Modeling of alternating impulses of pressure for hydrodynamic conditions in mixing technology

Iryna Dubovkina

Institute of Engineering Thermophysics of the National Academy of Sciences of Ukraine, Kyiv, Ukraine

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Corresponding author:

Iryna Dubovkina
E-mail: dubovkinai@ukr.net

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Abstract

Introduction. The aim of this study is to investigate the influence of the application of alternating impulses of pressure throughout treatment of liquid solutions by the numerical modelling.

Materials and methods. The volume parametric imitation and visualization, modeling methods, math modeling methods were used for the description of the conditions at the working parts of the rotary-pulsed apparatus during the liquid treatment.

Results and discussion. By the modelling processes, mathematical and numerical modelling was found that the value of the linear speeds of a stream should be from 21.98 m/s to 22.13 m/s for the first rotor and from 23.58 m/s to 23.70 m/s for the second rotor. The value of angular velocity was 314 s^{-1} and the frequency of hydrodynamic oscillations was $3 \cdot 10^3$ Hz. The coaxial clearance between first rotors, stator and second rotor was from 100 to 500 μm. The value of shear rate was for the first rotor from $2.2 \cdot 10^5$ s^{-1} to $0.44 \cdot 10^5$ s^{-1} and for the second rotor from $2.4 \cdot 10^5$ s^{-1} to $0.47 \cdot 10^5 s^{-1}$. The value of shear stress for the first rotor was from 219.8 Pa to 44.26 Pa and for the second rotor from 235.5 Pa to 47.4 Pa. The pressure difference between the input and the output liquid solutions at the working volume before and after treatment is $\Delta P = 50 \cdot 10^3$ Pa. According to the results of the research, it was found that the alternating pressure pulses in the system are $\Delta P = 370 \cdot 10^3$ Pa near the outer surface of the inner rotor; $\Delta P = 240 \cdot 10^3$ Pa near the outer surface of the stator; $\Delta P = 155 \cdot 10^3$ Pa near the inner surface of the stator; $\Delta P = 190 \cdot 10^3$ Pa near the inner surface of the outer rotor. The local pressure values in the zone of water and alcohol inlet and water-alcohol mixture outlet from the clearance change: near the outer surface of the inner rotor from $-50 \cdot 10^3$ Pa to $+300 \cdot 10^3$ Pa; near the outer surface of the stator from -150 to $100 \cdot 10^3$ Pa; near the inner surface of the stator from $+40 \cdot 10^3$ Pa to $-120 \cdot 10^3$ Pa; near the inner surface of the outer rotor from $+ 100 \cdot 10^3$ Pa to $-100 \cdot 10^3$ Pa.

Conclusions. A numerical calculation was accomplished to determine the hydrodynamic parameters of equipment that implements the basic mechanisms and concept of the alternating impulses of pressure, that realize in rotary-pulsed apparatus for the processing of water and ethanol-containing products.

Introduction

Today alternative foodstuff technologies, methods and equipment as innovative food production technologies provide increased productivity with limited resources and an improved carbon footprint. Food security has become a major challenge for the future owing to the scarcity of land, rising global population, urbanization, and polluted soil and water resources (Erekath et al., 2024). There are intensively developing novel food processing technologies that are environmentally-friendly and energy-saving ones (Ivanov et al., 2021).

Understanding how liquid interact with each other is key to conseption how structures arise and how their properties arise from these (Welton, 2018). These interactions arise from a combination of Coulomb forces, hydrogen bonds, pi-pi interactions, and dispersion forces (Fumino et al., 2014).

Hydrodynamic cavitation includes many structures, such as a Venturi tube, orifice, and pulsed jet Selfexcited oscillation cavitation is a kind of pulsed jet (Nie et al., 2022). Consequently, electrical plasma discharge can be used alone as well as in combination with other advanced oxidation processes techniques, such as UV photocatalysis and ozonation (Fang et al., 2019).

Cavitation is another advanced oxidation processes that generates cavities through ultrasound or changes in device geometry, and the processes of cavity generation, growth and collapse increase mass transfer rates and generate highly reactive free radicals to intensify certain chemical reactions (Wang et al., 2022). As regards industrial processes, assessing the heat exchanges occurring as two fluid constituents are mixed together is a most common requirement, whatever the quantities to be considered (Mhammedi et al., 2019).

