CREATION OF BIOLOGICALLY ACTIVE AEROSOLS BY METHOD OF ELECTROACTIVATION AND ATOMIZATION OF WATER IN ELECTRIC FIELD

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Abstract: A new method of conducting liquid atomization is worked out on the base of water bubbling in electric field and studied.. The aerosol movement dynamics in a parallel-plate capacitor is investigated. A life stimulating and bactericidal properties by means of a preliminary treatment of water in a diaphragm electrolyzer is proposed.

Key words: Bubbling, Fluid Atomization, Electric Field, Liquid Electroaerosols, Water Electroactivation

1. INTRODUCTION

Liquid aerosols (mainly water ones) are widely adopted in medicine and veterinary science for inhalation therapy and immunization of people and animals, desinfection and desodoration of premises. Specific claims concerning drop size, concentration, temperature, electric charge, etc. are laid to medical aerosols depending on purpose and procedure. Biologically active aerosols, suppressing or, on the contrary, stimulating vital functions of microorganisms, plants, cells are of great interest in this aspect.

Liquid atomization is the principal process of aerosol generation. Various methods of dispersion are known [1], among which an electrostatic pulverization stands out. Use of electric field reduces power inputs, ensures a fine process control and improves many technological indices. At electrostatic atomization of low-resistance liquids, water in our case, a formation of large drops takes place, due to its high electric conductivity and surface tension [2].

An effective atomization of a low-resistance liquid is ensured by its bubbling in electric field [3], at which under its free surface a cloud of small drops forms as a results of the bubbles bursting. Electric field being absent, under the action of gravity force the droplets return back or are partly primed by a gas flow. At electric field localization between the free surface of the liquid and situated under it electrode, the droplets owing to a high electric conductivity acquire a contact charge and form a charged aerosol flow the direction and rate of which could bee controlled by change of electric field configuration and parameters.

Activation of the aerosol biological properties takes place in a diaphragm electrolyzer, water bubbling occurring as a result of electrolyzis gases liberation that permits to organize the process without a compressed gas source [4,5].

The results of experimental and theoretical investigation of biologically active aerosols generation process are presented in this work.

2. ANALYTICAL RESULTS

To present theoretically the drop formation kinetics at liquid bubbling it is assumed as a basis the bubble film dispersion by Cornfield scheme [8], according to which bubble destruction begins after "puncture" appearance and consists in separation from the film free edge of thin filaments, decomposing in their turn into a lot of drops with different dimensions. At the filament ends the liquid tightens into drops, resulting in release of the surface energy, proportional to the liquid free surface area variation ΔS multiplied by its surface tension coefficient σ. A part of the released energy A transforms into drop motional energy, another part dissipates as heat, spent for the liquid deformation work and frictional force overcoming. The law of conservation of energy in this case has a form

$$\frac{m\upsilon_0^2}{2} = \sigma\Delta S - A = \eta\sigma\Delta S, \tag{1}$$

where m - the drop mass; $\eta = (\sigma\Delta S - A)/\sigma\Delta S$ - the coefficient of transformation of the surface energy into kinetic one.

Obviously, a drop forms out of the film element with thickness δ, the free surface area S_1 of which is possible to express through the dimension a, using the liquid volume balance equation

$$S_1 = \frac{4\pi a^3}{3\delta}.$$

Taking into account that $\Delta S=S_1-S_2$, where $S_2=4\pi a^2$ is the drop surface area, and expressing its mass by the relation $m=4\pi a^3\rho_l/3$, from formula (1) find an expression for calculation of its motion initial velocity

$$\upsilon_0 = \left[\frac{6\eta\sigma\left(\frac{2a}{3\delta}-1\right)}{a\rho_l}\right]^{\frac{1}{2}}, \tag{2}$$

the film thickness δ and the coefficient η being not determined.

The film thickness, defined by the conditions of its kinetic stability [9] in the form $d(\Delta P)/d\delta > 0$ is considerably more than the critical thickness δ_{cr} at the "puncture" origin section. As a first approximation assume the linear relationship $\delta \sim b\delta_{cr}$, where b- proportionality factor, estimated through experiment.

