

## NANOSCALE EFFECTS IN DISCRETE-PULSE TRANSFORMATION OF ENERGY

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*The physical principles of the discrete-pulse transformation of energy in fluid disperse heterogeneous systems have been investigated. A classification of the working elements and physical processes realizing the temporal and linear nanoscale effects is given. Examples of physicochemical nanoprocesses have been considered.*

Classified with nanostructural systems are usually those systems in which at least one of the characteristic linear sizes, for example, the layer thickness, is from 1 to 100 nm. Nanostructures exhibit unique properties: anisotropy of heat or electricity conduction; they are very strong and have other physical properties. As a rule, the term "nanos-structure" is widely used for semiconductor materials, metals or alloys, ceramics, composite materials, i.e., solid-state media. Accordingly, the technologies by means of which such systems are obtained are placed into the category of nanotechnologies. The aim of the present work is to investigate the appearance of nanostructures in heterogeneous disperse fluid-based systems: suspensions, emulsions, bubble systems.

That the investigation of nanostructures is topical is evidenced by the statement that nanotechnologies, along with information technologies and biotechnologies, will form the main innovative direction at the beginning of the 21st century.

**Principle of Discrete-Pulse Input and Transformation of Energy.** The concept of the principle of discrete-pulse energy input (DPEI) was first proposed in the early 1980s [1] as a generalizing method for purposeful, local, and intensive use of concentrated energy in compressible vapor-fluid disperse systems. The physical phenomena of the dynamics of the main DPEI elements were subsequently investigated theoretically in [2–4], and the technological and engineering applications of this principle are presented in [5–7] and generalized in [8, 9]. A more detailed and consistent consideration of the DPEI principle is given in monographs [10, 11].

The main idea of DPEI is that the preliminarily stationarily input energy arbitrarily distributed in the working volume is accumulated (concentrated) at locally separated discrete points of the system and subsequently realized as pulses in order to attain the required physical effects. Therefore, the point of DPEI is to create the physical prerequisites for providing its concentration upon energy input into a technological medium, a discrete and local distribution in the space (technological volume of the medium), and a pulsed (short-term) action in time. As working systems where the use of the DPEI principle is effective, one usually chooses two-phase systems, namely, vapor (gas)-liquid heterogeneous systems with several components. For example, the liquid phase of such a system is an emulsion of the type water–oil. As working processes using the DPEI principle, one uses the processes of mixing, crushing, emulsification, or homogenization of the dispersed component or the dispersed phase, i.e., the phenomena of a decrease in the size of inclusions, an increase in their homogeneity, and a marked increase in the total contact surface of components or phases, which is required in many technological processes.

**Elements of the Discrete-Pulse Input of Energy.** In using the DPEI principle, local and discrete concentration of energy is possible in the presence in the system of considerable gradients of the thermodynamic and hydrodynamic parameters: temperature, pressure, velocity, density, etc. This is the necessary condition for realizing the principle. A sufficient condition is the presence of working elements (or working parts), i.e., such formations in the heterogeneous system that could play the role of microaccumulators and then microgenerators or microtransformers of energy.

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As the basic DPEI working elements or parts as local microsources of preaccumulated energy, the following ones are used [2, 4].

*Vapor (vapor-gas) bubble and ensembles of bubbles.* The DPEI principle uses all stages of the bubble dynamics and its interaction in an ensemble of bubbles, i.e., the radial increase or decrease in sizes, including the collapse of the bubble, as well as the high-frequency oscillations of its interface. Here preference is given to vapor bubbles, since they have higher characteristics (rates of growth and collapse, oscillation frequency, etc). The methods of creation and uniform distribution of bubbles in the volume of the dispersive liquid medium are:

- (a) nucleation and evolution of a bubble upon thermal loading of the liquid, i.e., adiabatic boiling of the liquid;
- (b) nucleation and dynamics of a bubble upon a change in the external potential of the liquid, e.g., upon a marked change in the external pressure: at depressurization — manifestation of adiabatic boiling of the liquid; at a sharp increase in the pressure — collapse of the bubble;
- (c) volume-distributed external introduction of vapor into the liquid. Examples of such a method are barbotage of cold liquid by superheated vapor, introduction of vapor into tangentially swirled flows of fluid, etc. The DPEI realization efficiency thereby is the higher, the wider the difference between the liquid and vapor potentials, for example, the greater the temperature or pressure difference between them.

