Phenomenological modeling of systems with continuous liquid phase for optimal control of ultrasonic cavitation influence

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Abstract. The paper presents approach to optimal control of intensity of ultrasonic oscillations. The goal of control is providing maximum of energy efficiency of changing of structure and characteristic of mediums. The goal is achieved by developing complex phenomenological model of process under ultrasonic oscillations. The phenomenological model takes into account kinetics of processes and allows to determine real energy consuming. The model was tested on processes mechanical destruction of macromolecules and dispersing. The results of calculations by the model are dependencies of fractional composition liquid macromolecules and solid particles on time and viscosity of liquid, structure component of attenuation coefficient on intensity and viscosity of liquid. The model allows to evaluate multipliers for intensity providing maximum efficiency of cavitation. The multipliers allow to optimizing ultrasonic influence (increasing energy efficiency) and constant for specific process. Using of the multipliers increases the energy efficiency of process up to 1.8 times. Obtained results confirmed by experiments and can be used for ultrasonic equipment development.

1. Introduction
It is known and repeatedly proven that the ultrasonic (US) vibrations (US effect) action on systems with a liquid phase implements cavitation (shock waves and cumulative jets) and other nonlinear effects (forces of orthokinetic and dispersed particles hydrodynamic interaction in a liquid) [1–4]. These effects are capable of changing the systems structure and characteristics with a liquid phase (changing the carrier liquid phase molecular weight and viscosity, the dispersed phase particles fractional composition), which makes it possible to obtain new materials or to impart new, unique characteristics to known materials (multiply increased permeability, interaction surface, tensile strength after curing, reduced unwanted impurities content, etc.).

To date, the modes (ultrasonic transducer surface amplitude and the US vibrations generation principle) and conditions (geometry technology volume) effects, allows to reach the processes greatest possible efficiency in the system with the liquid phase (e.g., a chemical reaction, dispersion, coagulation, emulsification), mainly experimentally selected individually to specific environments and maintained at a constant level during the ultrasonic treatment whole time [3, 5-7]. However, this approach has fundamental disadvantages number, namely:

- does not provide the ultrasonic action maximum efficiency using the selected modes, since the energy consumption actual ratio for a system transforming the structure and characteristics with a liquid phase (energy for the liquid phase breaking interatomic and intermolecular bonds,
dispersed particles destruction or coagulation) to the introduced acoustic energy is not determined;
• does not guarantee that the selected modes will provide the process maximum energy efficiency throughout its entire duration. This is because, under the ultrasound action, the treated medium properties and characteristics change over time;
• does not allow predicting optimal exposure modes for newly developed processes. This is because this approach does not make it possible to establish structure formation uniform patterns and systems characteristics with a liquid phase, depending on the ultrasonic exposure modes and conditions.

One of these shortcomings consequences is that in ultrasonic technological devices existing industrial models that implement experimentally selected modes and conditions, more than 90% of the energy is lost in the heating' the sounding medium form.

In this case, as noted above, the medium properties change continuously during the ultrasonic treatment process, and to ensure the most effective impact, it is necessary to continuously or periodically adjust the modes to change the ultrasonic exposed medium properties.

In this regard, to solve the ultrasonic action optimal control problem on systems with a liquid phase to achieve the processes maximum energy efficiency, it is necessary to create a complex interconnected model for converting the ultrasonic vibrations’ energy into a target change in the medium structure and characteristics being processed, which will reveal the modes and conditions that provide an increase in the impact efficiency, depending on the environment properties current values.

The ultrasonic action optimal control ultimate goal on systems with a continuous liquid phase is to establish the variation law in the ultrasonic action intensity over time to achieve the following criterion:

\[
u \left\{ \frac{d \mathcal{C}}{d \tau} \mid \frac{d \mathcal{C}}{d \tau} = \mathcal{A} \left( \mathbf{C}(\tau), I(\tau) \right) \right\} = a(0) \rightarrow \text{max};
\]

where \( u \) is the interatomic and intermolecular bonds potential energy per the medium unit volume, \( \text{J/m}^3 \); \( \mathcal{X} \) – the ultrasonic treatment product target characteristic (the dimension depends on the physical quantity – viscosity type, a specific interface between the solid and dispersed phase, etc.). \( \mathcal{X}_{\text{start}} \) – the final product target characteristics value in the initial time; \( \mathcal{X}_{\text{finish}} \) – the final product target characteristics desired value after ultrasonic exposure; \( \mathbf{C} \) – the environment vector structure that determines the different types structural elements number density at different points in time