Difference of pressures, acting on a thin spherical film, taking into account the capillary effects of the first and the second type, might be described by the equation

$$\Delta P = \frac{2\sigma}{R} - P^*, \tag{3}$$

where R - the bubble radius; P^* - loosening pressure in the film.

Taking into consideration the loosening pressure electrostatic component being essential at typical for the bubbles $\chi>1$, by Langmuir formula [10] $P_l^* = \pi\varepsilon_0\varepsilon_l(kT/2z^*e\delta)^2/2$ valid at dimensionless potentials of the film outer surface $\varphi_S^* = e\varphi_S/kT >> 1$, and, expressing σ in (3) according to Gibbs-Tolman-Konig approximated relation [11], from the stability condition

$$\left.\frac{d(\Delta P)}{d\delta}\right|_{\delta=\delta_{cr}} = 0,$$

receive a formula for calculation of the film critical thickness

$$\delta_{cr} \cong \left[\frac{\pi \varepsilon_0 \varepsilon_l R^2}{16\sigma} \left(\frac{kT}{z^* e} \right) \right]^{1/3} = \left[\frac{\pi}{8\sigma} \left(\frac{R}{\chi} \right)^2 nkT \right]^{1/3}, \tag{4}$$

where $n = \sigma_{el} / 2z^* ek^*$, z* and k*- concentration, valence and mobility of ions and antiions in the bulk of the symmetrical electrolyte; ε_l , σ_{el} and T - liquid dielectric permitivity, conductivity and temperature; k - Boltzmann's constant; χ - antiions diffused layer inverse Debye extent.
Comparison of the quantity δ_{cr}, calculated by formula (4), with the experimental data [11] gives the value $b \cong 7{,}9$.
Then an average number of drops, formed at one bubble destruction, is

$$n = \frac{n_d}{n_b} = \frac{W\overline{R}^3}{G\rho_l \overline{a}^3},$$

where n_d - number of drops, formed out of a liquid free surface area unit per unit time; n_b - number of bubbles, destructed on the same area in the same time.
The bubble film part, decomposing into drops, is determined by the formula

$$c = b^* \frac{\overline{n}\overline{a}^3}{3\overline{R}^2 \delta}, \tag{5}$$

received from the liquid volume balance equation, assuming the bubble spherical film thickness being the same in the whole bulk and equal to δ . Here b* - relation of the liquid volume, primed at the bubble film dispersion, to the dispersed liquid total volume.
Obviously, the least drop size might be estimated from the condition of energy release at the change of the liquid free surface $4\pi a^2\sigma[(2a/\delta)-1]>0$. whence

$$a_{\min} > \frac{2}{3}\delta, \tag{6}$$

and the largest size is estimated according to formula (5) at $b^* \overline{n} = 1$ when one big drop having a size

$$a_{\max} = \left(3c\overline{R}^2 \delta \right)^{1/3} \tag{7}$$

forms of a destructing bubble.
Comparison of the initial drop rate, calculated according to formula (2) taking into account (4) showed a good coincidence with experimental values v_0 [12] at η , changing with gas rate increase from 0.34 to 0.78. Drop sizes, determined according to dependencies (6) and (7), also agree well with the experiment, that confirms the adequacy of the proposed estimate model.
Another mathematical model concerns the dynamics of the liquid aerosol motion in the parallel-plate capacitor field. The volume content of drops in aerosol flow is estimated not to exceed 10^{-4} , that permits to make the following assumptions: it is considered a flow of a monodispersed electroaerosol obtained as a result of homogenization of real flow drop sizes and ensuring equal priming rate W and transfer current density j ; the drop deformation from the spherical form within the obtained limits of drop size variation is neglected; evaporation of drops under the conditions of absence of heat exchange with the dispersed medium isn't taken into account as the passed way is negligibly small; interinfluence of drops in the flow (forces of electrostatic seatering, polarization and aerodynamic interaction) in comparison with the external electric field forces are negligible too.