As a linear size characterizing a given working DPEI element, one may suggest, though quite tentatively, the critical size  $R^*$  of bubble nucleation

$$R^* = \frac{2\sigma_{12}}{P_\infty \exp\left(\frac{2\sigma_{12}M_1}{R^* \rho_1 \mathfrak{R}T_1}\right) - P_1},$$

which is in the range of  $R^* \approx 10^{-6}$ – $10^{-5}$  m for water and up to  $10^0$  C at superheating. This size is likely to characterize the degree of locality of the energy concentration in the working system. The degree of discreteness of the arrangement of the DPEI working elements in this case is determined by the bulk density of the vaporization centers (analog of the concentration of bubbles), which varies from  $10^6$  to  $10^{13}$  m<sup>-3</sup>. In considering metastable mixtures of several components, in the above values of the critical radius and the bulk density, it is necessary to take into account some thermodynamic features and make adequate corrections.

*Vapor (vapor-gas) cavity.* As a rule, it is of cavitation origin. The DPEI method uses all effects of the dynamics of a hydrodynamic cavity, i.e., its pulsations, crushing of the tail part, and separation of individual bubbles, as well as their dynamic evolution in a liquid. The necessary condition for the formation of a cavity is the attainment by the flow of the required parameters (rate) as it bends around obstacles (local or specially created ones). The second method for creating vapor cavities or lower-density regions is the ultrasonic action on the liquid, the so-called ultrasonically induced cavitation. There are also other methods: point action by powerful laser radiation; electric discharge in the liquid; sharp mechanical tension of the liquid. As a linear scale, one can suggest the least size of the bubble which no longer collapses and is in equilibrium with the liquid, i.e., the size of the gas dissolved in water. This value is equal to 0.5–3 μm. Another characteristic size is the size of the region of ultrasonic wave antinodes in the liquid, which, e.g., for water under normal conditions corresponds to about 10 μm.

*Cumulative microjet.* This is one of the most powerful elements of the collapse dynamics of a vapor cavity and represents the appearance in the liquid of fast jets and flows. The sources of their formation are analogous to the methods of obtaining vapor cavities. A cumulative microjet is accompanied by the appearance of abnormally high local pressures, temperatures, velocities, and accelerations. The intensity of its action is such that it even leads to a splitting and ionization of molecules. The experimentally measured values of the velocity reach 100 m/sec or more, and theoretical calculations lead to values an order of magnitude higher.

*Thin liquid film.* Thin liquid films and foam-liquid structures are a continuation of the dynamics of the development of ensembles of vapor bubbles in the flow. Breakdown of films is accompanied by high rates of motion and a low dispersion of particles in aero- and hydrodynamic crushing. Foam structures arise in the presence of surface-active substances (SAS) and play the determining role in the liquid dispersion, e.g., in the liquid pneumoatomization or atomization due to the adiabatic boiling, or in the field of centrifugal forces. As a linear scale, the critical thickness

of the film  $\delta^*$  at which it spontaneously breaks down can be recommended. The value of  $\delta^*$  is determined by the expression

$$\delta^* = 0.22 \left( \frac{AR^2}{\sigma f} \right)^{1/4}.$$

For water, under normal conditions for spontaneous breakdown of the film the value of  $\delta$  is in the 50–100-nm range.

*Elementary turbulence volume, elementary vortex.* The elementary local volume in a high-turbulence liquid flow with a characteristic linear scale equal to the inner scale of turbulence in A. N. Kolmogorov's definition is

$$\delta = k \left( \frac{v^3 D}{V^3} \right)^{1/4}.$$

In the case of outflowing and boiling water, the size of  $\delta$  measures microns. Taking into account that the "inner scale" determines the minimal distance at which the differences in the local turbulent flow rates are comparable to the absolute values of the flow-rate pulsations, in the first place inclusions or formations whose size is comparable to  $\delta$  will be subjected to turbulence.

