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Mathematical Modeling of EDM Method of Water Purification

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***Abstract*— There are known many approaches for water purification at the present time. New technologies are developed to improve the efficiency of water purification plants. Electrical discharge machining process is started to use for this reason. The paper addresses the mathematical modeling of the water purification process by means of electrical discharge machining method.**

***Index Terms*—electrical discharge machining, mathematical model, metal balls, water purification.**

I. Introduction

The access for safe drinking water is main problem in Russia and the all world in recent times. On top of that, there is a problem connecting with sewage water purification in industry. It is adversely affected on humans and environment. Therefore, water resources development is critical task for all countries.

Generally, modern water purification plants are organized a sequential multistage process of water purification in consequence of the large variety of pernicious contraries [4, 5]. Nowadays, there are known many approaches to water purification: sedimentation, reagent deposition [1], oxidation, reverse osmosis [2, 3], extraction, and evaporation. They are become widely used in practices, but they are offered several disadvantages:

- Reagent strong flow;
- Necessity of huge installations for sedimentation and deposition;
- High cost;
- The absence of cleaning from toxic substances;
- Water high flow for own needs.

Thus, development of resource efficient and soft technologies for water purification is become the main objective. Scientists from Tomsk Polytechnic University offers to use metal electrical erosion for sewage water purification from the wide variety of harmful impurities.

This work proposes the math model development of electrosparking water purification process. It will be used for control system development of the electrosparking water purification plant and energy cost optimization of water conditioning and purification process.

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II. Electrosparking Method of Water Purification

In the following sections, the metal electrical discharge machining (EDM) process and its implementation for water purification will be reported.

A. EDM process

B.R. Lazarenko offered EDM process in 1943. This process is based on particles evolution from the surface by using short-length electrical impulses. The scheme EDM process is reported in Figure 1.

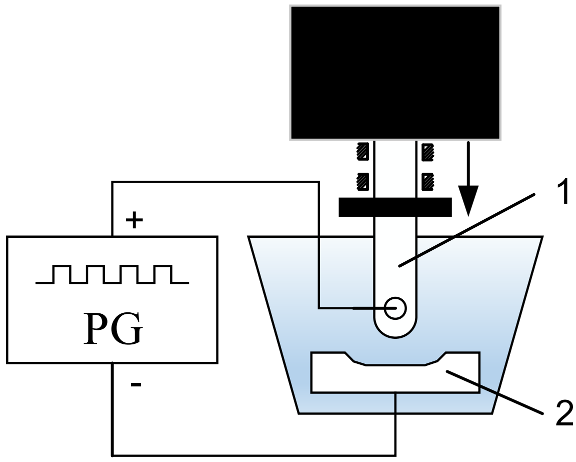

Fig. 1. The scheme of EDM process

The scheme is powered by impulse voltage of different polarity. The electrode (1) and the workpiece (2) are bound up in the sheath fluid with low dielectric constant. There is happen dielectric breakdown when the electrode and the workpiece are come closer together. Liquid is brought to boil and made the gas cavity from the liquid vapor. Next, the electric discharge is advanced in the gas phase. This is a reason of local workpiece heating. At the result, material surface is melted. This part is cooled in liquid and it is lifted out from the area clearance. Released heat is not spread deeper into the material in response to getting short-length electrical impulses.

Processing speed is defined by parameters of electrical

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impulses (length, frequency, capacity) [6].

Nowadays EDM process is widely used for grinding and slicing operation.

B. Electrosparking water purification

The technology of water purification based on EDM method will reported in this section.

The reactor tank is filled by metal balls with a 1.5 – 2 cm in diameter. Water with harmful impurities is leaked out through the tank. Short-length electrical impulses energize metal balls. EDM process is occurred on the balls surface. Products of erosion are metal fine particles. Size of particles is 1-100 nm. EDM process of water purification is reported in Figure 2.