However, various chemical and physical processes can be strengthened by utilizing the high temperature and pressure liquid environment generated by cavitation bubble collapse, which makes it possible to apply hydrodynamic cavitation to water treatment(Song et al., 2022). Using an effective and economic hydrodynamic cavitation reactor can increase the quality of water treatment and the commonly used hydrodynamic cavitation reactor include the venturi tube cavitation reactor, orifice plate hydrodynamic cavitation reactor and rotor hydrodynamic cavitation reactor (Wang et al., 2021).

The method of alternating impulses of pressure is one of the methods of controlled energy impact with many hydrodynamic effects, such as power of pressure of shift, cavitations, the effect of explosive boiling, collective effects in assembly of vials, crossness of an interphase surface in gas-liquid bubbly medium, action of hydrodynamic oscillations, alternating impulses of pressure, effects which associated with acceleration of movement of a continuous phase. During the last values cavitation and adiabatic boiling can be present (Li et al., 2018).

The most important effects of the alternating impulses of pressure are allied with increase of velocity of association of a continuous phase of medium. Three-dimensional and period concentration of energy gives the possibility to receive the big capacity of pulsation power accomplishment, to release internal energy of substance, to create active energetic processes which take place at microlevel and also at nanolevel (Shurchkova et al., 2015).

To intensify mixing of water and another component such as ethanol or fertilizers it is necessary to use rotary-pulsed apparatus. High energy transitional hydro-mechanical influence on liquid media and solutions in rotary pulsed apparatus conducts to transformation of structural formation and in the same time there is no intensive destruction of macromolecules and associates.

To optimize the process of hydrodynamic treatment it is necessary to define the level of power influence on the liquid media and solutions for indispensable transformations which can provide predictable physical and chemical parameters. Thus, the numerical and mathematical modeling of the hydrodynamic conditions in the rotary-pulsed apparatus is relevant and needs further study.

The aim of this study is to investigate the influence of the application of alternating impulses of pressure throughout treatment of liquid solutions by the numerical modelling.

Materials and methods

Materials

Liquid solutions and systems: water, alcohol, water-alcoholic solutions and mixtures in a wide range of concentration, percentage of alcohol in mixtures was varied from 5 to 90%, double distilled water, hydroponic, hydroponic with fertilizers were used for experiments.

Methods

The volume parametric imitation and visualization, modelling methods OF numerical simulation of the flow dynamics based on the Navier-Stokes equations, math modeling methods on RNG k-ε model of turbulence were used for the description of the conditions at the working parts of the rotary-pulsed apparatus during the liquid treatment.

Experimental installation

The experimental investigation was carrying out on the investigational unit on Figure 1.

The main device of this unit is rotary-pulsed apparatus. That's why the object of this scientific investigation study was rotary-pulsed apparatus in which liquid solutions of different types were processed by alternating impulses of pressure and were powered by hydrodynamic effects such as the speeds of shift of a stream, pressures of shift of a stream.

The work of the experimental unit is carried out as follows. At first liquids: associated liquid aqueous systems, water solutions, media are inflowing at the tank for liquid 1. After that through the flowmeter 3 liquid aqueous systems and solutions follows into the chamber of rotary-pulsed apparatus 8 for the processing by alternating impulses of pressure. From the tank 2 for another liquids such as alcohol or nutrients, or fertilizers are inflowing through the flowmeter 3 and follows into the chamber of rotary-pulsed apparatus 8. In the chamber of rotary-pulsed apparatus 8 instant mixing occurs by the alternating impulses of pressure in the hydrodynamic conditions.

There are two ways of the processing. The first way is in continuous uninterrupted mode at once and the second way is in recirculation mode after instant mixing by alternating impulses of pressure in the chamber of rotary-pulsed apparatus 8 in the hydrodynamic conditions with specific variable duration period of processing.

After mixing liquid solutions and mixtures follows into tank of treatment liquids 10 through the valve 9.