*The pulsed character* of the action of the working element, i.e., the characteristic time scale of the DPEI, can be evaluated on the basis of the expressions for the period of natural oscillations of a gas bubble (zeroth approximation of the Rayleigh problem):

$$\tau = 2\pi R \left( \frac{\rho_1}{3\gamma\Delta P} \right)^{0.5}$$

or a liquid drop (Lamb formula):

$$\tau = \pi \left[ \frac{(2\rho_1 + 3\rho_3)R_0^3}{6\sigma} \right]^{0.5}.$$

For gas (vapor) particles of size 1  $\mu\text{m}$  the calculations give a value of  $\tau = 0.15 \mu\text{sec}$ , and for liquid particles of a similar size — 0.05  $\mu\text{sec}$ , i.e., the times of realization of the DPEI principle correspond to the nanosecond or submicrosecond range.

The classification of the basic working elements of the DPEI principle shows that their characteristic size is in the micron and submicron ranges and, therefore, allows them to actively influence operating systems with a close dispersivity of heterogeneous formations. This proves the most effective practical realization of the DPEI principle for thermophysical processes in disperse fluid systems of the type of emulsions, suspensions, and other bubble systems where the size of inclusions is in the range from fractions to hundreds of micrometers.

**Nanoscale Aspect of the DPEI Principle.** The main resistance to the processes of energy, pulse, and mass transfer in a heterogeneous fluid system is concentrated and occurs in the boundary layer on the interface. The interface (or the boundary between insoluble components) is schematically represented in Fig. 1.

A distinguishing feature of the liquid–gas (vapor) or mutually insoluble liquid–liquid interface is the presence of at least one SAS layer. It fixes the contact surface of phases and thus stabilizes the self-organization of the disperse structure of a heterogeneous system and physically predetermines its existence in principle. The SAS molecules are characterized, as a rule, by a branched multiradial structure but are organized so as to form, as a minimum, a monolayer oriented along the molecule length perpendicular to the interphase boundary. In natural systems, e.g., in emulsion of natural milk, the structure of the SAS layer at the fat ball–milk plasma (analog of water) interface consists of three sequential monolayers of different milk albumins intimately mating one another. Such a complex and branched structure of the surface of the milk emulsion fat ball makes it extremely elastic and strong, and, therefore, resistant to the processes of deformation and crushing (i.e., to the processes of emulsification or homogenization). Note that the above

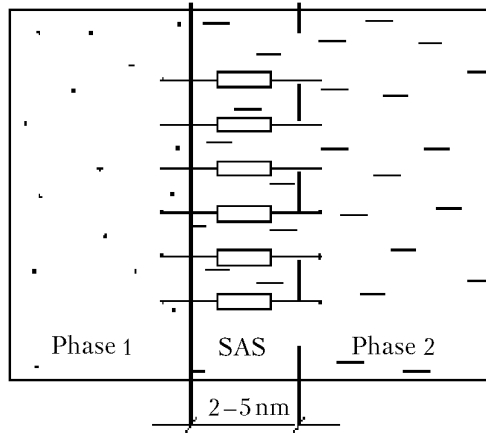


Fig. 1. Scheme of the interface of mutually insoluble components.

fact forms the physical basis for engineering-design difficulties in designing and employing homogenizing equipment for treating milk emulsions.

The presence of an SAS layer at the interface is physically justified by the fulfillment of the principle of potential surface energy minimization:

$$E = \sigma S \Rightarrow \min.$$

Consequently, either  $S$  or  $\sigma$  can tend to a minimum, which leads to the organization of a phase boundary in the form of a sphere (at an a priori equal phase volume) or to the requirement that the surface tension should decrease due to various factors, including, in particular, additions to the SAS system, superposition of external fields — temperature, electric, magnetic, electromagnetic ones, etc. For example, a microscopic additive of oil as an SAS for a perfectly pure water–vapor (gas) surface, where  $\sigma = 73\text{--}74$  mN/m, leads to a decrease in the value of  $\sigma$  by a factor of about 1.8, thereby reaching  $\sigma = 39\text{--}43$  mN/m. In natural fluid systems, e.g., at the interface between the fat ball membrane and the natural milk emulsion plasma, the value of the surface tension  $\sigma = 1.12\text{--}0.06$  mJ/m<sup>2</sup>.

