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SIMULATION OF THE PROCESS OF CAVITATION TREATMENT OF LIQUID FEED

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Abstract. The same fractional composition and uniformity of distribution of raw material components of plant origin in the mixture are the main criteria for the liquid feed quality. This is ensured by the homogenisation and dispersion of feed components using cavitation treatment. The purpose of the study is to simulate the process of cavitation treatment of liquid feed with a rotary cavitation disperser-homogeniser and substantiate its rational design and technological parameters. The task is to create such a rotary cavitation disperser-homogeniser, which allows simultaneously performing technological processes of dispersion, emulsification, and homogenisation of mixture components in a liquid medium with higher productivity, quality, and lower energy consumption. As a result of modelling the action of a rotary cavitation disperser-homogeniser in the Star CCM+ software, the distributions and dynamics of velocities of the liquid phase of the mixture and the pressure and concentration of the gaseous phase of liquid in the diffuser are established, which indicates the presence of cavitation. This confirms the operability of the developed design and technological facilities for the preparation of liquid feed and indicates the expediency of further research to substantiate its technological parameters. As a result of numerical modelling of the operation process of a rotary cavitation disperser-homogeniser, the dependences of the maximum (max) and minimum (min) movement speed of the liquid phase of the mixture in the inlet V_{in} and in the diffuser V_{rot} on the rotor speed n, inlet diameter D_{in} and the number of resonators N_{hole} are determined. The qualitative criterion for evaluating the cavitation phenomenon in the developed equipment is the maximum and minimum cavitation number X_{max} and X_{min}, which depends on the rotation speed of the rotor n, the inlet diameter D_{in} and the number of resonators N_{hole}. The value of the cavitation number $X_{min} = 0.08$ and $X_{max} = 0.57$ is achieved at $n = 2725$ rpm, $D_{in} = 0.049$ m, $N_{hole} = 48$, which corresponds to a film flow of liquid with a stable separation of the cavitation cavity from the rest of the continuous flow (film cavitation)

Keywords: feed production, cavitation, disperser-homogeniser, numerical modelling, parameters, speed, pressure

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INTRODUCTION

Providing animals with high-quality feed at a competitive price in accordance with a balanced diet determines the effective operation of animal husbandry. One of the factors of the unstable development of animal husbandry in Ukraine is the supply of poor-quality feed [1]. The development of new and improvement of conventional technical and technological support for feed production for organic animal husbandry should be carried out taking into account the criteria of efficiency, energy and resource saving and competitiveness of its products. This is possible by improving the quality of the feed base with the help of technological and technical innovations [2; 3].

The value of liquid feed is determined by the appropriate technological operations during their preparation. Liquid feed should have a high degree of uniformity in the fraction composition. In this regard, feed grinding should be provided with the same fractional composition for each of the components of plant raw materials that are part of the feed. In addition, the feed must be homogeneous in the distribution of components in the liquid mixture. That is, the mixing process should be provided with a high coefficient of variation in the distribution of components of raw materials of vegetable origin in the mixture volume. Prepared liquid feed should preserve nutrients and vitamins, do not contain substances that can adversely affect the health and productivity of the animal, and also ensure a waste-free transformation of plant raw materials. That is, the technological process of feed preparation must meet the specified conditions [4; 5].

These conditions correspond to the processes of homogenisation and dispersion of feed components using cavitation treatment. According to [6], dispersion is a technological process that results in dispersed systems (suspensions, powders, aerosols, emulsions) formed by grinding and redistributing components of a solid material, liquid, or gas. For a heterophase system, a decrease in the degree of inhomogeneity of the phase and component distributions occurs during the technological process of homogenisation [6]. The physical process of cavitation is determined by the build-up and collapse of bubbles (cavities) in liquid media with the release of a large amount of energy (shock wave) [7]. Bubbles resulting from cavitation contain liquefied steam. A decrease in the pressure in the liquid and an increase in its velocity leads to the phenomenon of hydrodynamic cavitation. The bubble formed as a result of hydrodynamic cavitation moves with the flow of liquid into the high-pressure zone. Further, as a result of collapse, the bubble emits a shock wave. By its nature, hydrodynamic cavitation has the same mechanism of action as a shock wave in air that occurs when a solid body overcomes a sound barrier. The cavitation phenomenon is local in nature and occurs within the appropriate conditions [8]. In the process of cavitation treatment, the feed components are crushed under the action of a shock wave.