Poisson equations, describing electric field distribution, after substitution of (2) for an one-dimensional case assumes a form:

$$\frac{dE}{dz} = \frac{qN}{\varepsilon_0} = \frac{j}{\varepsilon_0 v}, \tag{8}$$

which after substitution of v=dz/dt , might be integrated and we obtain the expression for the dependence of the field strength in the point, where the examined drop is situated, on its motion time

$$E = \frac{j}{\varepsilon_0} t + E_0. \tag{9}$$

Considering the gas motion according to the scheme of the inundated axially symmetrical laminar jet [13] and approximating the force of gas resistance to a drop motion according to Klyachko formula [1], after substitution of expression (8) into the motion equation obtain a system of differential equations, describing drops motion, electric field distribution and aerosol dispersed phase concentration along the parallel-plate capacitor gap z:

$$\frac{d^2 z}{dt^2} = \frac{j^2}{\varepsilon_0 W} t + \frac{j}{W} E_0 - \frac{9\mu_g}{2\bar{a}^2 \rho_l} \cdot \frac{dz}{dt} + \frac{9\mu_g G}{2\bar{a}^2 \rho_l \left(\frac{32 v_g}{\sqrt{3} d^2 G} z + 1 \right)^2} - \frac{3\mu_g}{4\bar{a}^2 \rho_l} \left(\frac{2\bar{a}}{v_g} \right)^{2/3} \left[\frac{dz}{dt} - \frac{G}{\left(\frac{32 v_g}{\sqrt{3} d^2 G} z + 1 \right)^2} \right]^{5/3} - g; \tag{10}$$

$$\frac{dE}{dz} = \frac{j}{\varepsilon_0 v}; \tag{11}$$

$$\frac{dz}{dt} = v; \tag{12}$$

$$N = 3W / 4\pi \bar{a}^3 \rho_l v, \tag{13}$$

where μ_g and ν_g - viscosity dynamic and kinematic coefficients; g- gravity acceleration.

Equations (10)-(13) solutions, satisfying the initial conditions

$$t = 0: \quad z = 0, \quad \frac{dz}{dt} = v_0, \quad E = E_0 \tag{14}$$

are considered.

To determine the intensity value E_0 at the flow formation boundary (t= 0. z = 0) the problem (10)-(14) is solved by a method of iterations. And the value E_0 , for which the integral of function of strength distribution along the interelectrode gap is equal to the applied voltage U ,

$$\int_0^l E(z) dz = U \tag{15}$$

is found.

The nonlinear initial-boundary-value problem (10)-(14) was integrated by a numerical method using Runge-Kutta procedure.

The calculation results for drops rate distribution along the interelectrode gap are presented in Fig.1 for three characteristic regimes of motion: decelerated (curve 1), uniform (curve 2) and accelerated (curve 3).

If at the initial moment the inertial force prevails above the electric one ($K=(vdv/dz)/(jE_0/W)=v_0^2W/jE_0l>1$ the decelerated motion regime is observed. At $K\approx1$ the drops motion is uniform, and at $K < 1$ - it is accelerated. Thus, the field influence on the dynamics of aerosol flow priming decreases at the growth of the role of the dispersed phase inertial properties. The aerosol motion rate grows with the increase of drops size, and besides for large drops ($\bar{a} > 40 - 50$ μm) this growth becomes less and less, particularly at the field strength rise, that agrees well with the charged particles mobility theory [1].

This results showed a good coincidence with experimental values of drop velocities, that confirms the adequacy of the proposed model.

The corresponding dependencies of the charge particles concentration distribution (Fig.2) are stated in relation to their motion regimes. The accelerated motion of drops results in some concentration of them at the free surface of the bubbling layer and on the contrary at the decelerated motion the drops concentrate at a receiving electrode. At the uniform motion the concentration distributes along the interelectrode gap uniformly. Gas rate, field strength and drops size growing, average along the interelectrode gap dispersed phase concentration decreases.