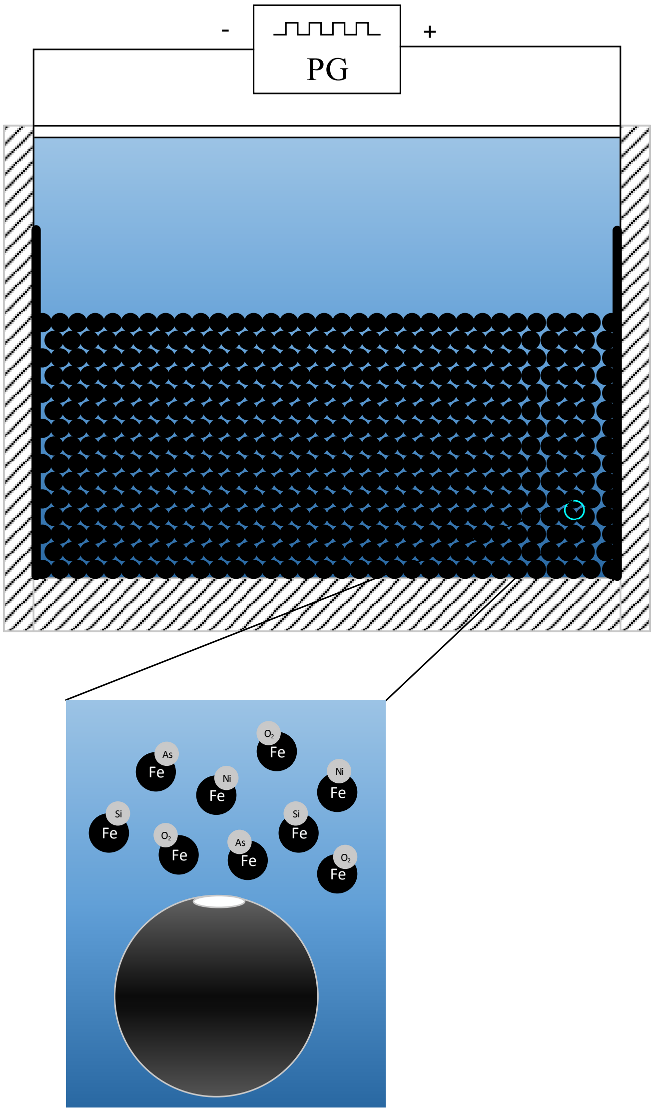

Fig. 2. EDM process of water purification

During the process, products of erosion is oxidized by water and oxygen. It is described by following reactions:

$$Fe+H_2O \rightarrow FeO+H_2$$
$$FeO+Fe_2O_3 \rightarrow Fe_3O_4$$
$$4FeO+O_2+2H_2O \rightarrow 4FeOOH$$
$$2Fe(OH)_2+0.5O_2+H_2O \rightarrow 2Fe(OH)_3$$

Generated hydroxides and metal oxides are activated coagulants, which catch harmful impurities.

Naturel water and sewage water include ions of different salts. Present paper reports evacuation process of As^- and Ni. Purification process is described by following chemical reactions:

$$FeOOH + H_3AsO_4 \rightarrow FeO(H_2AsO_4) + H_2O$$
$$2Fe(OH)_3 + Ni(OH)_2 \rightarrow NiFe_2O_4 + 4H_2O$$

Adsorbed harmful substances are removed from the treated water during sedimentation and deposition processes.

III. Mathematical Model

There is expected of chemical process modeling and physical modeling at the same time. A conceptual model for EDM process is reported in Figure 3.

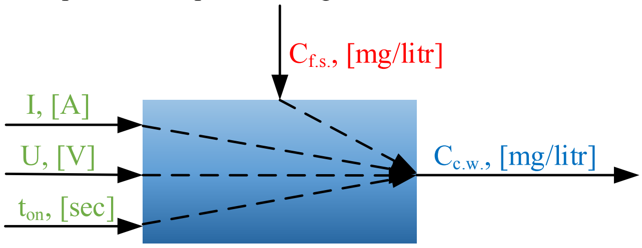

Fig. 3. Conceptual model for EDM process

The purification process depends on EDM processing speed, which is governed by parameters of electrical impulses.

Thus, concentration of harmful substances in filtered water is outcome variable of modeling object ($C_{c.w.}$, mg/l). Concentration of harmful substances in initial water ($C_{f.s.}$, mg/l) and parameters of electrical impulses are income variable.

The Equation 1 describing components concentration change is out of electrosparking poder analysis [7].

$$\frac{dC_i}{dt} = -k_i \cdot M_{Fe} \cdot C_i \qquad (1)$$

where: C_i – concentration of components, mg/l; k_i – speed constant, mg/(l·sec); M_{Fe} – products mass.

Value of effective constants for ions is reported Table 1. Cations are slowly than anions.