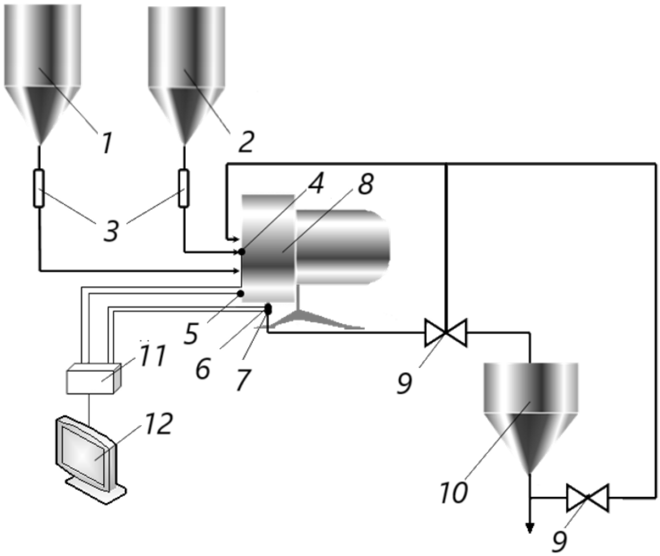

Figure 1. Scheme of experimental unit:
1 – tank for alcohol; 2 – tank for water; 3 – flow meters; 4 – thermocouple;
5 – pressure transducer; 6 – thermocouple; 7 – pressure transducer;
8 – rotary-pulsed apparatus; 9 – valve; 10 – tank for water-alcohol mixture;
11 – analog-to-digital converter; 12 – personal computer.

During the experimental investigation a number of parameters are controlled: temperature by the thermocouple 4 and 6, pressure by pressure transducer 5 and 7. Other parameters are controlled by analogue-digital transmitter 11 and results transmitted on personal computer 12. The construction of rotary-pulsed apparatus was the cylindrical type with the working chamber. The subsequently positions in working volume between coaxial cylinders of the «rotor-stator-rotor» system were selected (Fig. 2) (Dubovkina, 2017).

Figure 2. Working chamber of rotary pulsed apparatus
1 – external rotor; 2 – stator; 3 – internal rotor

Important technical parameter such as speed of shift of a stream was recognized for treatment of liquid solutions with the appliance of the alternating impulses of pressure (Dubovkina et al., 2019).

By the consequences of the computation was established that the principal values of speeds of shift of a stream emerge in RPA with coaxial clearances between first rotors, stator and second rotor 100×10^{-6} m. For circulation out of processes of treatment liquid solutions and mixing provided in to processing in uninterrupted mode during special time and exceptional hydrodynamic conditions which can realize during the alternating impulses of pressure.

The duration of treatment varied from 0.5 s to 300 s. This time was found by the mathematical calculating and volume parametric imitation modeling and was applied in nature experimental investigations.

Throughout the treatment in uninterrupted mode was used instantaneous depressurization in a working volume. The recovering of the parameters to the atmosphere pressure was spent by two ways. The first way was recovering to primary pressure during 30 s. The second way was recovering to primary pressure instantly.

Results and discussion

Numerical simulation model

The lowest energy costs in the implementation of energy impact are characterized by the pulsating form of implementation and implementation – the principle of discreteness. Today, a significant number of impacts are implemented only in the pulsating form.

The rotary pulsation apparatus is designed for structural transformations of liquids at the micro- and nano- levels in order to change their physicochemical parameters intensify mass exchange and hydromechanical processes. In RPA, the conversion of low-concentration energy into high-local-concentration energy at unstable points of the substance structure is carried out. Its well-known that the cavitation reactor consists of rotor, stator and casing. There are a number of blind holes on the stator and rotor (Song et al., 2022).

The numerical simulation and visualization was employed for hydrodynamic computation of the treatment and mixing processes in working volume (chamber) of the rotary pulsed apparatus (RPA). For the choice of numerical model of fluid flow in the «rotor-stator-rotor» system of the RPA, it was suggested that the current in the prevailing case is two-dimensional. The heterogeneous stream was considered to be a homogeneous medium with the effective thermophysical properties.

