparing the significance levels of the model coefficients and their calculated values, it is can be concluded that all the model coefficients are significant, i.e. significantly affecting the dispersible mass m.

Table 1 – Experimental studies on the influence of factors on the dispersion of the metal

No.	f	C	H	S	V	Y_n	Y_0	Y_m
0	100	20	5	40	0.1	0.055	0.062	0.049
1	250	20	5	40	0.1	0.122	0.126	0.12
2	250	20	5	25	0.1	0.111	0.119	0.11
3	250	20	5	5	0.1	0.032	0.039	0.037
4	250	15	5	40	0.1	0.102	0.11	0.099
5	250	15	5	25	0.1	0.101	0.101	0.1
6	250	15	5	5	0.1	0.029	0.033	0.025
7	250	10	5	40	0.1	0.073	0.08	0.07
8	250	10	5	25	0.1	0.072	0.072	0.072
9	250	10	5	5	0.1	0.021	0.021	0.021
10	500	20	5	40	0.1	0.18	0.191	0.175
11	500	20	5	25	0.1	0.18	0.186	0.17
12	500	20	5	5	0.1	0.052	0.061	0.048
13	500	15	5	40	0.1	0.164	0.171	0.159
14	500	15	5	25	0.1	0.16	0.165	0.158
15	500	15	5	5	0.1	0.047	0.05	0.045
16	500	10	5	40	0.1	0.117	0.125	0.113
17	500	10	5	25	0.1	0.116	0.121	0.11
18	500	10	5	5	0.1	0.036	0.037	0.033
19	750	20	5	40	0.1	0.215	0.22	0.211
20	750	20	5	25	0.1	0.185	0.19	0.191
21	750	20	5	5	0.1	0.071	0.075	0.072
22	750	15	5	40	0.1	0.181	0.186	0.185
23	750	15	5	25	0.1	0.17	0.175	0.171
24	750	15	5	5	0.1	0.056	0.06	0.051
25	750	10	5	40	0.1	0.139	0.147	0.135
26	750	10	5	25	0.1	0.138	0.147	0.133
27	750	10	5	5	0.1	0.0412	0.044	0.04
28	1000	20	5	40	0.1	0.217	0.231	0.21
29	500	20	0.5	40	0.1	0.106	0.115	0.101
30	500	20	1	40	0.1	0.135	0.142	0.13
31	500	20	2	40	0.1	0.177	0.189	0.171
32	500	20	3	40	0.1	0.195	0.197	0.193
33	500	20	4	40	0.1	0.2	0.22	0.21
34	500	20	6	40	0.1	0.14	0.148	0.137
35	500	20	7	40	0.1	0.079	0.085	0.071
36	500	20	5	10	0.1	0.095	0.103	0.091
37	500	20	5	20	0.1	0.157	0.164	0.151
38	500	20	5	30	0.1	0.185	0.195	0.19
39	500	20	5	40	0.07	0.163	0.171	0.156
40	500	20	5	40	0.2	0.206	0.215	0.199
41	500	20	5	40	0.3	0.185	0.194	0.181
42	500	20	5	40	0.4	0.116	0.12	0.108
43	500	5	5	40	0.1	0.04	0.041	0.039

To assess the adequacy of the model obtained at each experimental design two additional tests were conducted (see Table 1). When checking the adequacy, the achieved accuracy of the S_d model was compared with the value characterizing the observation accuracy S_e:

$$S_d^2 = \sum_{i=1}^{44}\left(y_{avi} - y_i^m\right)^2 \cdot \nu = 2.039 \cdot 10^{-3}, \qquad (5)$$

where ν – number of tests at each point in the plan, (ν =3);

$$S_e^2 = \sum_{i=1}^{44}\sum_{j=1}^{3}(y_{ij} - y_{avi})^2 = 4.093 \cdot 10^{-3}, \qquad (6)$$

where y_{ij} – experimental values of the dispersed mass at the i-th point of the experiment in the j-th test.

The model was tested using Fisher distribution F. In this case, the hypothesis was used that if the model is adequate, then relation (7) has the Fisher distribution with φ_1 and φ_2 degrees of freedom:

$$F = \frac{S_d / \varphi_1}{S_e / \varphi_2} = 1.461. \qquad (7)$$

For the significance level $\alpha = 0.05$ and

$$\varphi_1 = N - (k+1) = 44 - 14 = 30,$$

$$\varphi_2 = N(\nu - 1) = 44 \cdot 2 = 88$$

critical value of the Fisher distribution argument is equal to F_{cr}= 1.589, which is bigger than F = 1.461.