TABLE I
EFFECTIVE CONSTANTS FOR ANION AND CATION

Ion	$H_3AsO_4^-$	Ni^{2+}
k_i	$8 \cdot 10^{-4}$	$9 \cdot 10^{-5}$

Components concentration is determined by mass value determination of electroerosion products. At the result of EDM process, small holes are generated on the ball's surface. Mass value determination of electroerosion products is proportional to volume of generated holes.

There are assumptions for the system:

- the electrical discharge effects to the ball;
- the radius of the hole is a function of amperage and discharge duration;
- there is not electroerosion products on the ball's surface;
- the hole is a segment of ball, which has constant size;
- temperature in the system is constant.

The scheme of the hole is reported in Figure 4

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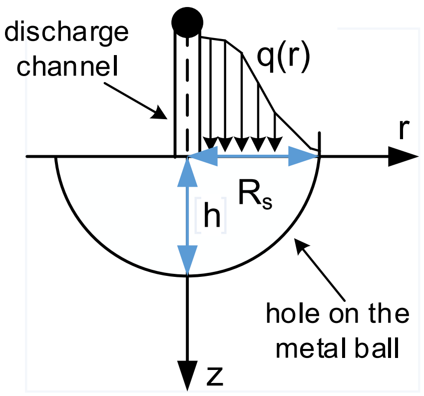

Fig. 4. The hole's scheme

Temperature distribution is described by Fourier heat conduction equation [8]:

$$\frac{\partial^2 T}{dx^2}+\frac{\partial^2 T}{dy^2}+\frac{\partial^2 T}{dz^2}+\frac{q(r)}{K}=\frac{1}{\alpha}\cdot\frac{\partial T}{\partial t} \quad (2)$$

$$\alpha=\frac{K}{\rho\cdot c_\rho} \quad (3)$$

where: T - temperature (K); x, y and z are coordinates of the cartesian coordinate system, $q(r)$ heat transfer rate (W/m^2); K - the thermal conductivity (W/m·K); t - time (sec); ρ - the mass density (kg/m^3); c_ρ - specific heat (J/kg·K).

Heat transfer rate or quantity of energy having Gaussian distribution is equal:

$$q(r)=\frac{4.45\cdot P\cdot V\cdot I}{\pi\cdot R_S^2}\cdot\exp\left(-4.5\cdot\left(\frac{r}{R_S}\right)^2\right) \quad (4)$$

where: P is fraction of heat going to work piece; V - discharge voltage (V); I - discharge rate (A), R_S - spark radius (m). A spark radius is described by following equation [9]:

$$R_S=2.04\cdot exp(-3)\cdot I^{0.43}\cdot t_{on}^{0.44} \quad (5)$$

where: t_{on} impulse duration (ms).

It is necessary to determine the depth of holes for value determination of electroerosion products. The depth of the hole depends from thermal conductivity of material, boiling temperature and heat flow rate on the ball's surface. It is described by equation 6:

$$h=\frac{q(r)}{K\cdot(T_m-T_0)} \quad (6)$$

where: h - depth of the hole (m); T_m Fe boiling temperature (K); T_0 initial temperature of balls in the plat (K).

Based on the assumption, volume of generated hole is equal:

$$V_h=\pi\cdot h^2\cdot\left(R_S-\frac{h}{3}\right) \quad (7)$$

Mass value determination of electroerosion products is equal:

$$M_{Fe}=\rho\cdot V_h \quad (8)$$

Time of hole generation shorter than time of electrical impulse. Time of hole generation, which needs for determination of number of generated holes during one electrical impulse, is equal:

$$\Delta t=\frac{h}{v_K} \quad (9)$$

Number of generated holes during one electrical impulse is equal:

$$N=\frac{t_{on}}{\Delta t} \quad (10)$$

Thus, mass value of electroerosion products during one electrical impulse is equal:

$$M_{Fe}=N\cdot\rho\cdot V_h \quad (11)$$

where: ρ Fe mass density (kg/m^3), V_h volume of electroerosion products (m^3).