\[
\mathbf{C}(\tau) = \begin{cases} 
C_1(\tau) \\
C_2(\tau) \\
\vdots \\
C_n(\tau)
\end{cases}
\]

environment structural elements number concentration \( i \)-type, for example, macromolecules [8], solid-liquid phase weight \( i \) or the dispersed phase particles, with size \( d_i \), \( \text{m}^3 \); \( \mathbf{A} \) - an operator that determines the rate of medium structure vector change, \( \text{m}^{-3}/\text{sec} \); \( I \) - the ultrasonic vibrations' intensity, \( \text{W/m}^2 \); \( \tau_{\text{finish}} \) – ultrasonic exposure time, sec.

To develop a control algorithm, it is initially necessary to identify the medium structural elements concentrations dependences \( \mathbf{C}(\tau) \) on the time \( \tau \) and the potential energy \( u \) on the structure vector \( \mathbf{C} \). Therefore, the developed complex phenomenological model should, first, be aimed at identifying these dependencies.

Developing a phenomenological model process is described below.
2. Phenomenological model of processes under ultrasonic cavitation influence

To develop a phenomenological model that allows creating an algorithm for controlling ultrasonic action on systems with a continuous liquid phase, which will provide the action maximum energy efficiency, the ultrasonic vibrations converting the energy stages when they are emitted into a liquid are initially identified.

The emitter surface vibrational energy forms pressure drops in the liquid. The resulting pressure drops are dissipated in a medium with a total absorption coefficient of $K$ (the ultrasonic wave intensity upon passing a certain small distance $\Delta x$ decreases by $K \Delta x$) [9].

![Figure 1. Ultrasonic vibrations energy conversion stages. $V$ – volume of insonified system with a fluid phase; $I_{PRIM}$ – intensity of the initial ultrasonic wave generated by the ultrasonic radiator, W/m$^2$; $I$ – intensity of ultrasonic oscillations in separate zone of the technological volume, W/m$^2$; $\Delta I$ – change of the intensity of ultrasonic oscillations as a result of dissipation (absorption) at the passing of ultrasonic wave the distance $\Delta x$ (m), W/m$^2$; $K$ – total oscillation absorption coefficient, m$^{-1}$; $K_m$ – the structural component of the absorption coefficient, m$^{-1}$; $K_t$ – the thermal component of the absorption coefficient, m$^{-1}$.

Specific power dissipated per the medium unit volume $2KI$ per time unit includes 2 components ($2KI = 2K_mI + 2K_tI$):

1) the specific power spent on undesirable and in some cases unacceptable the medium heating (increase in the molecules chaotic movement kinetic energy) - $2K_tI$;

2) the specific power spent on changing the structure (molecules hydrogen or carbon bonds destruction, solid particles dispersion) the specific power expended to change the structure (molecules hydrogen or carbon bonds destruction, solid particles dispersion or coagulation) of the medium – $2K_mI$.

Structural changes in the environment change its macroscopic characteristics. The medium macroscopic characteristics, which have changed over a time short period, during the next time interval begin to influence the pressure perturbations field in the liquid differently as compared to the previous interval. This is due to a change in the fluid acoustic properties. For example, changing viscosity changes the cavitation intensity. Consequently, the liquid average wave resistance and the oscillations average absorption coefficient in the liquid change.
As already mentioned, changes in liquid acoustic properties must be taken into account to implement ultrasonic exposure control.

Structural changes in the environment are proposed to be described by the structure vector $C$, which was introduced in equation (1). The interactions type analysis in common processes showed that interactions between cavitation bubbles, dispersed particles, or continuous liquid phase molecules are of two types:

- paired interactions between the medium structural elements (pressure drops initiated by the ultrasonic' vibrations action increase the paired interactions' frequency);
- the pressure drops impact a medium single structural element.