Field strength distribution along the interelectrode gap appears to bee practically uniform. On the basis of the aerosol flow stationarity $\mathrm{div}(N\vec{v})=0$. where in conformity with the mobility theory [1] at Re> 0.5 the drops rate is approximated by the expression $v \cong k * qE^n$ (0.5 < n < 1), and N is determined from Poisson equation (8), under boundary conditions

$$z = 0 : E = E_0, \quad \frac{dE}{dz} = \frac{qN_0}{\varepsilon_0} = \frac{\pi^2 \alpha_0 E_0}{2\bar{a}}$$

it is determined an analytical dependence of the field strength distribution along the interelectrode gap

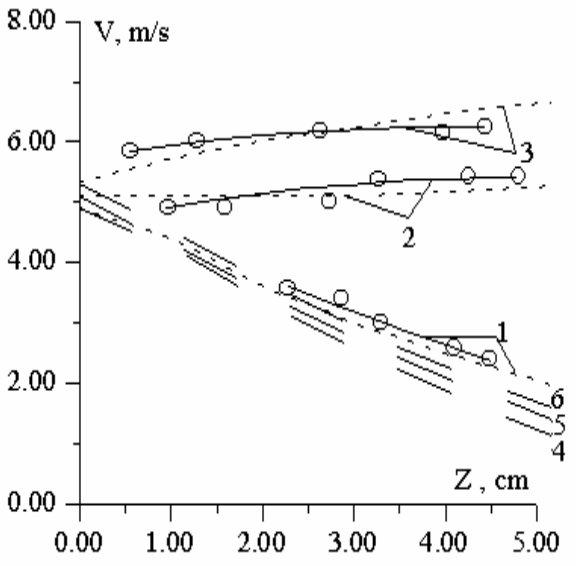

Fig.1. Motion rate distribution for drops with radius 50 μm along the interelectrode gap versus electric field strength (dot-and-dash line - at field absence; solid lines and dot ones - in electric field; solid lines - experiment; dot ones - numerical computation):
E , kV/cm: 1 - 3; 2 - 8; 3 - 10; 4, 5, 6 - 0;
G , $m^3/(m^2 h)$: 1. 4 - 2.44; 2, 3, 5, 6 - 1.44.

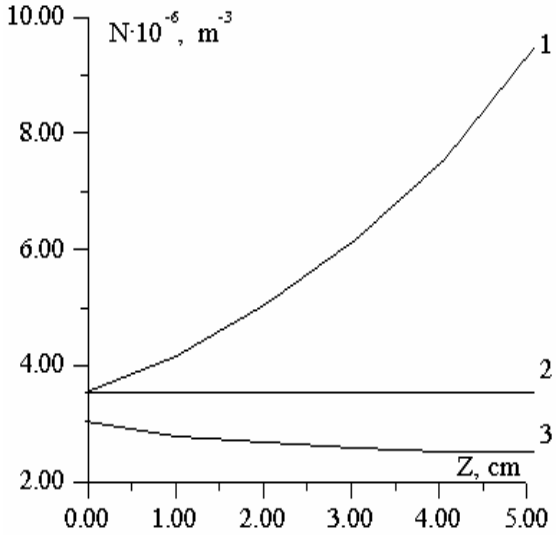

Fig.2. Electric field influence on the character of volume concentration distribution of drops with $\bar{a}$ = 50 μm along the inter-electrode gap:
E , kV/cm: 1 - 3; 2 - 8; 3 - 10.

$$E = E_0\left[\frac{(n+1)\pi^2}{2\bar{a}}\alpha_0 z + 1\right]^{1/(n+1)} \tag{16}$$

on the dispersed phase volume content α_0 .
Field strength value E_0 at the bubbling layer surface is determined from the condition (15)

$$E_0 = \frac{(n+2)\pi^2\alpha_0 U}{2\bar{a}\left\{\left[\frac{(n+1)\pi^2\alpha_0 l}{\bar{a}} - 1\right]^{(n+2)/(n+1)} - 1\right\}}. \tag{17}$$

Field strength distribution calculation according to formulas (16) and (17) shows, that distribution uniformity is actually broken at $\alpha_0 > 10^{-4}$, while $\alpha_0 > 10^{-4}$ $E=u/l$.