To consider the dynamics difficulty, the horizontal section of the working parts of the RPA, perpendicular to the axis of the «rotor-stator-rotor» system, was selected. This section has slits on the surfaces of the first rotor, stator and second rotor. Also this section consists of the left and right parts of the rotors.

$$\frac{1}{R}\frac{\partial(RV)}{\partial R}+\frac{\partial\Omega}{\partial\theta}=0 \qquad (1)$$

$$\frac{\partial V}{\partial H}+\frac{1}{R}\frac{\partial (RV^2)}{\partial R}+\frac{\partial (V\Omega)}{\partial \theta}-\Omega^2 R=-\frac{\partial P}{\partial R}+\frac{2}{\mathrm{Re}R}\frac{\partial}{\partial R}\left(R\beta\frac{\partial V}{\partial R}\right)-$$
$$-\frac{2}{\mathrm{Re}R}\beta\left(\frac{\partial \Omega}{\partial \theta}+\frac{V}{R}\right)+\frac{1}{\mathrm{Re}R^2}\frac{\partial}{\partial \theta}\left(\beta\frac{\partial V}{\partial \theta}\right)+\frac{1}{\mathrm{Re}}\frac{\partial}{\partial \theta}\left(\beta\frac{\partial \Omega}{\partial R}\right) \quad (2)$$

$$\frac{\partial \Omega}{\partial H}+\frac{1}{R^2}\frac{\partial (R^2\Omega V)}{\partial R}+\frac{\partial \Omega^2}{\partial \theta}+\frac{\Omega V}{R}=$$
$$\frac{1}{R^2}\frac{\partial}{\partial \theta}\left[-P+\frac{2}{\mathrm{Re}}\beta\left(\frac{\partial \Omega}{\partial \theta}+\frac{V}{R}\right)\right]+ \quad (3)$$
$$\frac{1}{\mathrm{Re}R^3}\frac{\partial}{\partial R}\left[R\beta\left(R^2\frac{\partial \Omega}{\partial R}+\frac{\partial V}{\partial \theta}\right)\right]$$

$$\frac{\partial \vartheta}{\partial H}+\frac{1}{R}\frac{\partial (R\vartheta V)}{\partial R}+\frac{\partial \vartheta\Omega}{\partial \theta}=$$
$$\frac{1}{\mathrm{RePr}}\left[\frac{1}{R}\frac{\partial}{\partial R}\left(\Lambda R\frac{\partial \vartheta}{\partial R}\right)+\frac{1}{R^2}\frac{\partial}{\partial \theta}\left(\Lambda\frac{\partial \vartheta}{\partial \theta}\right)\right]+\beta S^2 \quad (4)$$

$$\bar{S}=\left[2\left(\frac{\partial V}{\partial R}\right)^2+2\left(\frac{\partial \Omega}{\partial \theta}+\frac{V}{R}\right)^2+\left(\frac{1}{R}\frac{\partial V}{\partial \theta}+R\frac{\partial \Omega}{\partial R}\right)^2\right]^{0.5} \quad (5)$$

The adduction to the dimensionless form of the equation system made by the changing. Where standard values were calculating:

$$V=\frac{v_r}{\omega_0 r_0};\quad \Omega=\frac{\omega}{\omega_0};\ R=\frac{r}{r_0};\ \ H=\tau\omega_0;$$

$$P=\frac{(p-p_0)}{(\rho\omega_0 2r_0^2)};\qquad \vartheta=\frac{(T-T_0)\rho Cp}{(\omega_0\mu_0)};\qquad \mathrm{Re}=\frac{\rho\omega_0\times r_0^2}{\mu_0};\quad \mathrm{Pr}=\frac{c_p\mu_0}{\lambda_0};$$

p_o – the pressure of the medium behind the working chamber of the rotary-pulsed apparatus;

T_o – the temperature of the medium behind the working chamber of the rotary pulsed apparatus;

$\omega=\frac{\vartheta}{r}$ – angular velocity;

ω_0 – angular velocity of the rotor spinning;

r_0 – radius of the internal surface of the internal stator;

$\beta=\frac{\mu_{ef}}{\mu_0}$; $\Lambda=\frac{\lambda_{ef}}{\lambda_0}$; μ_{ef} – effective values of the viscosity coefficient;

λ_{ef} – effective values of the coefficient of thermal conductivity;

μ_0 – conditional scale of the viscosity coefficient;

λ_0 – conditional scale of the coefficient of thermal conductivity.

Since rotary-pulsating apparatuses belong to periodic devices, it is necessary to recompense attention to the fact that there is a geometrical periodicity of the design of the «rotor-stator-rotor» system of working volume. The periodic relative motion of rotor and stator leads to a periodic close and leave process between grooves, which results in periodic cavitation (Sun et al., 2021).

In this connection, the frequency of changes in the dynamic characteristics of the fluid flow through the working area of the RPA is observed.

When the RPA mode is set, the movement of the fluid is repeated after rotating the rotors at a periodic angle $\Delta\theta$.