Accumulation of electroerosion products is equal:

$$\frac{dM_{Fe}}{dt}=N\cdot\rho\cdot V_h \quad (12)$$

Thus, EDM process of water purification is obtained by solving following simultaneous equations:

$$\begin{cases}\frac{dC_i}{dt}=k_i\cdot M_{Fe}\cdot C_i\\ \frac{dM_{Fe}}{dt}=N\cdot\rho\cdot V_h\\ V_h=\pi\cdot h^2\cdot\left(R_S-\frac{h}{3}\right)\\ h=\frac{q(r)}{K\cdot(T_m-T_0)}\\ q(r)=\frac{4.45\cdot P\cdot V\cdot I}{\pi\cdot R_S^2}\cdot\exp\left(-4.5\cdot\left(\frac{r}{R_S}\right)^2\right)\\ R_S=2.04\cdot exp(-3)\cdot I^{0.43}\cdot t_{on}^{0.44}\end{cases} \quad (13)$$

IV. RESULTS AND DISCUSSIONS

The mathematical model of electroerosion water purification is implemented by using MATLAB.

Initial parameters of electrical impulse is set:
$I = 500$ A, $U = 800$ V, $t_{on} = 10^{-6}$ sec.

Quantity of energy on the surface of the ball is computed by using Eq. 4. Result is reported in Figure 5.

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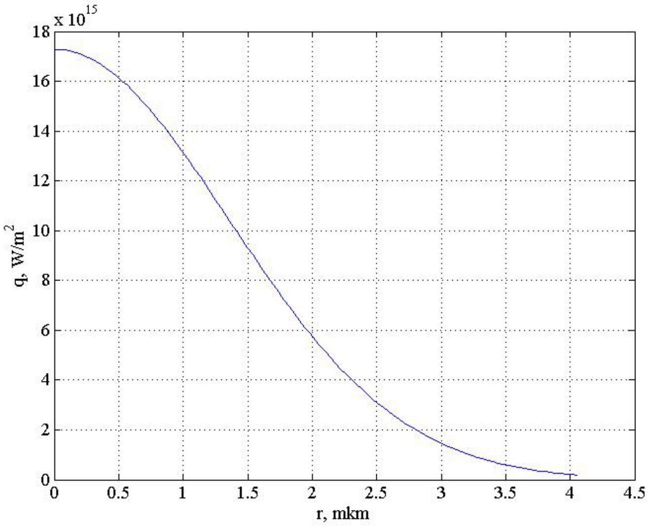