Thus, the ratio of the achieved model accuracy to the observed accuracy is less than F_{cr} and, therefore, with the probability $P = 1 - \alpha = 1 - 0.05 = 0.95$, it can be argued that the presented model is adequate.

The values of the coefficients of the model, obtained by the least square adjustment method, and their confidence intervals are given in Table 3. Thus, the final expression for the mathematical model of the metal dispersion process has the form:

$$\begin{aligned} y = {} & -0{,}354 + 0{,}245 \cdot f + 0{,}29 \cdot C + \\ & + 0{,}552 \cdot H + 0{,}188 \cdot S + 0{,}395 \cdot V - 0{,}242 \cdot f^2 - \\ & - 0{,}188 \cdot C^2 - 0{,}514 \cdot H^2 - 0{,}196 \cdot S^2 - 0{,}388 \cdot V^2 + \\ & + 0{,}056 \cdot f \cdot C + 0{,}314 \cdot f \cdot S + 0{,}1 \cdot C \cdot S, \end{aligned} \qquad (8)$$

where f, C, H, S, V – relative values of factors obtained by dividing current values by their respective maximum values (f_{max} = 1000 Hz, C_{max} = 20 μF, H_{max} = 7 cm, S_{max} = 40 cm^2, V_{max} = 0.4 m^3/h).

It is known that the surface of metals processed in an electropulse reactor, is a set of overlapping crater holes. The formation of these holes, their shapes and sizes determine the amount and rate of melting, evaporation and ejection of the material, the characteristic particle sizes.

Materials with high melting and boiling points and thermal conductivity have been found to be highly resistant to erosion. Analysis and comparison of experimental data and heat-physical constants of materials showed that the amount of erosion decreases with the increase of heat of melting and evaporation of the unit mass of the material. In this case, depending on the duration of the discharge pulse and its specific power, the substance from the hole, the size of which depends on the parameters of the pulse, will be discharged in the molten or vapor state.

Table 2 – The value of the model coefficients a_i and their confidence intervals

a^T=		0	1	2	3	4	5	6	7	8	9	10	11	12	13
	0	–0.354	0.245	0.29	0.522	0.188	0.395	–0.242	–0.188	–0.514	–0.196	–0.388	0.56	0.134	0.1
dt^T=		0	1	2	3	4	5	6	7	8	9	10	11	12	13
	0	–0.371	0.224	0.258	0.503	0.175	0.361	–0.257	–0.207	–0.532	–0.205	–0.417	0.038	0.124	0.09
	1	–0.338	0.256	0.322	0.541	0.202	0.429	–0.227	–0.169	–0.495	–0.187	–0.359	0.075	0.145	0.11

Table 3 – Dispersion matrix of the experiment

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	13.41	–8.08	–19.97	–3.13	–2.88	–10.64	2.74	9.91	2.54	–0.37	9.16	5.46	0.65	3.18
2	–8.08	20.38	6.44	3.24	–0.63	–1.62	–10.19	–1.13	–2.56	0.59	0.65	–10.38	–1.00	0.75
3	–19.97	6.44	49.92	–2.58	3.17	1.29	–0.80	–27.81	2.03	1.90	–0.52	–8.04	1.42	–6.84
4	–3.13	–2.58	–2.58	17.48	–2.38	–2.21	–3.52	1.20	–16.20	1.09	0.89	0.31	0.17	1.83
5	–2.88	3.17	3.17	–2.38	8.95	1.19	1.58	–1.04	1.88	–4.12	–0.48	1.19	–2.82	–3.27
6	–10.64	1.29	1.29	–2.21	1.19	56.04	1.76	–0.60	1.74	–0.55	–47.70	–0.16	–0.09	–0.92
7	2.74	–0.80	–0.80	–3.52	1.58	1.76	11.47	1.33	2.78	–0.63	–0.71	–1.42	–0.77	–0.78
8	9.91	–27.81	–27.81	1.20	–1.04	–0.60	1.33	18.02	–0.95	–1.05	0.24	–0.22	–0.12	2.35
9	2.54	2.03	2.03	–16.20	1.88	1.74	2.78	–0.95	16.03	–0.86	–0.70	–0.25	–0.13	–1.45
10	–0.37	1.90	1.90	1.09	–4.12	–0.55	–0.63	–1.05	–0.86	3.95	0.22	0.05	0.02	–0.51
11	9.16	–0.52	–0.52	0.89	–0.48	–47.70	–0.71	0.24	–0.70	0.22	41.70	0.06	0.03	0.37
12	5.46	–8.04	–8.04	0.31	1.19	–0.16	–1.42	–0.22	–0.25	0.05	0.06	16.66	–2.53	0.04
13	0.65	1.42	1.42	0.17	–2.82	–0.09	–0.77	–0.12	–0.13	0.02	0.03	–2.53	5.55	0.02
14	3.18	–6.84	–6.84	1.83	–3.27	–0.92	–0.78	2.35	–1.45	–0.51	0.37	0.04	0.02	4.83