To solve this assigned problem, a certain segment was selected that periodically repeats the angle $\Delta\theta$.

The segment contained a fragment of the «rotor-stator-rotor» system with a slits on the surfaces of the rotors and stator also clearance between these working elements of the system.

The pressure difference between the input and the output liquid solutions at the working volume before and after treatment is $\Delta P = 50 \cdot 10^3$ Pa.

Geometric sizes of working elements were set according to constructional and design dimensions of RPA.

The frequency of rotation of the rotor was given $n = 60$ sec^{-1}. In the calculation it was considered that the flow regime of the liquid in the RPA is turbulent, so for this case RNG k-ε model of turbulence was chosen.

The system of equations was reduced to dimensionless form:

$$\frac{\partial K}{\partial H}+\frac{1}{R}\frac{\partial(RVK)}{\partial R}+\frac{\partial(\Omega K)}{\partial \theta}=\frac{1}{\mathrm{Re}}\left[\frac{1}{R}\frac{\partial}{\partial R}\left(\frac{R\varsigma}{\sigma_K}\frac{\partial K}{\partial R}\right)+\frac{1}{R^2}\frac{\partial}{\partial \theta}\left(\frac{\varsigma}{\sigma_K}\frac{\partial K}{\partial \theta}\right)\right]+\frac{\bar{S}^2}{\mathrm{Re}}\varsigma-E$$

$$\frac{\partial E}{\partial H}+\frac{1}{R}\frac{\partial(RVE)}{\partial R}+\frac{\partial(\Omega E)}{\partial \theta}=\frac{1}{\mathrm{Re}}\left[\frac{1}{R}\frac{\partial}{\partial R}\left(\frac{R\varsigma}{\sigma_K}\frac{\partial E}{\partial R}\right)+\frac{1}{R^2}\frac{\partial}{\partial \theta}\left(\frac{\varsigma}{\sigma_K}\frac{\partial E}{\partial \theta}\right)\right]+$$

$$\left[C_1-\frac{\eta_\varepsilon}{1+\beta_\varepsilon\eta_\varepsilon}\left(1-\frac{\eta_\varepsilon}{\eta_{\varepsilon_0}}\right)\right]\frac{\bar{S}^2}{\mathrm{Re}}\varsigma\frac{E}{K}-C_2\frac{E^2}{K}$$

Where were used for calculating:

$$\xi=\frac{\nu_1}{\nu}=C_\mu \mathrm{Re}\frac{K^2}{E};\ \ \varsigma=\frac{\mu_{ef}}{\mu};\ \ K=\frac{k}{(\omega_0 r_0)^2};$$

$$E=\frac{\varepsilon}{(\omega_0^{\,3} r_0^{\,2})^2};\ \ \eta_\varepsilon=\frac{K\bar{S}}{E}$$

The constants for this model were taken in accordance with (Basok et al., 2002) and were:

$C_\mu = 0.0847$; $C_1 = 1.42$; $\beta_\varepsilon = 0.012$; $\eta_\varepsilon = 4.38$

Number σ_k was determined from the equation:

$$\left|\frac{\sigma_k^{-1}-1.3929}{0.3929}\right|^{0.632}\left|\frac{\sigma_k^{-1}+2.3929}{3.3929}\right|^{0.3679}=\frac{\nu}{\nu_1}$$

Number σ_1 was taken equal to σ_k. The turbulent Prandtl number for the energy equation was also calculated from the equation:

$$\left|\frac{\sigma_0^{-1} - 1.3929}{\sigma^{-1} - 1.3929}\right|^{0.632} \left|\frac{\sigma_0^{-1} + 2.3929}{\sigma^{-1} + 2.3929}\right|^{0.3679} = \frac{\nu}{\nu_1}$$

and was solved in conjunction with (1)–(5) using numerical methods.

The investigation of the structure of the stream, and the vortical nature of the fluid movement, was performed by numerical simulation of the flow dynamics based on the Navier-Stokes equations. The main factors of the flow structure is determined by the fields of pressures, speeds, accelerations (Nakorchevskii et al., 2002) .

The changes of the pressure in different points of the working volume have complicated pulsating character. For the numerical simulation were selected different positions of the «rotor-stator-rotor» system of working chamber.

It was selected for calculations the next points: on the external surface of the internal rotor, on the external stator surface, on the inner stator surface, on the inner surface of the external rotor.

