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PROGRAMMING A NUMERICAL MODEL OF SPHERICAL PROPAGATION OF ELECTRIC DISCHARGE IN LIQUID

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***Abstract**. The subject of research is the determination of the hydrodynamic parameters of a liquid in the process of an electric discharge in a liquid. A numerical algorithm was constructed and a program was drawn up to determine the hydrodynamic parameters of a liquid in the process of an electric discharge in a liquid for a spherical problem. In the numerical solution of the problem, a uniform rectangular grid was used. Some results of computational experiments are presented.*

***Keywords:** electric discharge in liquid, spherical problem, numerical simulation, finite-difference equation, density of fluid.*

***Аннотация.** Tadqiqot predmeti suyuqlikdagi elektr razryad jarayonidagi suyuqlikning gidrodinamik parametrlarini aniqlashdan iborat. Sferik masala uchun suyuqlikdagi elektr razryad jarayonidagi suyuqlikning gidrodinamik parametrlarini aniqlash uchun sonli algoritm tuzildi va dastur tuzildi. Masalani sonli yechishda bir xil to‘rtburchakli to‘rdan foydalanilgan. Hisoblash tajribalarining ba’zi natijalari keltirilgan.*

***Tayanch so‘zlar:** suyuqlikdagi elektr zaryadsizlanishi, sferik masala, sonli modellashtirish, setkali tenglama, suyuqlik zichligi.*

***Аннотация.** Предметом исследования является определение гидродинамических параметров жидкости в процессе электрического разряда в жидкости. Построен численный алгоритм и составлена программа определения гидродинамических параметров жидкости в процессе электрического разряда в жидкости для сферической задачи. При численном решении задачи использовалась равномерная прямоугольная сетка. Представлены некоторые результаты вычислительных экспериментов.*

***Ключевые слова:** электрический разряд в жидкости, сферическая задача, численное моделирование, сеточное уравнение, плотность жидкости.*

Introduction

Impulsive energy technology is widely used in various fields of production and processing of useful materials. A brief review presented in [1] shows the advantage of the method with a high-voltage discharge current in the production of porous materials from powders of titanium, niobium and tantalum. Recycling useful materials such as metals and plastics is rated as important in terms of conserving resources and protecting the environment. In this regard, the use of impulsive energy technology [2] in the field of utilization has attracted considerable attention.

Experimental studies of the phenomena occurring in drops of various liquids under the action of nanosecond spark discharges [3] have shown the need to pay attention to hydrodynamic and physicochemical phenomena in drops. Experimental and theoretical studies carried out on partial discharges in liquids [4] showed that an additional source of ionizing radiation (X-rays) should be used to generate partial discharges under these conditions.

The use of this process in a liquid also has its application in the processing of various materials, stamping, crushing, and inthe food industry [5]. In this case, mathematical modeling of hydrodynamic processes during an electric discharge in water is a way to find the optimal parameters of this process.

From a hydrodynamic point of view, an electric discharge in a liquid is considered a process of expansion of a cavity in a liquid. The dynamics of the cavity can be described by an analytical solution [6] or determined by numerical methods for problems of gas dynamics [7, 8]. The process of fluid flow behind the cavity can be determined by the equations of hydrodynamics [9].

Experimental studies of an electric discharge in a liquid in order to determine the hydrodynamic parameters were conducted at a considerable distance

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from the source. Theoretical studies also refer to areas located far from the discharge channel.

A mathematical model of an electric discharge in a liquid is proposed, which determines the change in hydrodynamic parameters, both in distant areas and near the source of the discharge.

Research Methods and the Received Results

Research methods are based on classical laws of fluid and gas mechanics; methods of mathematical and numerical modeling. Consider a spherical model. Let the spherical cavity formed in the liquid as a result of the breakdown of the inter electrode space expand at a high velocity and set the liquid in motion. The fluid flow is described by a system of nonstationary equations [9] in the conservative form

$$\left.\begin{aligned}&\frac{\partial(r^2\rho)}{\partial t}+\frac{\partial(r^2\rho v)}{\partial r^2}=0,\\&\frac{\partial(r^2\rho v)}{\partial t}+\frac{\partial\left[r^2\left(P+\rho v^2\right)\right]}{\partial r^2}=0.\end{aligned}\right\}\quad(1)$$

where *r* is the radial coordinate, *v* is the flow velocity, *P* is the pressure,*ρ* is the density of the medium, *t* is the time. The system of equations (1) is closed by the equation of state of the liquid in the formof Theta

$$P=A(\rho/\rho_0)^{\chi}-B,\quad(2)$$

where

$$\chi=7, A=3{,}04\cdot10^8 Pa, B=A-P_\infty, \rho_0=10^3 kg/m^3, P_\infty=1{,}04\cdot10^5 Pa$$

is the hydrostatic pressure.