As an SAS, various oils and oil additives, for whose characteristic linear scale the molecule length can be taken, are used, as a rule. For saturated fatty acids, it is between 15 and 20 Å. The second widely distributed class of SASs is polymers of both artificial (synthetic, detergents) and natural origin (plant or animal proteins). The molecule size of synthetic polymers reaches 40–80 Å, whereas for natural proteins it is somewhat larger — 50–150 Å. Thus, the thickness of the SAS monolayer enveloping, e.g., a water–gas (vapor) interface is a few nanometers (Fig. 1). Let us emphasize again that the basic physical problem of the DPEI principle is the overcoming of the mechanical and/or thermal resistance of the SAS layer. This is realized in a sequence of processes: perturbation of the SAS layer, its deformation and breakdown and subsequent restoration, but already on the newly created interface. Therefore, the region of the main action of energy fluxes and the main dissipative effects are realized at distances of the thickness, e.g., of the SAS monolayer of 2–5 nm. This fact predetermines the linear nanoscale aspect of applying the DPEI principle.

The time scale of the DPEI realization can be estimated in several ways. First, for the effects of hydrodynamic crushing of liquid or vapor–gas dispersed inclusions of a homogeneous fluid system, the characteristic times of interface breakdown correspond to the period of natural oscillations of the corresponding inclusion. Obviously, the crushing process is resonant in nature and manifests itself, as a rule, when the natural frequency of oscillations of the dispersed inclusion and the frequency of the external perturbing action of different origins coincide. The period of natural oscillations of a gas bubble of size 1 μm is 150 nsec, while that of a fluid particle of analogous size is 50 nsec, i.e., the crushing times correspond to the submicrosecond or nanosecond scale.

Second, one can estimate the maximal time of enveloping by an SAS layer of the initially absolutely pure surface, i.e., the time of formation and stabilization of an isolated structural element of the heterogeneous system. The addition of an SAS leads, as a rule, to a decrease in the surface tension by  $\Delta\sigma$  and a respective decrease in the surface energy  $\Delta E$  corresponding in the absence of dissipative effects to the kinetic energy of motion of the SAS enveloping molecules. The propagation velocity of an SAS of thickness  $\delta = 5$  nm

$$V = (2\Delta\sigma/\rho\delta)^{0.5}$$

at  $\Delta\sigma = 25 \cdot 10^{-3}$  mN/m and  $\rho = 10^3$  kg/m<sup>3</sup> is equal to the value of  $V = 100$  m/sec, i.e., it is fairly high. The time of enveloping a dispersed inclusion of size 1  $\mu\text{m}$  is 31 nsec, which corresponds to the nanosecond range and is close to the above time estimates for the realization of the DPEI effects.

Consider the energy indices of the elementary DPEI processes, e.g., the process of breaking a spherical particle of initial radius  $R_0$  into two identical particles of radius  $R = R_0/2^{1/3}$ . Obviously, the energy required to realize the breaking effect corresponds to the increase in the value of the total surface energy of the two particles formed as compared to the surface energy of the initial particle:

$$\Delta E = \delta\Delta S = 4\pi\delta R_0^2 (\sqrt[3]{2} - 1) = 0.26E_0,$$

it is equal to a quarter of the initial surface energy and, e.g., at  $\sigma = 50$  mN/m for the initial size  $2R_0 = 2$   $\mu\text{m}$  equals  $\Delta E = 0.16 \cdot 10^{-12}$  J, i.e., it is extremely small. Of course, this value characterizes the idealized act of breaking into two particles without taking into account all kinds of dissipative effects and the threshold effects of the initial energy needed to break down the inclusions. As the mean size of the fat inclusion was changed from 2 to 1.5  $\mu\text{m}$ , the integral energy expended in the breaking down of one initial particle was 0.05 nJ, i.e., it is more than 300 times higher than the breaking energy in the idealized variant and corresponds to the subnanosecond range, which also points to nanoscale energetic effects of the DPEI principle.