In this regard, the medium structure vector obeys the differential equation (2).

$$\frac{dC}{dt} = B[p(r, t), C(t)] + D[p(r, t), C(t)];$$  \hspace{1cm} (2)

$$C(0) = C_0;$$ \hspace{1cm} (3)

$$B[p(r, t), C(t)] = \sum_{i} \left( \sum_{j} \kappa(i, j, k) \beta(j, k, p(r, t)) C_j C_i - C_i \sum_{j} \beta(i, j, p(r, t)) C_j \right) e_i;$$ \hspace{1cm} (4)

$$D[p(r, t), C(t)] = \sum_{i} \left( \lambda(i) \gamma(i + 1, p(r, t)) C_{i+1} - \gamma(i, p(r, t)) C_i \right) e_i;$$ \hspace{1cm} (5)

where $t$ is residence time of the allocated small volume (in comparison with the entire technological volume) of the medium in the apparatus, $B$ is quadratic operator that determines the effect of pairwise interaction of structural elements (dispersed particles or molecules) with each other on the medium structure vector; $D$ is difference operator, taking into account the effect of an external field (pressure drops field) on a separate structural element; $p(r, t)$ is field of pressure drops in the medium, depending on the microscopic coordinates $r$ and time $t$, $P_a$; $\beta(j, k, p(r, t))$ is the probability of the formation of a new $i$-th type structural element in the interaction of structural elements of types $j$ and $k$; $\kappa(i, j, k)$ is the number of structural elements of the $i$-th type formed during an elementary act of interaction of a pair of structural elements of the $j$-th and $k$-th types; $\gamma(i, p(r, t))$ is the probability of destruction of an individual structural element of the $i$-th type by external field; $\lambda(i)$ is the number of structural elements of the $i$-th type formed during the destruction of the structural element of the $(i+1)$-th type.

Equation (2) obeys all common processes occurring under the ultrasonic cavitation influence. Based on the equation (2) solution, the ultrasonic action efficiency on a medium unit volume element $\Delta x \Delta S$ ($\Delta x$ is the volume length along the axis parallel to the ultrasonic wave propagation direction; $\Delta S$ is the cross-sectional area perpendicular to the ultrasonic wave propagation direction) is determined according to the following expression:

$$\eta = \frac{I \Delta S \Delta t - (I + \Delta I) \Delta S \Delta t}{I \Delta S \Delta t} = \frac{\Delta I \Delta S \Delta t}{I \Delta S \Delta t} \approx \frac{\partial l}{\partial x} \frac{\Delta x \Delta S \Delta t}{I \Delta S \Delta t} = \frac{\partial l}{\partial x} \Delta x \frac{\Delta S \Delta t}{I} \approx \frac{\partial l}{\partial x} \Delta x = \frac{2K_m \Delta x}{l} = 2K_m;$$

$$K_m = \frac{1}{2l} \frac{du}{d\tau}(C) = \frac{1}{2l} \left( \nabla_{\text{ct}} \frac{dC}{d\tau} \right).$$

The structural component of the absorption coefficient $K_m$ determines the ultrasonic action efficiency in a linear proportional manner. Therefore, the problem of maximizing the ultrasonic action efficiency is reduced to the problem of maximizing the value of $K_m$. To identify the optimal modes that provide the absorption coefficient structural component maximum, it is necessary, first, to determine the proportionality coefficients $\beta(j, k, p(r, t))$, $\kappa(i, j, k)$, $\gamma(i, p(r, t))$, $\lambda(i)$ in the equation (3).
The odds represent the environment structure transformation elementary acts probability, and for these coefficients' determination the special models of elementary acts are developed, which are described further on the mechanical destruction' macromolecules processes example and of particle dispersion in a liquid.

In the mechanical destruction, process, the structure vector is the macromolecules molar concentration with monomer units' different numbers \((C_i)\) is the macromolecules molar concentration with the monomer units - weight number \(i\). The mechanical destruction probabilistic model is based on a physical mechanism, according to which the observed molecule destruction can occur only when it collides with other molecules [8]. In this case, cavitation, which creates extremely high pressures, increases the molecular velocity dispersion. As a result, the molecules’ fraction whose movement relative speed exceeds the critical value required for destruction increases many times. To determine the critical velocity, which depends on each molecule orientation we analysed the molecules’ interaction near their contact with each other according to the conservation equation for the kinetic and potential energies sum, using the Morse potential function to calculate the interaction force between a pair of individual monomer units.

Since each mechanical destruction elementary act occurs only during molecules pair collisions, the difference operator coefficients are identically equal to zero:

\[
L(i) = 0; \tag{6}
\]
\[
\gamma(i, p(r,t)) = 0. \tag{7}
\]