In addition to the amount of discharge energy and its duration, the amount of material ejected from the hole is significantly affected by the interelectrode gap (the distance between the electrodes). If the breakdown between the electrodes is carried out in direct contact between them or at a gap in 1…3 μm, the formation of the holes proceeds in such a way that the processes on the cathode and on the anode are so identical, that the holes are almost indistinguishable.

To determine the amount of metal to be removed from the electrode surface.

1. The technique of a large number of consecutive pulses initiated with a given frequency and frequency at a fixed charge-discharge circuit characteristics. Using this method, the above physical and mathematical model of metal dispersion process in water is constructed.

2. The method of unit holes, which allows to precisely determine and maintain the conditions of interelectrode gap and parameters of electric discharge, formed hole.

The method of unit holes for determining the amount of electrode erosion is as follows. In real conditions of electrode material dispersion at specified energy and pulse duration, unit discharges are carried out between the polished surfaces of the examined materials (anode-cathode), leaving the corresponding marks on the studied surface in the form of separate holes. Then, microscopically, the electron raster system of low vacuum REM-106 microphotographed the surface of the hole and its cross-section. Pre-prepared the grinding of the corresponding section.

Fig. 2 gives the typical microphotographs of the holes (Fig. 2, a, b) and the corresponding transverse profiles (Fig. 2, c, d), obtained on the steel 20 electrode.

Transverse profiles were photographed in 3-4 hole sections. The studies were carried out with two values of energy directed to electrodes: $W = 25 \cdot 10^{-3}\,\text{J}$ (Fig. 2, a, c) and $W = 50 \cdot 10^{-3}\,\text{J}$ (Fig. 2, b, d), corresponding to the discharge capacity $C = 20 \cdot 10^{-6}\,\text{F}$ and voltage of $U = 71\,\text{V}$ and $U = 50\,\text{V}$.

The holes at the photographs are characterized by a low depth and uneven bottom. The diameter of the holes is 150…200 μm, the depth is 15…32 μm. The holes are framed by a fairly clear cushion width 5…10 μm, its height does not exceed 2…2.5 μm.

The volume of the hole corresponding to the profile obtained (it was assumed that the profile corresponds to a semi-ellipsoid of rotation):

$$V = 2.095 \cdot R^2 \cdot h, \qquad (9)$$

where $R = D/2$ – the radius of the equivalent area of the horizontal cross-sectional image of the hole; h – the depth of the hole at the level of the original surface.

The hole volume was also calculated using the formula:

$$V = \sum_{i=1}^{n} S_i \cdot \delta x_i \qquad (10)$$

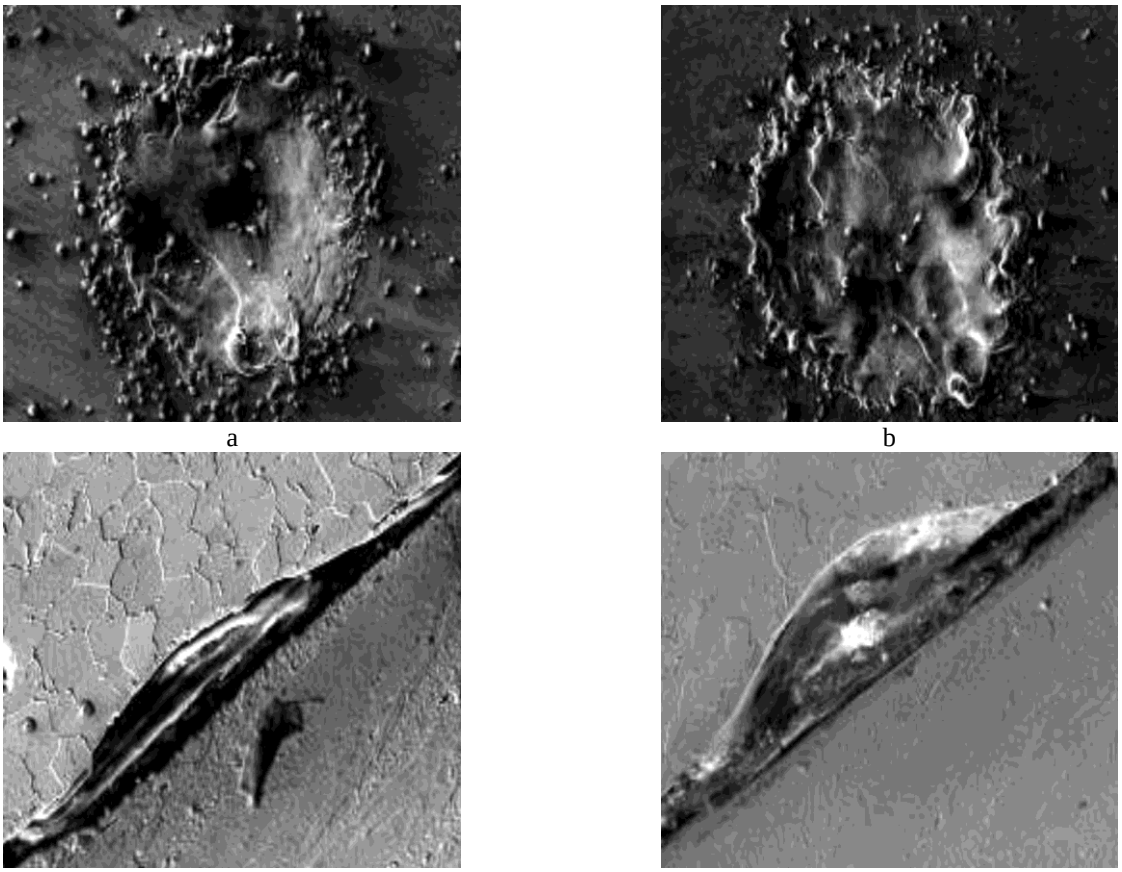
where S_i – the area of the hole's i -cross-section, δx_i – the distance between the sections.

The volume of metal removed from the unit pit at $W = (25..50) \cdot 10^{-3}\,\text{J}$, calculated by formula (9) is $(0.250...0.695) \cdot 10^{-6}\,\text{cm}^3$, and the mass of the discarded metal (steel 20) $m = (1.90..5.29) \cdot 10^{-6}\,\text{g}$. The difference between the volumes calculated according to the formulas (9) and (10) shall not exceed 20...30 %.

This can be explained by the fact that the hole during the discharge does not have time to fully form. The molten metal in the hole is affected by hydrodynamic, electromagnetic forces, a spot pressure at the bottom of the hole, etc. Metal discharge occurs when these forces are combined when the internal bonds of metal atoms are weakened by melting and evaporation.

At the same time, not all phase-transformed metal is discarded from the hole into the environment. At the bottom of the holes there are characteristic protrusions and flows of metal, having the appearance of islets of irregular shape. This may be explained by the fact that the electrical discharge in the process is not sufficiently effective to emit all the particles of the molten and evaporated metal.

In addition to the microirregularities on the surface of the hole, it is necessary to note the presence of metal droplets in the form of spherical formations surrounding the hole. This is due to the fact that the metal that is thrown from the hole and falls on the surface of the electrode is welded to it in the form of drops. The volume of metal in the form of spherical droplets welded on the electrode surface is up to 15…20 % of the volume of metal ejected from the hole.



a b c d

Figure 2 – Microphotographs of the holes (a, b) and their corresponding transverse profiles (c, d)

Conclusion

Presented physical and mathematical model and experimental data confirm the dependence of the magnitude and nature of the electric pulse erosion of the material on the dispersion conditions.

This paper presents the results of an experimental investigation of energy technology factors influence on the dispersion of metal in an electroerosive reactor. A mathematical model of the dependence of the process productivity and specific energy expenditure has been obtained. The results of an experimental investigation of the discharge dimple on a microscope REM 106 for steel electrodes are presented.