**Main Physical Processes of Realization of the DPEI Principle.** The application of the principle of discrete-pulse transformation of energy is possible with the use of various physical phenomena and processes, but mainly through the realization of actions or a combination of actions of the following thermophysical effects: depressurization or pressurization over a gas (vapor) fluid medium, adiabatic boiling, hydraulic shock, pressure or rarefaction shock wave, shear stress, local turbulence, cavitation.

A pressure drop over a dispersive fluid medium may cause effects of intensive boiling of the volatile component of the system, e.g., at a sudden drop of pressure down to a level lower than the saturation pressure. As the pressure is subsequently increased, there occurs a condensation of vapors of the boiling phase with its all dynamic and thermal effects: collapse of bubbles, appearance of micro- and cumulative jets, phenomena of hydraulic shocks of microflows, a sharp increase in the temperature at the epicenter of the collapsing bubble, etc. This process can be most effectively realized periodically and used repeatedly for portion volumes of the medium being treated.

A particular case of the above method of DPEI realization is a continuous drop in pressure over the medium flow, e.g., by directing the flow into a region of rarefaction lower than the saturation pressure of a metastable liquid. The possible variants of application are: the outflow of a stream of high thermodynamic parameters (pressure, temperature) into the atmosphere or the outflow of a stream into vacuum. A positive feature of such a method is the continuous treatment of the medium in the flow rather than the portionwise treatment. A variant of not only a pressure drop, but also the action on the system being investigated by a high pressure is possible, e.g., barbotage of a cold liquid that is under a pressure higher than the atmospheric pressure by a superheated vapor, which is accompanied by intensive processes of condensation and, therefore, by the corresponding effect of intensification of the heat- and mass-exchange processes.

An active way of applying the DPEI principle is with the use of a hydraulic shock, i.e., a sharp slowing down of the flow and, therefore, of the attending effects: vortex formation, microturbulence, cavitation phenomena, shock waves, etc.

Overpressure shock waves and/or rarefaction arise, as a rule, with a loss of sealing of high-pressure contours, collapse of vapor cavities, ultrasonically induced cavitation, or under the action on the medium by electric discharge or pulsed laser radiation. They are characterized by an intensive one-time or periodically dynamic and/or temperature action on the stationary volume of the working medium or its flow.

Intense shear stresses are realized at small linear sizes in outflow or flow devices: in rotating or circular flows, in small slots or narrow clearances; when the flow is moving under a high pressure through special valves, matrices or nozzles. This method of using the DPEI is the most effective one for high-viscosity Newtonian fluids.

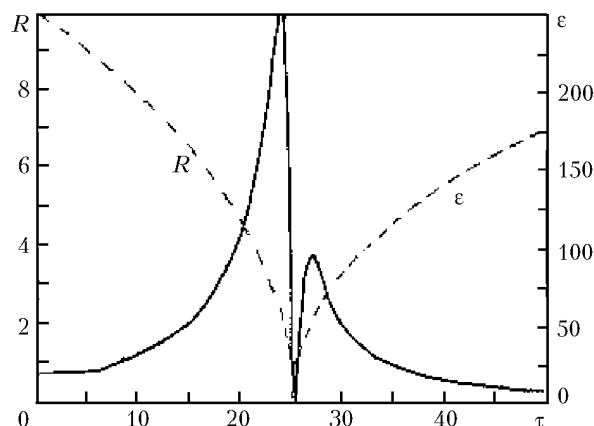


Fig. 2. Specific kinetic energy of the liquid at the interface in the process of bubble collapse.  $R$ ,  $\mu\text{m}$ ;  $\varepsilon$ ,  $\text{MJ}/\text{m}^3$ ;  $\tau$ , nsec.

The phenomena of flow turbulence are inherent in all methods of realization of DPEI processes and determine the intensification of the dynamic and heat and mass exchange processes in heterogeneous systems. They arise, as a rule, either with a special organization of the flow motion or due to the local resistances or vortex generators.

Cavitation processes are a separate kind of special flow turbulization. They arise in the presence of local or specially created resistances to the flow (the so-called hydrodynamic cavitation), as well as under the action on the liquid by a powerful ultrasonic radiation or periodic laser radiation. They are characterized by high intensities of dynamic perturbation of the gas-fluid medium.