The quadratic operator coefficients are determined according to the obtained expressions (8, 9):

\[
\kappa(i, j, k) = \begin{cases} 
  j \leq i \lor k = 1, & 0 \\
  j > i \land k > i, & \frac{j + k - 2}{(j-1)(k-1)} \\
  j > i \land k > 1 \land k \leq i, & \frac{1}{j-1} 
\end{cases} \tag{8}
\]

\[
\beta(i, j, p(r,t)) = \frac{8(i-1)(j-1)N_A n_{hab}}{T^2 \pi} \sqrt{2\delta_i^2 + 2\delta_j^2} \times 
\]

\[
\times \int_{0, \delta_i^{-1} + \delta_j} \int_{0, \delta_j^{-1} + \delta_i} \int_0^\pi r_i^2 \sin^2 \theta_i \sin^2 \theta j e^{-\frac{r_{\min}^2}{2\delta_i^2 + 2\delta_j^2}} \times 
\]

\[
\times \left[\frac{v_{\max}^2}{2\delta_i^2 + 2\delta_j^2} + 1\right] d\theta_i d\theta_j d(\cos(\theta_i - \theta_j)) dr_i; \tag{9}
\]

where \(r_i\) is the equilibrium distance between monomer units, m; \(\delta_i\) is the macromolecules mass centres velocity standard deviation with a weight of \(i\), m/s; \(\varphi_i\) and \(\theta_i\) - a molecule orientation azimuthal and polar angles with weight \(i\), rad; \(N_A\) - Avogadro's number; \(n_{hab}\) - cavitation bubbles concentration, m\(^{-3}\); \(R(t)\) - cavitation bubble radius dependence on time in the collapse phase, m; \(p(r)\) is the shock wave pressure dependence on the distance between the observed molecule and the cavitation bubble centre, Pa.

According to expression (9), the macromolecules collision and destruction probability \(\beta(i, j, p(r,t))\) depends on the formed cavitation region medium and the characteristics' temperature static pressure, determined on the model basis described in the publication [9].

After expressions substitution for proportionality coefficients (6–9) by solving equation (2), macromolecules distributions by weights at different points in ultrasonic mechanical destruction time were revealed (figure 2). Here and in what follows, changes in the medium structure vector were
calculated by numerically solving equation (2) using the Runge-Kutta method with an adaptive time step using a specially developed computer program.

![Figure 2. Macromolecules distribution by weights (monomer units numbers) at different points in time (sonicated medium - epoxy resin ED-20, ultrasonic vibration frequency 22 kHz, intensity - 25 W / cm²).](image)

Based on the found macromolecules fractional composition dependences on time at various vibration intensities and properties, calculations were made of the ultrasonic vibrations' absorption coefficient structural component, which provides the ultrasonic action maximum efficiency, and the optimal intensities at which this maximum is achieved (see the next section 3).

The process of ultrasonic dispersion occurs according to the following defining physical mechanism. Each separated dispersed particle disintegrates if and only if the cavitation bubble collapses inside some neighbourhood, called the decaying neighbourhood [10]. This assumption is valid in the fact view that the shock wave generated by the cavitation bubble attenuates in inverse proportion to the distance from its centre. This means that cavitation bubbles that appear at a distance from a dispersed particle that exceeds a certain threshold value do not affect its destruction. Accordingly, a bubble nucleation and collapse probability in the "decay neighbourhood" determines the particle destruction (dispersion) probability.

Since possible particles pair collisions have a weak effect on the dispersion process, the quadratic operator coefficients in equation (2) are taken to be identically equal to zero (10, 11):

\[
K(i, j, k) = 0; \quad (10)
\]

\[
\beta(j, k, p(r, t)) = 0; \quad (11)
\]

the difference operator coefficients are determined according to the expressions (12, 13):
\[ L(i) = 2; \]  
\[ \gamma(i, p(r, t)) = \zeta n_{\text{sub}} V_{bi}; \]  

where \( f \) is the ultrasonic vibrations' frequency, Hz; \( n_{\text{sub}} \) - cavitation bubbles concentration, \( \text{m}^{-3} \); \( \zeta \) is a correction factor that takes into account fatigue strength and microcracks accumulation in a particle before its destruction; \( V_{bi} \) is the “decay neighbourhood” volume for a particle with a diameter of \( d_k \), \( \text{m}^3 \).

By solving equation (2) after substituting expressions for the coefficients (10-13), the particle size distributions were revealed at ultrasonic dispersion at different times (figure 3).

The presented histograms can be directly used to predict the suspension particle size at the apparatus outlet for a given initial size, the intensity of ultrasonic action and the suspension residence time in the apparatus. In this case, the histograms in figure 3 indicate an optimal intensity existence (for a model suspension - 4 W/cm\(^2\)), at which the maximum dispersion efficiency is achieved at the same energy consumption (for a model suspension - \( It = \text{const} = 3600 \text{ J/cm}^2 \)).

\[ \text{Figure 3. Aluminium suspension particles distributions in the water at different intensities } I \text{ and exposure times } t (\text{frequency} - 22 \text{ kHz}). \]

The obtained particles fractional composition dependences are confirmed by experimental data (obtained by students and researchers of Biysk Technological Institute (branch) of Altai State University named after I.I. Polzunov), which also indicate the optimal intensity presence (figure 4).

