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A MODEL OF AN ULTRASONIC EXTRACTOR USED IN THE FOOD INDUSTRY

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The modern development of mechanical engineering, instrument making, energy, medicine, transport, aviation and rocket and space technology is determined by new materials and substances created with improved mechanical, adhesion, absorption, chemical and other properties **[1, 2].**

The main task of today is to obtain material media with given properties requires the solution of two mutually exclusive tasks - the simultaneous provision of a low content of parasitic impurities and a high ability of substances to react with other useful substances, withstand thermal, mechanical, and other loads**[2].**

A promising and successfully developing direction for solving this problem is the creation and application of high-intensity ultrasonic (US) exposure, which ensures the destruction and coagulation of the dispersed phase in the carrier medium, the destruction of macromolecules of polymer liquids **[3-4].**

The emerging cavitation bubbles in the stage of rarefaction of ultrasonic vibrations expand to a size of 100 ... 150 microns, thereby storing energy. In the stage of compression, cavitation bubbles collapse, thereby instantly releasing energy in the form of high amplitude shock waves with a pressure amplitude of up to 100 MPa and a velocity of liquid phase movement up to 1500 m/s **[5].**

Purposeful production of a material environment with the necessary properties and characteristics for a specific application requires the selection of ultrasonic exposure modes. To identify the optimal modes and conditions of ultrasonic exposure, it is necessary to develop phenomenological models of physical effects and phenomena that arise under the influence of cavitation, and contribute to the intensification of technological processes.

The degree of manifestation of one or another physical effect **[6-7]** that forms the structure and properties of the material environment (destruction of molecular bonds, acceleration of mass transfer, destruction of a solid, destruction of the “liquid-liquid” surface) obviously depends on the characteristics of the cavitation region being formed - concentration, volumetric content and specific collapse energy of bubbles. Next, a model of the formation of the cavitation region is described, which makes it possible to determine its characteristics.

The model of the formation of the cavitation region includes the analysis of the dynamics of a single bubble depending on the properties of the carrier liquid phase to reveal the dependence of the radius of the cavitation bubble $R = f(t, I, Λ)$ on time t, the intensity of ultrasonic vibrations, and the rheological properties of the liquid $Λ$ (initial viscosity μ_0 *(Pa (λ >> L >> R).*

The analysis of the dynamics of a single bubble is aimed at revealing the functional dependence of the radius of the cavitation bubble on time, which is determined on the basis of the obtained equation of the dynamics of a single bubble for the stage of expansion (1) and the well-known Kirkwood-Bethe equation for the stage of collapse:

$$\frac{3}{2}\left(\frac{\partial R}{\partial t}\right)^2+R\frac{\partial^2 R}{\partial t^2}=\frac{-4\mu_0}{\rho_0}\left(1+\left(\frac{K}{2\mu_0}\right)\left(\frac{6\left(\frac{\partial R}{\partial t}\right)^2}{R^2}\right)^{\frac{N}{2}}\right)^{-sgnN}\frac{\frac{\partial R}{\partial t}}{R}+\left(\frac{p_0}{\rho_0}+\frac{2\sigma}{\rho_0 R_0}\right)\left(\frac{R_0}{R}\right)^{3\gamma}+\frac{p_\Pi-p_0+\sqrt{2\rho c I}\sin(2\pi f t)+}{\rho_0} \tag{1}$$

where R is the instantaneous radius of the cavitation bubble, m; ρ_0 — density of the carrier liquid phase, kg/m^3; R_0 — radius of the cavitation nucleus, m; γ is the adiabatic index in a gaseous medium; σ — surface tension of the carrier liquid phase, N/m; ρ is the density of the cavitating heterogeneous medium, kg / m3; c — speed of sound in a cavitating medium, m/s; I — intensity of ultrasonic vibrations in the vicinity of the cavitation bubble, W / m^2; p_0 — static pressure in the processed medium, Pa; f - frequency of ultrasonic vibrations, Hz; F is the function characterizing the nonlinear-viscous properties of the liquid phase surrounding the cavitation bubble **[2],** kg/(m·s^2).