The initial and boundary conditions are as follows:

$$P(0,r)=P_\infty, v(0,r)=0 \qquad a_0\le r\le r_b,\quad(3)$$

$$P(t,a)=P_a(t), v(t,a)=\frac{da}{dt}.\quad(4)$$

where a_0 is the initial radius of the plasma cavity or the lower boundary of the liquid (≈0.1-0.15 mm), $r_в$ is the upper boundary of the computational domain.

To solve the problem, it is necessary to know the law of expansion of the discharge channel *a(t)* or the pressure at the boundary of the channel $P_a(t)$. For this purpose, we use the energy balance equation in the channel

$$\frac{d}{dt}\frac{P_aV}{\gamma-1}+P_a\frac{dV}{dt}=\frac{dE}{dt},\quad(5)$$

where *dE/dt* is the power released in the channel, *V* is the channel volume, γ = 1.26 is the effective adiabatic exponent.

We take the law of energy input into the discharge channel in the following form:

$$E(t)=(1{,}9\frac{t^2}{\tau_0^2}+1{,}3\frac{t^3}{\tau_0^3}-2{,}2\frac{t^4}{\tau_0^4})E_0,\quad(6)$$

where τ_0 is the discharge duration, E_0 is the total energy released in the channel.

Equations (1), (2) and (5) with initial (3) and boundary (4) conditions represent a closed system of equations for an electric discharge in a liquid, but they do not subject to an analytical solution.

The numerical solution of such problems is performed in a moving grid. The numerical calculation can be conducted in a normalized interval from 0 to 1, if a new coordinate system is introduced. Introducing the following variables

$$\tau=t, \xi=\frac{r-a(t)}{r_b-a(t)}$$

where the boundary of the cavity corresponds to zero value of the newly introduced coordinate ξ, and the upper boundary corresponds to ξ=1. By making the resulting equations dimensionless, we obtain

$$\left.\begin{aligned}&\frac{\partial\left[\rho\left(a+\xi\left(r_b-a\right)\right)^2\right]}{\partial\tau}-\frac{1-\xi}{r_b-a}a'\frac{\partial\left[\rho\left(a+\xi\left(r_b-a\right)\right)^2\right]}{\partial\xi}+\frac{1}{r_b-a}\frac{\partial}{\partial\xi}\left[\rho v\left(a+\xi\left(r_b-a\right)\right)^2\right]=0,\\&\frac{\partial\left[\rho v\left(a+\xi\left(r_b-a\right)\right)^2\right]}{\partial\tau}-\frac{1-\xi}{r_b-a}a'\frac{\partial\left[\rho v\left(a+\xi\left(r_b-a\right)\right)^2\right]}{\partial\xi}+\frac{1}{r_b-a}\frac{\partial}{\partial\xi}\left[\left(a+\xi\left(1-a\right)\right)^2\left(P+\rho v^2\right)\right]=P,\end{aligned}\right\}\quad(7)$$

The initial and boundary conditions in the newly introduced coordinates have the form

$$\left.\begin{aligned}&P\left(0,\xi\right)=P_\infty,\quad v\left(0,\xi\right)=0\quad for\quad 0\le\xi\le1;\\&P\left(\tau,a\right)=P_a\left(\tau\right),\quad v\left(\tau,a\right)=\frac{da}{d\tau}.\end{aligned}\right\}\quad(8)$$

The pressure P_a is determined from equation (5), by introducing the expression for volume $V=\frac{4}{3}\pi a^3$. When solving the problem, the equations were made dimensionless. The scale values were taken as

$$u_m=c_\infty,\ t_m=l/c_\infty,\ \rho_m=\rho_0,\ P_m=\rho_0c_\infty^2.$$

In the numerical solution, a uniform rectangular mesh $t^n = nh_t,\ n = 0,1,2,...;\ \eta_m = mh_x,\ m = 0,1,2,..$ was used. For the stability of the calculation, time derivatives were approximated by forward differences, derivatives with respect to spatial variables were approximated by central differences.

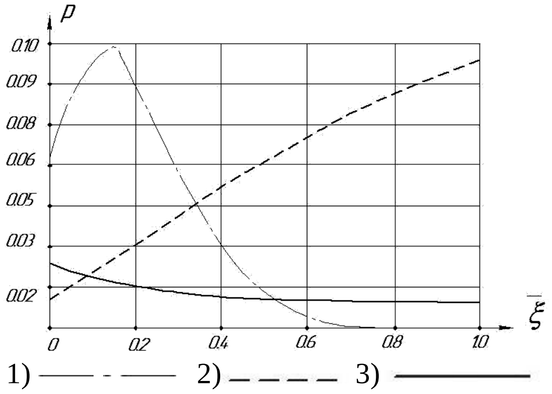
To determine the density of the liquid at the internal points of the computational domain, from the continuity equation, we obtain the grid density equation; from the equations of the momentum and energy balance in the discharge channel, the fluid velocity and the pressure between the cavity and the fluid boundary are determined, respectively. The value of *a* is determined in the process of calculating by numerical integration of velocity *v* at $\xi = 0$.