The subsequently positions in working volume between coaxial cylinders of the «rotor-stator-rotor» system were selected: open slit; half closed slit; half open slit; closed slit.

Investigation of velocity

By the volume three-dimensional parametric imitation visualization modelling processes, mathematical and numerical modelling was found that the value of the linear speeds of a stream should be from 21.98 m/s to 22.13 m/s for the first rotor and from 23.58 m/s to 23.70 m/s for the second rotor in Table 1.

According to the calculation results, it was found that the largest shear stresses occur in the RPA with annular coaxial clearances of 100 μm. The flow shear rate acquires the greatest value at annular coaxial clearances of 100 μm too.

Investigation of alternating impulses of pressure

For the processing of liquid media, namely for the processing of water and the process of mixing water and alcohol (ethanol) in the hydrodynamic conditions by influence of alternating impulses of pressure, an important geometrical parameters. When conducting a numerical experiment, the design and geometric parameters of the rotary-pulsed apparatus, which are given in Table 1, were occupied into account.

The pressure fields that arise when the components are separately passed into the working zone of the RPA for mixing were calculated.

The pressure change in different areas of the working volume shown on Figures 3 and 4.

It has a complex pulsating character. By the numerical calculation were visualizated pressure fields in the rotary-pulsed apparatus during the passing components (water and ethanol) into the working area of the chamber.

The study of the flow structure and the vortex nature of fluid motion was performed using numerical modelling of flow dynamics based on the Navier-Stokes equations.

Table 1

Technical parameters of rotary-pulsed apparatus

Technical parameter, dimension	Frequency of hydrodynamic oscillations, kHz	Angular velocity, s^{-1}	Linear velocity, m/s		Shear rate, 10^5 s^{-1}		Shear stress, Pa		Coaxial clearance , µm
No			Rotor 1	Rotor 2	Rotor 1	Rotor 2	Rotor 1	Rotor 2	
1	3	314	21.98	23.58	2.2	2.4	219.8	235.5	100
2	3	314	22.02	23.60	1.5	1.6	146.8	157.3	150
3	3	314	22.04	23.61	1.1	1.2	110.2	118.5	200
4	3	314	22.05	23.62	0.88	0.94	88.20	94.48	250
5	3	314	22.07	23.64	0.73	0.79	73.57	78.80	300
6	3	314	22.09	23.66	0.63	0.68	63.11	67.60	350
7	3	314	22.10	23.68	0.55	0.59	55.25	59.2	400
8	3	314	22.12	23.69	0.49	0.53	49.15	52.64	450
9	3	314	22.13	23.70	0.44	0.47	44.26	47.4	500