Based on the analysis [9-11], it was established that the production of liquid feed and feed supplements based on cavitation treatment is effective. Cavitation dispersion improves the biochemical qualities of liquid feed. This process allows using any components of plant origin. Cavitation treatment affects the protein complex of plant components. This ensures a high degree of fat emulsification, which leads to an increase in its digestibility by animals (by 6.3%). As a result of cavitation dispergation, the extraction of biologically active substances and soluble proteins is accelerated. That is, the obtained biochemically prepared liquid feeds are highly efficient when fed to farm animals of all kinds.

Thus, the scientific and practical task is to ensure the value of liquid feed by applying technological processes of dispersion, homogenisation with cavitation treatment of feed components in the preparation process.

The purpose of the study is to simulate the process of cavitation treatment of liquid feed with a rotary cavitation disperser-homogeniser and substantiate its rational design and technological parameters.

MATERIALS AND METHODS

To implement the process of cavitation dispersion and homogenisation of liquid feed, the following design and technological scheme of the corresponding technical means is proposed, which is shown in Figure 1 [12; 13].

To perform the simulation, a CAD model grid of the area between the rotor, stator, and working chamber of a rotary cavitation disperser-homogeniser with a base cell size of 0.001 m was constructed in the Star CCM+ software package. The geometric parameters of the rotor and stator of a rotary cavitation dispersant-homogeniser were used for modelling, which is shown in Figure 2-3. The working chamber was adopted with a diameter of 340 mm and a height of 270 mm. The absolute roughness of the rotor and stator surfaces – $\varepsilon = 2.5 \cdot 10^{-6}$ m.

Numerical simulations were performed using the Eulerian multiphase model, multiphase interaction, and the volume of fluid method (VOF). The motion of the liquid phase follows the k-ε model of turbulence. To determine the flow of the liquid phase and the presence of the cavitation phenomenon, the mixture is taken as a medium of two phases (liquid-gas). In addition, the gas is represented as the gaseous phase of a liquid (steam). It is accepted that the liquid phase in the process of motion had a constant density, and the gas was real and obeyed the Van der Waals equation. The gas-liquid phase interaction corresponds to the model of cavitation (Schnerr-Sauer) and volume of fluid (VOF-VOF) [14-16].

For this numerical simulation, the iteration period was 0.001 ms. At the initial point in time, the area between the stator and the rotor was filled only with liquid, that is, its content was $\alpha_f = 1$. At the initial time, the temperature was 300 K (27°C), the pressure was 101.3 kPA. Accepted: constant liquid density $\rho_f = 997.6$ kg/m^3, dynamic viscosity $\mu_f = 8.88 \cdot 10^{-4}$ Pa·s, saturation pressure

p_f = 2338 Pa, molecular weight M_f = 18 kg/kmol, thermal conductivity coefficient λ_f = 0.62 W/(m·K), specific heat capacity C_f = 4181 J/(kg·K). In turn, the gaseous phase of the liquid has a dynamic viscosity $\mu_g = 1.267 \cdot 10^{-5}$ Pa·s, a molecular weight M_g = 18 kg/kmol, a thermal conductivity coefficient λ_g = 0.0253 W/(m·K), and a specific heat capacity C_g = 1938 J/(kg·K).