Using the revealed functional dependence of the bubble radius on time, the characteristics of the cavitation region as a whole are determined. One of the characteristics of the cavitation area is the concentration of cavitation bubbles (2):

$$n_\infty=\frac{j-1}{i k_B T_o} \tag{2}$$

The concentration n_∞ depends on the coalescence (k_B) and fragmentation (j) constants of the bubbles. The coalescence constant is determined by the rate of convergence of bubbles during their in-phase oscillations, and the fragmentation constant depends on the maximum bubble radius attained during the expansion stage, according to **[2, 8].**

The found concentration of cavitation bubbles and the functional dependence of the radius of an individual bubble on time makes it possible to determine their volumetric content according to the expression:

$$\delta=\frac{4}{3}\pi R^3(t)\, n_\infty \tag{3}$$

The energy released during the collapse of cavitation bubbles and spent on changing the structure of properties and the material medium is determined by the absorption coefficient of oscillations in a cavitating liquid medium. The absorption coefficient determined according to expression (4) is the most important characteristic of the formed cavitation region, since it is proportional to the total power of the shock waves of cavitation bubbles and serves as a measure of the effectiveness of the cavitation effect:

$$K_{¿}=\frac{-\omega}{c_0}\Im\frac{\rho_0 c_0^2\delta_1}{\left(\sqrt{2\rho c I}\right)e^{i\varphi}};I=\frac{\overline{\left|p_1\right|}^2}{2\rho c};\;\; p_1=\left|\overline{p_1}\right|e^{i\varphi};\;\; \delta_1=\frac{\omega}{2\pi}\int_0^{\frac{2\pi}{\omega}}\delta(t)e^{-i\omega t}\partial t \qquad (4)$$

where I is the intensity of ultrasonic vibrations, W/m^2; ρ is the density of the cavitating medium, kg/m^3; c-speed of sound in a cavitating medium, m/s; ϕ - phase shift of sound pressure 1 p, rad; t - time, s; ρ_0 — density of the liquid phase, kg/m^3; c_0 — speed of sound in the liquid phase, m/s; ω - circular frequency of ultrasonic vibrations, c-1; $\delta(t)$ is the instantaneous value of the volumetric content of bubbles in the liquid.

The dependences of the absorption coefficient on the intensity of action for liquid media with different rheological properties of the carrier liquid phases are shown in Fig. 1.

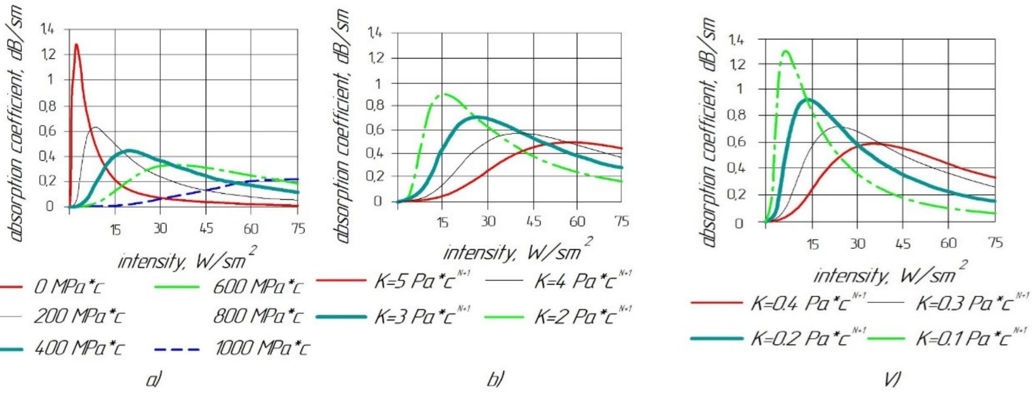

Fig. 1. Dependences of the absorption coefficient on the rheological properties of the carrier liquid phases: linear-viscous (*a*); pseudoplastic (N = –0.1) (*b*); dilatant (N = 0.1) (*v*)