3. ELECTRIC ACTIVATION OF BIOLOGICAL PROPERTIES OF WATER AEROSOLS

Electric activation of biological properties of water aerosols dispersed phase in accordance with the proposed method [4,5] consists in a preliminary electrochemical treatment of water in a diaphragm electrolyzer with the following bubbling of ano- and catholyte by gases of electrochemical reaction [4] or by gas additional flow [5]. In both cases generating biologically active aerosol is carried out by the method [3].
Semipermeable diaphragms (of tarpaulin, cellophane, etc.), which separate the anode volume from the cathode one, are utilized in those electrolyzers. Thanks to the diaphragm, alkaline medium concentrates at the cathode and acidic one - at the anode. As pH of anolyte is higher, the electroaerosol dispersed phase, generated on its base, is characterized by bactericidal properties. Catholyte being dispersed its dispersed phase possesses life-stimulating properties (plant growth stimulation, quicker wounds closing, etc.).
Generators of biologically active aerosols being used, high-voltage potential is usually supplied to water, as a plant or a patient is grounded to direct to them a flow of charged drops. Therefore to separate the current of the high-voltage circuit from the low-voltage one of the power source of anode and cathode, the last is switched up to the circuit through a separating transformer.
Struggle with the emission of heavy metal ions from the electrodes into electroactivated water is one of the problems of electrolyzes application. To solve the problem carbon electrodes or metal ones with platinum surface are used.
In medicine and veterinary science the aerosols are utilized for inhalation therapy or for immunization of people and animals, desinfection and desodoration of rooms. Reduction of the medical or prophylactic preparation losses is the most important problem, which might be solved by control of the preliminary charged aerosol supply.
According to their productivity the electroaerosol bubbling type generators may be used to solve the above-mentioned problems in small rooms and boxes, mainly in order to carry out scientific investigations. The effect of microorganisms (e.g. vaccine) concentration in drops priming [14] is one of these generators qualities. The aerosol inhaled dose and consequently the procedure duration decrease.
It is known, that the charged drops penetrate into living organism bronchial tubes more effectively rising the therapeutic and prophylactic action of an inhalating procedure, the electroaerosol dispersivity being rather important. Optimum drop size is dozens of microns at aerosol therapy and doesn't exceed 3-5 μm - at immunization. Thus the generator construction must provide a control of drops dispersivity, that is realized in the inventions [6,7].
Generators of biologically active aerosols [4,5] have been tested under laboratory conditions the room plants being sprinkled. It was established, that the plants, being sprinkled by bactericidal aerosol, die in two or three days, while being sprinkled by catholyte, its growth increased 5-10 times in comparison with the control one.

Liquid bubbling by the mixture of air with bactericidal gas (e.g. ozone) [6,15] is another principle of generating biologically active electroaerosols. On account of the electrostatic dissipation forces the bactericidal aerosol drops fill in the room volume and are the centres of microorganisms precipitation at dezinfection. According to the method [6] ozone-air mixture flow rate per 1 m^2 of water free surface is 0.0005-0.1 m^3 /s, providing ozone concentration in room air 10-20 mg/m^3 , dissipating the aerosol droplets at the field strengths from 1 to 5 kV/cm. This method has been tested under laboratory conditions. The experimental results on Penicillium Expansum culture survival rate are presented in Tab.1, which show the culture practically dies already at ozone concentrations 10-20 mg/m^3 .

Table 1

Surviveness of Penicillium Expansum culture, being treated by bactericidal aerosol

No	Ozone concentration in aerosol dispersive medium,mg/m^3	Culture survival rate (relation of the survived microorganisms quantity to their total quantity)
1	0.1	0.8
2	0.2	0.1
3	10.0	0.065
4	20.0	0.01
5	30.0	0
6	40.0	0

5. CONCLUSIONS

Summarizing, it might be noted, that the influence of the field strength and gas rate on generating kinematics and dynamics of their motion in parallel-plate condensor field, is determined. Distribution of rates and dispersed phase concentration is found, the effect of the last on the field distribution is determined. Methods of drops dispersivity control and of electroaerosol biological properties activation are elaborated. Application of the results in medicine, veterinary science and plant-growing is considered.

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