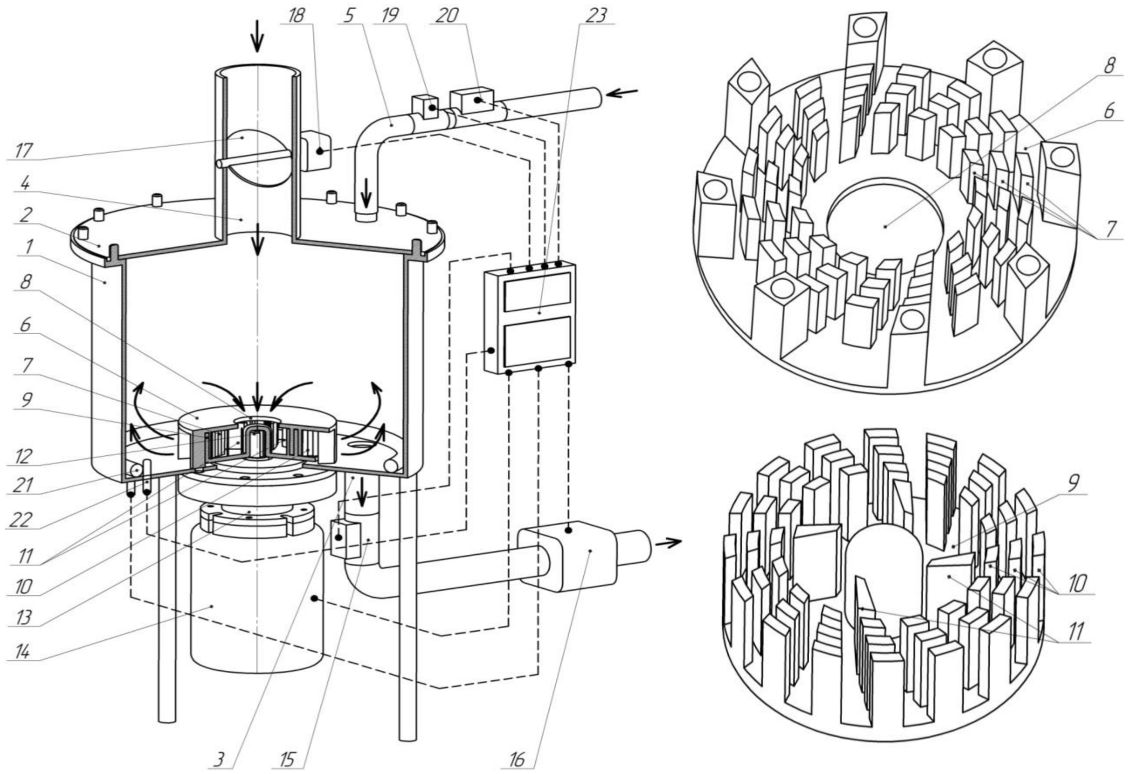

***Figure 1**. Design and technological scheme of a rotary cavitation disperser-homogeniser:*
1 – loading tank; 2 – tank cover; 3 – outlet pipe; 4 – loading sleeve; 5 – branch pipe for liquid components; 6 – stator; 7 – diffuser; 8 – through-hole; 9 – rotor; 10 – resonators; 11 – blades; 12 – shaft; 13 – bearing unit; 14 – asynchronous electric motor; 15 – electric crane; 16 – electric pump; 17 – flap; 18 – stepper motor shaft; 19 – liquid flow sensor; 20 – electric tap; 21 – heater; 22 – temperature sensor; 23 – control unit