**Dynamics of the Vapor Bubble — Head Working Element of DPEI Nanoprocesses.** As in the phenomena of hydrodynamic or ultrasonically induced cavitation, in the processes of adiabatic boiling of liquids the basic working element of the DPEI principle is the vapor bubble with all manifestations of its dynamics: appearance from the critical nucleus, or the process of intensive radial growth, effects of surface oscillations, realization of collapse, including that with the cumulative jet formation.

Consider some of the characteristic features of the behavior of a single bubble that arises suddenly in the bulk of a continuous fluid, calculated by the model of [2]. The bubble radius dynamics is accompanied by intensive oscillations of the radial velocity of the interface (vapor bubble–water), reaching locally 700 m/sec. The thus-arising accelerations of the interface are maximal at the moments the bubble radius is minimal and correspond thereby to values of  $10^{10}$   $\text{m}/\text{sec}^2$ , i.e., equal billions of values of the gravitational acceleration. At minimal values of the pulsing radius the vapor temperature inside the bubble is maximal, which is determined by the concentration of the kinetic energy of the interface motion inside and corresponds to the temperature values in the first half-period above  $1500^\circ\text{C}$ . Under these conditions, in the course of 1–5 nsec the instantaneous value of the vapor pressure increases to 12 thousand atm.

The specific kinetic energy of the collapsing bubble is maximal, as mentioned above, at the moments of the minimal radius and is characterized by two maxima (Fig. 2), reaching a limiting value above  $300 \text{ J}/\text{cm}^3$ , and the specific power of the kinetic energy of the compressed bubble increases to 100–300  $\text{MW}/\text{mm}^3$ . The instantaneous energy density at the interface in the course of 5 nsec exceeds  $100 \text{ MJ}/\text{m}^3$ , which is a few times higher than the bond-breakage energy of vapor molecules, i.e., the dissociation energy of water vapors equal to 493.8 kJ/mole. Moreover, such a level of collapse energy is enough to break the interatomic bond of the  $\text{OH}^-$  ion, whose energy is equal to 460.2 kJ/mole (according to Pauling–Syrkin). Note that the kinetic diameter of the water molecule measures 0.289 nm and the radius of the  $\text{OH}^-$  ion equals 0.153 nm. The characteristic values of the molecule dissociation energy for elements containing hydrogen, carbon, oxygen, and nitrogen, i.e., the structure-forming elements for many polymers, e.g., proteins, range from 10 to 25  $\text{MJ}/\text{m}^3$  and are comparable to or less than the pulse energy of the collapsing bubble. The analysis shows that the vapor-bubble collapse energy is enough to break, in the boundary layer, molecules of size 0.3–1 nm, i.e., realize the process of breaking nanometer-scale structures in a time corresponding to a few nanoseconds.

In turn, this is a physicochemical prerequisite for realization of the technological effects of catalysis of complex chemical reactions, sonoluminescence, fluid system activation, and superfine emulsification, as well as other physical phenomena of the nanometer scale that are determined by the collapse dynamics of a vapor bubble or a vapor

cavity. For example, in realizing in an aqueous medium different kinds of cavitation (hydrodynamic, induced by ultrasound, electric discharge, laser action), where the determining working element is the collapsing vapor (vapor-gas) bubble, various intensifying effects have been revealed experimentally.

**Physicochemical Nanoprocesses of the DPEI Principle.** *Sonoluminescence.* Luminescent glow under the action of collapsing cavitation bubbles was observed in various fluids, especially under their ultrasonic irradiation. The mechanism of luminescence is explained by the presence on the bubble surface of electric charges. Compression of the bubble leads to an increase in the electric field strength and an electric breakdown inside the vapor medium, as a result of which pulsed luminescence arises. And the formation of electric charges on the bubble–water interface is analogous to the mechanism of the balloelectric effect, which shows up as the appearance of voltage on the surface of water microdrops, which in turn arise inside the vapor bubble upon its condensation. The balloelectric effect is also inherent in other phase transformations, e.g., the processes of boiling and crystallization.