Further, the absorption coefficient structural component dependences on the liquid ultrasonic vibrations and the viscosity intensity for various processes occurring under the ultrasonic cavitation influence were obtained and investigated.
Micrograph (graduation 100 microns)

Initial composition

After ultrasonic dispersion without optimization
($I= 2 \text{ W/cm}^2 \ t=30 \text{ min}$)

After ultrasonic dispersion with optimization
($I=4 \text{ W/cm}^2 \ t=15 \text{ min}$)

Histogram (abscissa - particle size range, μm; ordinate - mass fraction)

Experiment | Theory
---|---

Figure 4. Aluminium suspension particles distribution in the water at different intensities $I$ and exposure times $t$ (experimental data).

3. Results and Discussions on Ultrasonic Cavitation Influence Energy Efficiency
The absorption coefficient structural component dependencies, which determines the impact efficiency, on the intensity and optimal intensity are shown in figures 5, 6 for the macromolecules mechanical destruction process and in figures 7, 8 for the dispersion process.

Figure 5. The absorption coefficient structural component dependences on the exposure intensity at the liquid different viscosities (mechanical destruction process).
The presented dependences indicate an optimal intensity presence that provides an absorption coefficient structural component maximum and, consequently, an ultrasonic exposure efficiency maximum for the considered processes each.

From the dependencies shown in figures 6, 8, it follows that the optimal intensity ratio at which the vibration energy maximum fraction is transferred to the process implementation $I_{opt}$, to the optimal intensity, at which the vibration energy maximum fraction goes into the bubbles collapse $I_{opt,cav}$, the liquid phase viscosity regardless, is the same value. By approximating the dependencies, the correction factor value $k_{disp} = \frac{I_{opt}}{I_{opt,cav}} = 1.75$ for the dispersion process and $k_{mech} = \frac{I_{opt}}{I_{opt,cav}} = 0.63$ the mechanical
The destruction process was established. At the same time, as follows from the presented dependencies (figures 5, 7), taking into account this correction factor increases the process efficiency by 1.3 ... 1.8 times (with an intensity equal to $I_{\text{opt}}$) compared to the intensity $I_{\text{opt,cav}}$.

Thus, the ultrasonic mechanical destruction and dispersion processes kinetics analysis showed that the optimal intensity $I_{\text{opt}}$, at which the absorption coefficient structural component maximum is reached, is linearly proportional to the intensity that provides the cavitation maximum development:

$$I_{\text{opt}} = kI_{\text{opt,cav}},$$

(14)

where $k$ is a correction factor that depends on an interface in the sonicated system presence/absence with a carrier liquid phase ($k = 0.63$ for homogeneous systems and $k = 1.75$ for heterogeneous systems).

Based on the obtained relationship (14), a previously created method modification for automatically maintaining the optimal intensity in an ultrasonic apparatus is proposed, depending on the system properties with a liquid phase at the current time.

The known method [11] consists of 3 cyclically repeating steps:

1) measuring the acoustic load $Z_{\text{LIQ}}$ in a sonicated cavitating medium form (when using the ultrasonic emitter itself, which has its electrical impedance $Z_{\text{OS}}$, as a sensor, figure 9);

2) the optimal intensity calculation $I_{\text{opt,cav}}$ based on indirect acoustic load data representing the electrical impedance active component $Z_{\text{LIQ}}$ caused by the acoustic load. The optimum intensity is determined by the maximum reaching point $\text{Re} Z_{\text{LIQ}}$ - the ultrasonic emitter active electrical resistance caused by the loss of acoustic energy in the medium;

3) setting the ultrasonic emitter oscillations intensity at the level of $I_{\text{opt,cav}}$.

The method modification concerns the 3rd step and consists of setting the intensity at the level of $kI_{\text{opt,cav}}$ instead of $I_{\text{opt,cav}}$.