An analysis of the above results shows that the general character of the discussed characteristics for both materials is approximately identical, although there are some peculiarities.

1. The dependence of the specific performance of the coagulant m(f) and energy expenditure E(f) in the frequency range 100…1000 Hz has a pseudo-linear character. In the range of the indicated frequencies for this type of reactor, the concentration of the coagulant increases with increasing frequency and tends to saturation. An increase in the discharge frequency above 800…1000 Hz leads to unstable operation of the reactor due to sintering of the charge particles.

2. The dependence of $m(C_0)$ and $E(C_0)$ on the discharge capacity shows acceptable values at $C_0 = 10…20$ μF, providing relatively low energy expenditure with good product quality. At $C_0 > 20$ μF, the specific component of coarse particles increases and thus the content of metallic iron and aluminum in the resulting coagulant increases due to their underoxidation.

3. The formation of a coagulant is also influenced by the mass of the backfill (pellets, shavings, granules) of the metal, the equivalent of which is the height of the backfill layer H, which determines the static pressure of the particles on each other and their mobility, which determines the quality of contact between the granules and the value of the ohmic resistance of the reactor at the time of passage primary electrical impulse. At a low filling elevation, it is observed a small number of particles participating in the discharge, and a small mass of the produced coagulant. With an increase in the loading height, the number of contacts between the filling elements increases, which leads to an increase in the mass of the dispersed material, and, consequently, of the coagulant. A further height increase of the charge leads to a decrease in the output of the coagulant due to an increase in pressure in the charge and a decrease in their mobility (lower layers of the charge), which can lead to a short circuit and a decrease in metal ejection.

The analysis of the given results shows that the optimal height is 3...5 cm for the selected modes and reactor geometry. This range can be expanded by increasing the pulse energy, i.e. due to the growth of capacitance, voltage and discharge frequency.

4. Influence of electrode area and power consumption performance initially contributes to these quantities proportional to the area increase. With an increase in the active area of the electrodes over 50 cm^2 for a given reactor, which leads to an increase in the

total number of discharges and, consequently, to a decrease in the energy of an individual discharge, the amount of dispersed metal decreases. With large areas of electrodes, it is necessary to increase the power supplied to the reactor.

5. At low water flow rates through the reactor, less than 200 l/hr, dispersion products are poorly removed, and discharge gaps become silted up. With an increase in the water consumption, there is a "gushing" of the shavings (backfill) with a hydraulic flow, which reduces the number of discharges. An increase in the mass of the reactor load and the input power expands the "stable" range of the installation during the dispersion process.

Therefore, based on the analysis of the experimental results there were obtained five significant factors: current pulse frequency f, s^{-1}, capacity of the working (discharge) capacitor C, μF, metal layer height in the electric discharge reactor H, cm, area of electrodes S, cm^2 and flow rate of water pumped through the reactor V, l/h, which affect the productivity of the metal dispersion process, i.e. by the amount of the obtained coagulant.

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ЕЛЕКТРОІМПУЛЬСНА ЕРОЗІЯ ЕЛЕКТРОДІВ У РІДКОМУ СЕРЕДОВИЩІ ПРИ ОЧИЩЕННІ ГАЛЬВАНІЧНИХ СТІЧНИХ ВОД

Актуальною є проблема якісного очищення стічних вод гальванічних виробничих дільниць. Найбільш відповідним методом очищення стічних вод такого типу є електроімпульсний метод.

В даній статті представлені результати дослідження залежності продуктивності основного технологічного процесу (диспергування металу) від енергетичних і технологічних характеристик генератора імпульсів і електророзрядного реактора. Результати дослідження необхідні для визначення оптимальних режимів роботи та адекватного конструювання обладнання для очищення стічних вод гальванічних виробничих дільниць авіаційного виробництва.

Представлені фізико-математична модель і експериментальні дані підтверджують залежність кількості і характеру електроімпульсної ерозії матеріалу від умов диспергування.

Таким чином в роботі представлено результати експериментального дослідження впливу енергетично-технологічних факторів на диспергування металів в електроерозійному реакторі. Отримано математичну модель залежності продуктивності процесу та питомої витрати енергії. Наведено результати експериментального дослідження розрядної лунки на мікроскопі REM 106 для сталевих електродів.

Ключові слова: обробка стічних вод, розряди імпульсу, диспергування, ерозія електродів.

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