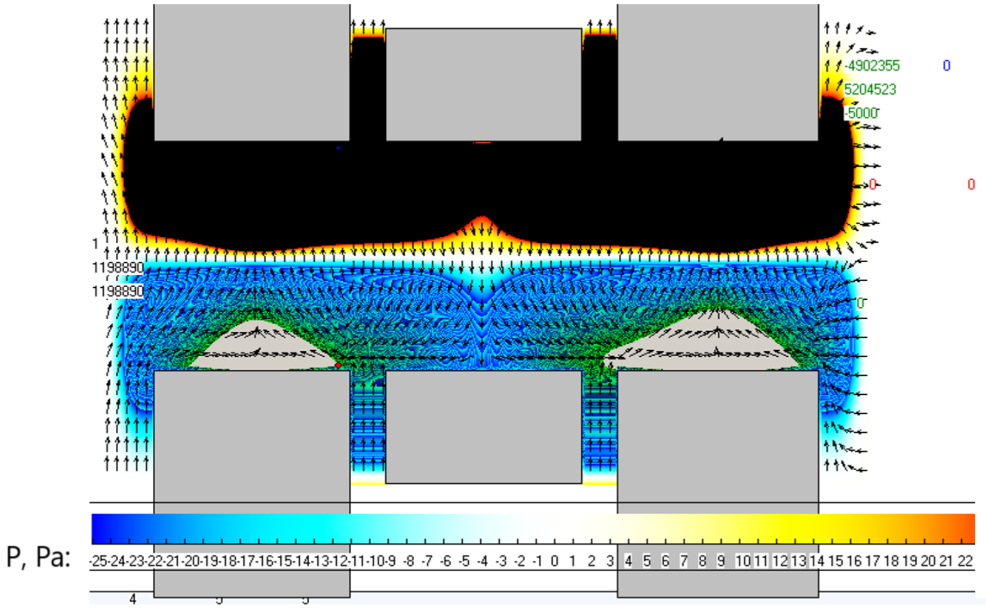

Figure 3. Pressure fields with an open channel in the system rotor-stator-rotor

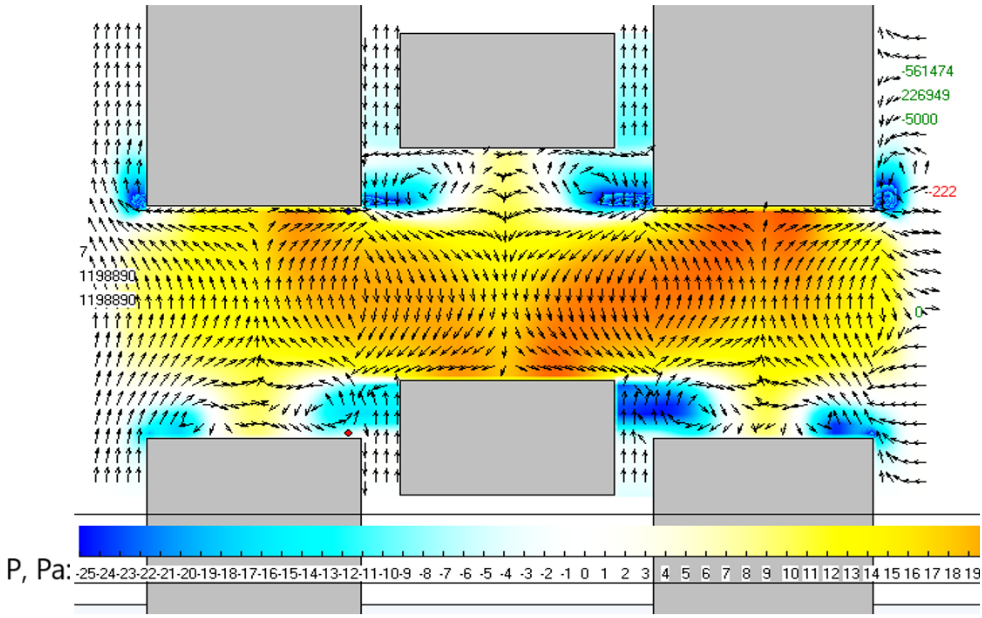

Figure 4. Pressure fields at half-closed channel in the rotor-stator-rotor system

During the research, the nature of the movement of water-alcohol mixtures was studied, so water and ethanol enter the working zone of the RPA with a pressure of P_0. Then a complex rotational-reciprocal motion is carried out under the action of a pressure drop Δ P = 50 kPa, while water and ethanol instantly mix Figure 5 and 6.

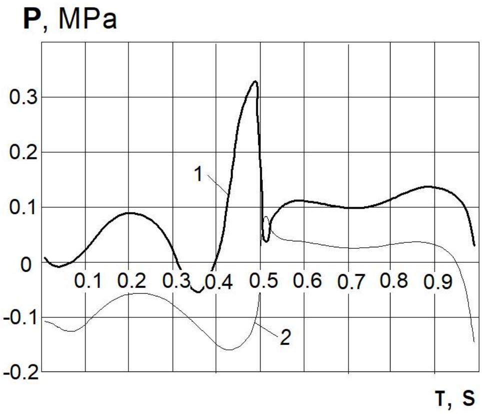

Figure 5. Pressure change at points:
1 – near outer surface of the inner rotor;
2 – near outer surface of the stator;

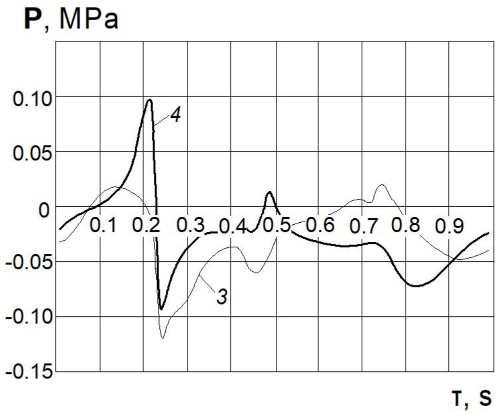

Figure 6. Pressure change at points:
3 – near inner surface of the stator;
4 – near inner surface of the outer rotor.