Fig. 5. Energy on the ball’s surface generated during EDM process

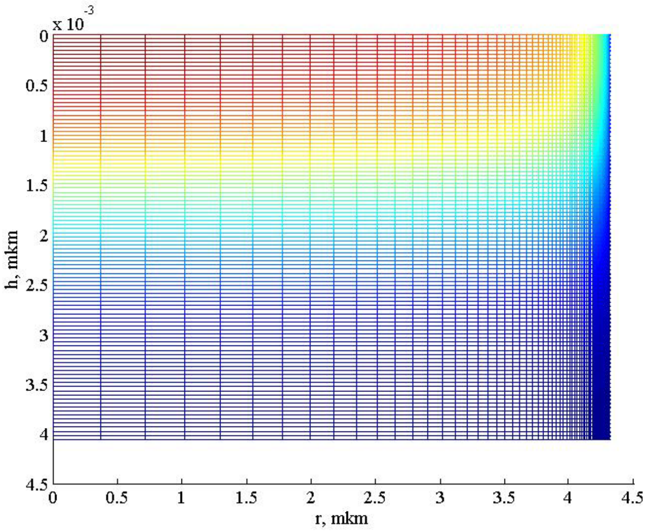

Fig. 6. Temperature distribution inside the ball

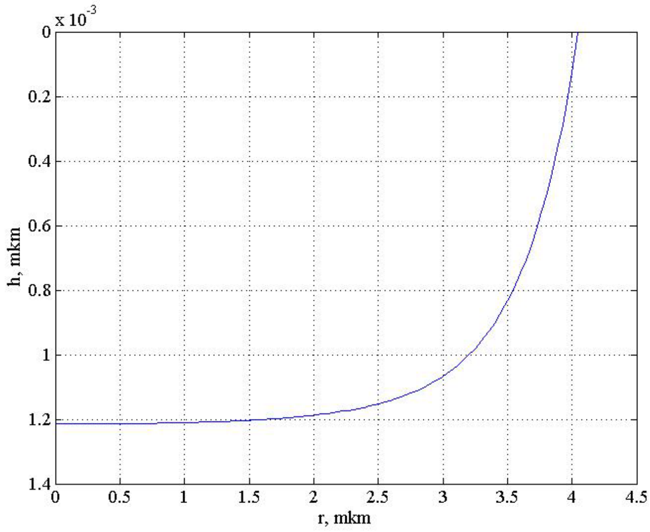

Fig. 7. An axi-symmetric image of generated hole

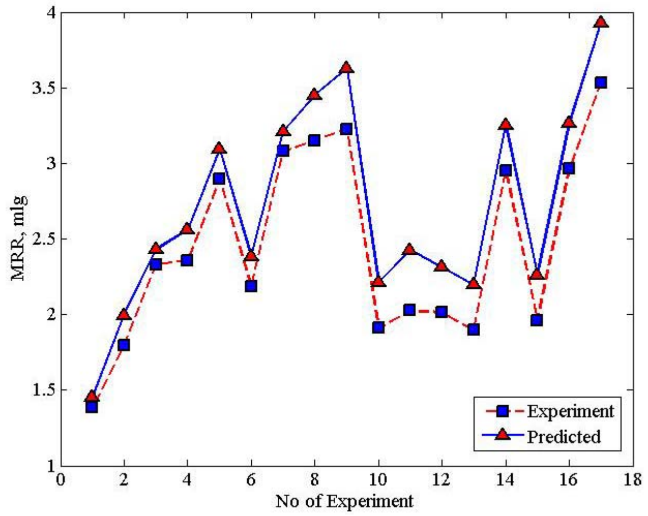

Fig. 8. Comparison of predicted MRR with experimental value

An axi-symmetric two dimensional distribution of energy is reported in Figure 5. It shows, that energy (heat transfer rate), moving from the epicenter of the electric discharge, is dispersed by the normal distribution law.

Temperature distribution inside the ball is presented in Figure 6.

The hole is generated as a result of influence of heat transfer rate. Parameters of the hole are computed by using Eq. 6 – 7. An axi-symmetric two dimensional image of generated hole is reported in Figure 7.

Volume of generated hole and mass value of electroerosion products during one electrical impulse are computed by using Eq. 7 –11.

Based on results of study [10], it was made sensitive analysis of developed model of EDM process for water purification Results of both experiments are reported in Figure 8.

Material removal rate (MRR) is used to associate computational data with experimental data [10] taking into account initial values of study [10]. The A discrepancy between experimental and computational data is equal 10,3 %. It is explained by the assumption that there is no accumulation of recast layers on the machined surfaces.

Concentrations of harmful substances in filtered water is computed by using Eq. 1. Ions of arsenic (As^-) and nickel (Ni^+) are main harmful substances in the system. Initial concentrations of ions are equal 5 mg/l for both. Results are reported in Figure 9.

Concentrations of both harmful substances are decreased in time (Fig. 9). Based on different chemical and physical properties of this substances, As^- ions are deduced from the system faster than Ni^+ ions.

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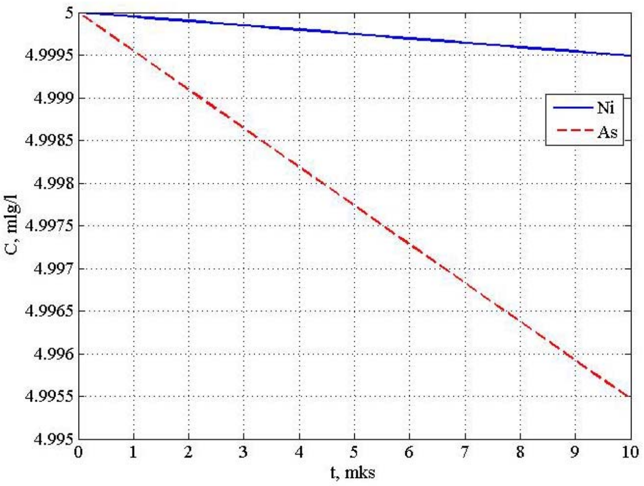

Fig. 9. Changing of concentrations of harmful substances.

In the next work, mathematical model will improved for element's size determination taking into account plant's geometrical adjectives.

It plans to keep energy costs down for EDM process of water purification and to increase the degree of purification.

V. Conclusion

In this study, developed mathematical model for EDM process of water purification was described. This model allows to consider amount of adsorbed substances on products. Model is adequate, a discrepancy between experimental and computational data is equal 10 %.

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