*Electrical phenomena.* Electric charges arising on the interface upon bubble or cavity collapse also determine other processes — water electrolysis, the appearance of ozone, manifestation of ionizing radiations. Under the action of the electric field strength arising upon bubble collapse, ionized molecules and ions and free radicals, e.g., valence-saturated hydrogen atoms  $H$  and hydroxyl radicals  $OH$ , arise. They have a high reactivity and activate phenomena analogous to the radiolysis of water — the appearance of  $H_2$  and  $H_2O$  molecules. The lifetime of primary free radicals is larger than the bubble collapse time and equals 0.1–10 msec. This fact is responsible for the formation of secondary radicals and the transition of chemically active radicals and ions to the liquid phase.

*Physicochemical action.* The effects of bubble and cavity collapse favor the appearance and intensification of many physicochemical transformations, activate redox and ionization processes, and, according to some ideas, cause even impulse X-rays. The splitting of water molecules and the appearance of radicals  $H^+$  and  $OH^-$  influence the basic properties of water solutions — their compressibility, density, diffusion coefficient, electrical and thermal conduction, dissolving ability, and other characteristics. For example, the action of ultrasound on reactions in water leads to the formation of clathrate cavities and  $H_2O_4$  and  $HO_2O_2$  complexes having a size of the order of 0.49 nm.

Concurrently with the process of water dissociation, the processes of recombination of radicals occur and reactions of other radicals, including secondary radicals of impurities or components, arise.

*Medium activation.* The action of the phenomenon of bubble collapse leads to an increase in the electrical conduction and acidity (pH index) that are due to the degree of hydration of ions and their mobility and chemical activity. For example, cavitation treatment of water in a dispersive mixture leads to an increase in the  $\xi$ -potential and the appearance of an electric charge upon solidification or crystallization of the system.

*Catalysis of chemical reactions.* The electrical phenomena, the appearance of electric charges at the interface, the electrical breakdowns caused by them, the molecule dissociation, the ionization, and the radiolysis of the vapor–gas mixture increase the rate of the chemical reactions proceeding in an aqueous medium. In the cavitation and ultrasonic fields, various processes of reduction and oxidation, dissociation and synthesis, polymerization and depolymerization, and molecular rearrangement are realized. For example, in water, upon collapse of bubbles, hydrogen peroxide  $H_2O_2$  and ozone  $O_3$  are formed, some heterocyclic and aromatic compounds in an aqueous medium upon the superposition of ultrasound fall apart with the opening of the benzene ring, and methylene chloride  $CH_2Cl_2$  transforms into a complex compound  $C_{10}H_7O_3Cl_2$ .

The action of the processes of bubble collapse activates the processes in biological media accompanied by ultraviolet radiation and photochemical transformations.

*Dispersion, emulsification, homogenization.* The dynamic processes of bubble collapse form the physical basis for the realization of the widely used technologies of crushing inclusions of the disperse phase (liquid, solid, or gaseous ones) in a fluid heterogeneous medium. For technological obtaining of vapor bubbles and vapor cavities, mainly all kinds of cavitation are used. For example, using ultrasonically induced cavitation, one can obtain mercury emulsion in water, which is unrealizable by classical methods.

## NOTATION

$A$ , Van der Waals–Hamaker constant;  $D$ , outflow cross-section diameter, m;  $E$ , energy, J;  $f$ , empirical coefficient;  $k$ , universal function determining distances from the flow axis;  $P$ , pressure, Pa;  $R$ , characteristic size (radius, film

size), m;  $S$ , area,  $m^2$ ;  $T$ , temperature,  $^{\circ}C$ ;  $V$ , flow velocity, m/sec;  $\delta$ , linear nanosize, m;  $\Delta$ , difference;  $\epsilon$ , kinetic energy,  $J/m^3$ ;  $\gamma$ , ratio of heat capacities,  $C_p/C_v$ ;  $\nu$ , kinetic-viscosity coefficient,  $m^2/sec$ ;  $\rho$ , density,  $kg/m^3$ ;  $\sigma$ , interfacial-tension coefficient, N/m;  $\tau$ , time scale, sec;  $\xi$ , potential, V;  $\mathcal{R} = 8.314 J/(mole \cdot K)$ , universal gas constant. Subscripts: \*, critical value of a quantity; 0, parameters of initial states; 1, liquid phase; 2, vapor (gas-vapor) phase; 3, liquid disperse inclusions of the second component.

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