The local pressure values in the zone of water and alcohol inlet and water-alcohol mixture outlet from the clearance change:

– near the outer surface of the inner rotor from $-50 \cdot 10^3$ Pa to $+300 \cdot 10^3$ Pa;
– near the outer surface of the stator from $-150 \cdot 10^3$ Pa to $100 \cdot 10^3$ Pa;
– near the inner surface of the stator from $+40 \cdot 10^3$ Pa to $-120 \cdot 10^3$ Pa;
– near the inner surface of the outer rotor from $+ 100 \cdot 10^3$ Pa to $-100 \cdot 10^3$ Pa.

The latter values determine the zone in which cavitation and adiabatic boiling can occur under certain conditions.

According to the results of the analysis of the obtained calculations, it was established that the reduction of the clearances between the outer and inner rotors and the stator leads to an increase in the depth of the negative pressure impulse, which contributes to the intensification of the instant mixing process, excluding the contact of the components before they enter the working zone of the RPA, intensification of masstransfer, which in turn affects the speed of the hydration process, structure formation and association.

In addition, the value of the average mass radial velocity of the liquid in the inlet section in front of the inner rotor Figure 7 and its change depending on time were determined.

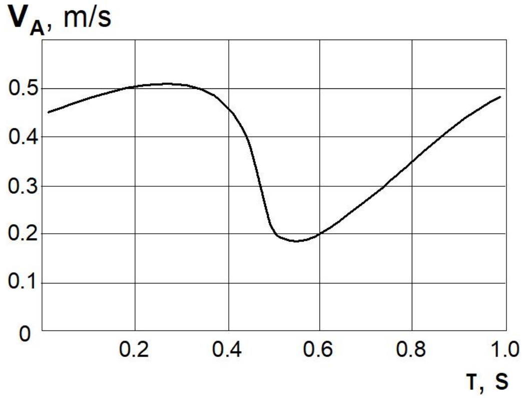

Figure 7. Change in the average velocity of fluid movement over time in entrance intersection

The radial motion of the fluid is provided by the external pressure drop $\Delta P = 50 \cdot 10^3$ Pa and the centrifugal force caused by the rotating motion of the fluid. As a result, a radial velocity is established that is periodic in time and averaged over the inlet cross section. It should be noted that the fluid flow in the RPA has a pulsating nature of movement; within one period the speed reaches 0.52 m/s and sharply decreases to the minimum value of 0.18 m/s.

At a molecular scale, molecular dynamic simulation is an appropriate tool for analyzing these static and dynamic properties (Obeidat et al., 2018).

At the moment when the speed decreases, there is a sharp braking of the liquid flow, thus pressure impulses appear in the zones before and after the stator intersection, which are caused by the inertia forces of the masses of the water-alcohol mixture.

According to the results of the research, it was found that the alternating pressure pulses in the system are $\Delta P = 370 \cdot 10^3$ Pa near the outer surface of the inner rotor; $\Delta P = 240 \cdot 10^3$ Pa near the outer surface of the stator; $\Delta P = 155 \cdot 10^3$ Pa near the inner surface of the stator; $\Delta P = 190 \cdot 10^3$ Pa near the inner surface of the outer rotor.

Conclusions

A numerical calculation was accomplished to determine the hydrodynamic parameters of equipment that implements the basic mechanisms and concept of the alternating impulses of pressure, that realize in rotary-pulsed apparatus for the processing of water and ethanol-containing products. It was established that the flow shear rates, flow shear stresses, high-frequency oscillations, and alternating impulses of pressure reach their greatest values at technological clearance between of coaxial working elements (cylinders) "rotor-stator-rotor" of 100 μm.

It was established that reducing the technological clearance leads to an intensification of hydrodynamic parameters, in turn; the design of clearance less than 100 microns is technologically complicated and requires special equipment, which is economically inexpedient due to the increased cost of manufacturing the equipment.

Based on a numerical experiment, the feasibility of using equipment that implements the basic principles and mechanisms of discrete-pulse input of energy, namely processing using alternating impulses of pressure, flow shear stresses, and flow shear velocities, has been substantiated and proven. It is gives the possibility to intensification of mixing processes.

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