The dependence of the absorption coefficient on the intensity of the impact is extreme, and the position of the maximum determines the optimal intensity of the ultrasonic impact, since in this case the maximum degree of transformation of the energy of the primary ultrasonic wave into the energy of shock waves created by cavitation bubbles is achieved. It was found that for liquid phases, which are most often used in practice in the processes of formation of the structure and properties of material media, the optimal intensities are from 1.6 to 80 W/sm^2

To predict the kinetics of technological processes of the formation of the structure and properties of material media, we describe below models that make it possible to determine the degree of manifestation of certain physical effects that directly affect the structure of the material environment.

The efficiency of the destruction of molecular bonds under the action of cavitation is obviously determined by the fraction of macromolecules subjected to destruction of the total amount. Depending on the characteristics of the cavitation region, assuming an equilibrium velocity distribution of molecules, the probability of destruction of an immobile macromolecule is determined according to the following expression:

$$P_{br}=\frac{45\left(max\left|\int_{S}^{\square}\frac{\partial p}{\partial n}(r,t)\partial S\right|\right)^{3}n_{bub}}{32\pi^{2}\rho^{3}v_{th}^{6}} \tag{5}$$

p-pressure of the shock wave in the core of the cavitation bubble during collapse, Pa; ρ-density of the liquid, kg/m^3; v_{th}-threshold collision velocity of macromolecules, m/s; n_{bub}-concentration of cavitation bubbles, m^{-3}; S is the surface of the wall of the cavitation bubble.

In expression (5), the pressure of the shock wave in the core of the cavitation bubble during collapse p and the bubble concentration nbub are determined based on the analysis of the previously described model of the formation of the cavitation region

The threshold collision velocity of macromolecules vth is the minimum velocity at which the decay of one of them occurs, is determined on the basis of Newton's second law for a system of particles interacting with the Rydberg potential **[9, 10, 11].**

The obtained dependences of the probability of decay of a macromolecule are shown in Fig. 2.

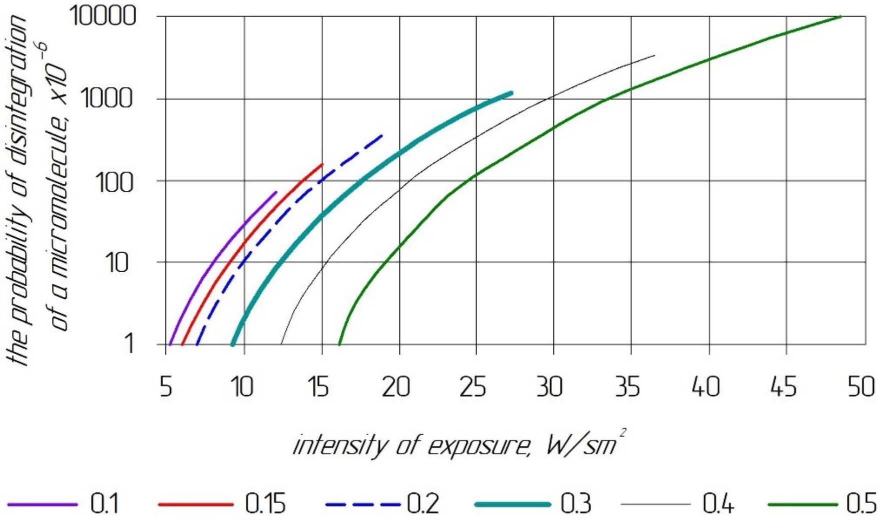

Fig. 2. Dependences of the probability of disintegration of a macromolecule on the intensity of ultrasonic action (frequency 22 kHz) at different viscosities of the liquid (in Pa s)

As follows from the presented dependences, the superposition of ultrasonic vibrations makes it possible to increase the probability of disintegration of macromolecules, and, consequently, to accelerate the depolymerization process up to 1000 times.

Thus, the proposed models made it possible to establish the high efficiency of ultrasound exposure for the formation of the structure and properties of material media.

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