The steps in the numerical calculations were $h_x = 0,06; h_t = 0,006$ .The parameters were determined by a marching method in time.

The pressure at the boundary of the cavity is determined from the energy balance equation in the discharge channel. The density and velocity of the liquid at $\xi = 0$ are determined in the same way from the corresponding equations.

At the upper boundary of the spherical region, the no-flow condition was used for the flow rate, and the values of density and pressure were determined by extrapolation.

The results of numerical calculations for different discharges showed that at the initial points in time the maximum values of the hydrodynamic parameters are in the lower boundary. Over time, the perturbation reaches the end of the computational domain. After a certain time, the perturbation goes from the end to the beginning of the fluid volume. Further, the pressure drops everywhere. The general pattern of the process is the same for all digits. Their difference lies in the values of the parameters and the times of the process. Here are the results obtained for one discharge. The electrical parameters of the circuit used in the calculations for this discharge had the following values: *u=1,6kV,C=321 μF,l=0,1sm,L=0,2 μH,τ₀=30 μs,E₀,=376J, Cu²/2,=412J, R₀ =0,84sm.*

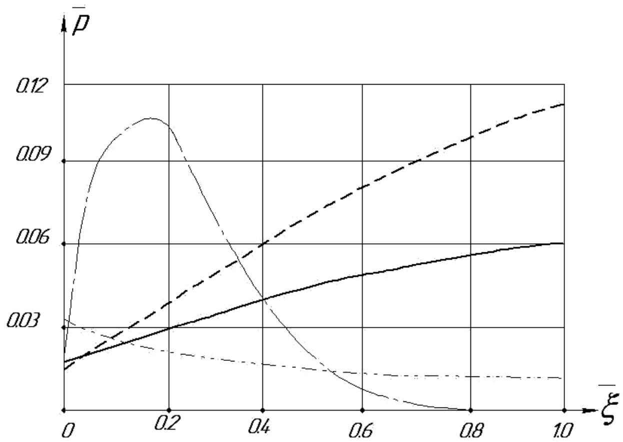


1) —— - —— 2) — — — — 3) ————

Fig.1. Pressure change in a spherical discharge channel

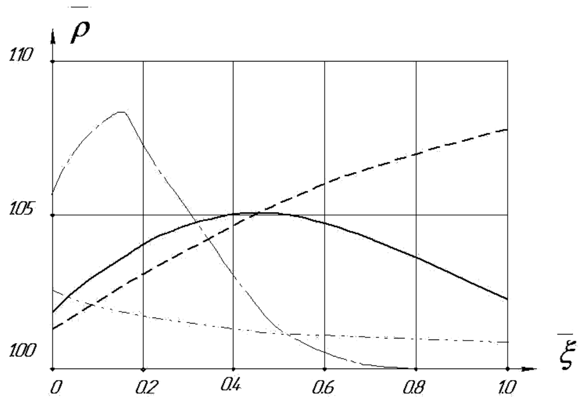
Fig. 1 shows the change in pressure for this discharge for the points in time $\tau/\tau_0 = 0,1\ (1);\ 1,0\ (2);\ 2,0\ (3)$. At the beginning, the pressure slowly increases and reaches its maximum and then decreases almost monotonically. At this time, the perturbation does not reach the upper limit. Over time, the distribution of pressure in the area of movement changes, reaching its maximum value near the upper boundary. Subsequently, the pressure stabilizes and has a pattern close to linear distribution.

Figures 2 and 3show the change in the pressure and density of the liquid, respectively, along the radius for this discharge for different points in time.



1)—·— 2) — — — — 3) ———— 4) — · · — · · —

Fig.2. Change in pressure in a spherical discharge channel



1) —— · —— 2) — — — — 3)—— 4) — · · — · · —

Fig.3. Change in density in a spherical discharge channel

Conclusions

Computational experiments have confirmed the correctness of the presented model for describing the ongoing physical processes of an electric discharge in a liquid. The advantage of this model is the determination of the hydrodynamic parameters near the discharge source.

The calculations performed for the electric discharge in a liquid under spherical propagation of the channel showed that the main parameters of this process are the values of the energy supplied to the unit of the interelectrode distance and the time of energy release. When developing various devices based on the phenomenon of an electric discharge in a liquid and varying these values, one can choose a mode in which rational characteristics are obtained for the accepted design.

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