Since the medium change properties, and the intensity establishment at the level of - takes a finite time, an algorithm for the optimal intensity periodic determination and its establishment is proposed. The proposed algorithm is that every $T$ seconds, during the time $\tau$, the intensity smoothly changes from 0 to $I_{\text{MAX}}$ (the maximum permissible intensity at which the emitter structural elements are not destroyed) and with this, a smooth change is defined by $I_{\text{cav}}$ according to the criterion $\text{Re} Z_{\text{LIQ}}(I_{\text{cav}}) \geq \text{Re} Z_{\text{LIQ}}(I)$ for any $I \in [0, I_{\text{MAX}}]$. Then, during the next time interval of $T - \tau$, the intensity is set at $kI_{\text{cav}}$.

A priori estimates have shown that the proposed control algorithm implementation will increase the ultrasonic action efficiency in comparison with the known algorithm by at least 1.25 times (possibly up to 1.7 times) when choosing the period $T$, during which the medium change properties slightly.

![Figure 9. Ultrasonic emitter (left) and its equivalent electrical circuit (right).](image-url)
Since the chemical-technological processes implemented in practice in systems with a liquid phase, as a rule, are not purely homogeneous or heterogeneous, for the correction factor practical determination $k$, a dimensionless criterion $Su$ was proposed based on the macromolecules and dispersion ultrasonic mechanical destruction developed kinetic models:

$$Su = \frac{\sum_{i} M N_A d_{32}^2 \alpha_c \phi_{\text{opt}}}{\text{MAX} \alpha_c}.$$  

where $i$ is the monomer units average number in a liquid macromolecule; $M$ - a single monomer unit molar mass, kg/mol; $D_{\text{min}}$ - the monomer units interaction potential energy absolute value, J/mol; $r_e$ is the distance between the carrier liquid phase individual monomeric units, m; $N_A$ - Avogadro’s number, $6.02 \times 10^{23}$ mol$^{-1}$; $\rho$ is the carrier liquid phase density, kg/m$^3$; $\sigma_{\text{crit}}$ - a dispersed particle substance tensile strength, Pa; $d_{32}$ - dispersed particles average volumetric surface diameter; $\tau_{\text{sh}}$ - a shock wave pulse characteristic duration, 1 μs; $\alpha$ - dispersed particles volumetric content; $\zeta$ is the correction factor that takes into account the fatigue strength and the microcracks accumulation in the dispersed particle.

Criterion $Su$ determines the interface effect on the process course, intensified by ultrasonic vibrations. The criterion physical meaning is the processes rate ratio (the change rate in the structure vector) at the interface to the processes rate in the liquid phase volume. Based on the $Su$ criterion, a refined expression was obtained for the correction factor $k$, which is included in the expression and is taken into account in the modified method for automatically maintaining the optimal intensity:

$$k = \frac{1.75 Su + 0.63}{1 + Su}.$$  \hfill (15)

The expression obtained takes into account the changes simultaneous ultrasonic intensification possibility in both the carrier liquid phase and the dispersed phase structure (for example, an epoxy resin mechanical destruction with a filler simultaneous dispersion mixed in it).

When $Su \gg 1$, the process is completely heterogeneous, and the correction factor $k = 1.75$; and at $Su \ll 1$ the process is completely homogeneous, and $k = 0.63$. At $Su$ intermediate values, the process is accompanied by simultaneous chemical transformations in the continuous liquid phase and dispersed phase surface restructuring.

The obtained expression for the correction factor must be taken into account when implementing the proposed algorithm for controlling the ultrasonic exposure intensity.

4. Conclusion

It has been established that the main reason for the systems ultrasonic treatment insufficient efficiency with a liquid phase is the scientific data lack on the exposure optimal modes that provide the vibration energy maximum fraction, which transforms into the medium structure transformation.

For the first time, a system characteristics evolution closed kinetic models with a liquid phase have been created taking into account the pressure drops initiated by ultrasonic vibrations, namely:
• high molecular weight liquids ultrasonic mechanical destruction model (homogeneous systems);
• heterogeneous systems ultrasonic dispersion model with a carrier liquid phase.

The created models for the first time make it possible to predict system characteristics with a liquid phase as an ultrasonic vibrations superposition result and to determine the energy consumption for the process depending on the feedstock action and characteristics modes.

The proposed models made it possible to create a method modification for the ultrasonic exposure intensity automatic control, which makes it possible to increase the ultrasonic exposure efficiency by 1.25 ... 1.7 times.

Acknowledgements
The study of cavitation influence on the materials structure was supported by Grant of President of Russian Federation MK-5387.2021.1.1. The development of algorithm of optimal control was supported by Russian Foundation for Basic Research (Project No. 20-21-00017 Rosatom).

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