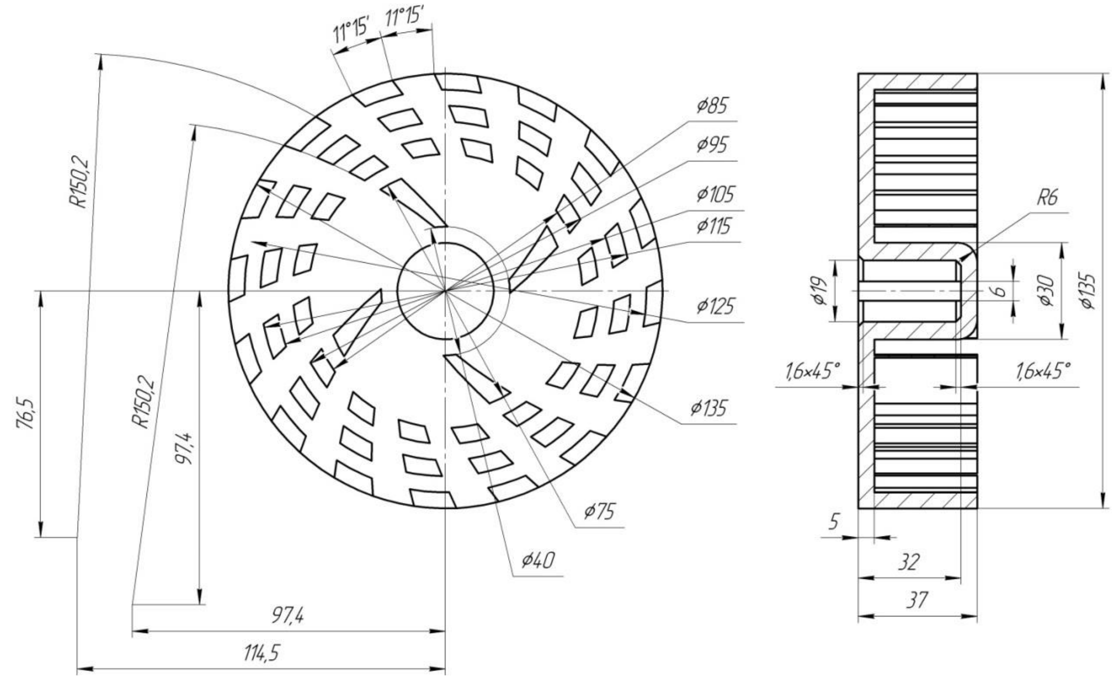

***Figure 2.** Geometric dimensions of the rotor of the rotary cavitation disperser-homogeniser*

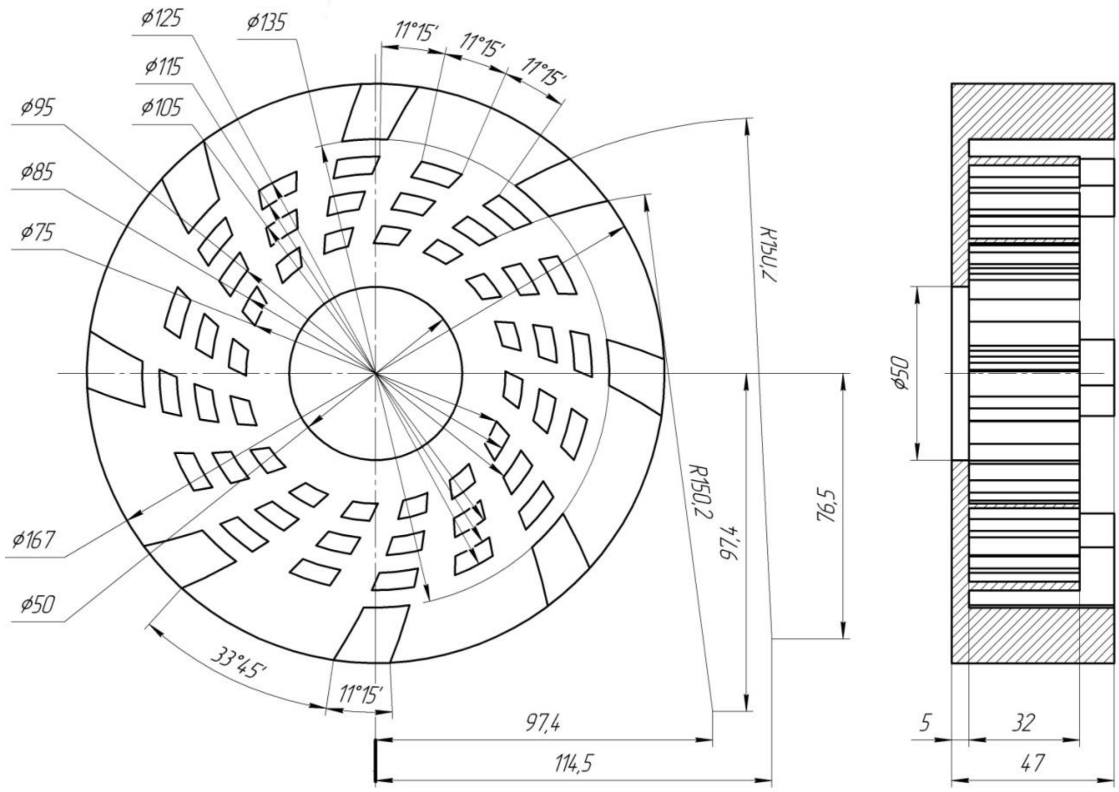

Figure 3. *Geometric dimensions of the stator of the rotary cavitation disperser-homogeniser*

The 3D model grid of the area between tank and working bodies of the cavitation disperser-homogeniser in Star CCM+ is shown in Figure 4.

The rotor speed n, the Inlet diameter Din, and the number of resonators Nhole were selected as research factors. The limits and intervals of research factors are shown in Table. 1.

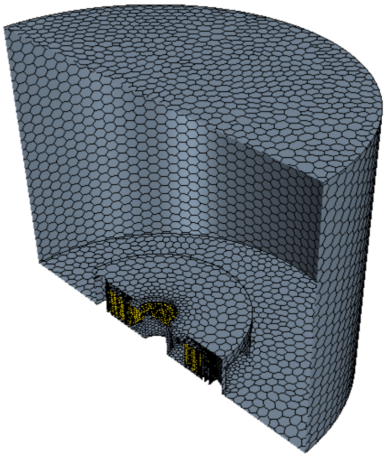

***Figure 4**. The 3D model grid of the area between the tank and working bodies of the cavitation disperser-homogeniser in Star CCM+*

***Table 1**. Limits and intervals of numerical modelling factors*

Level	Rotor speed n, rpm. (x_1)	Inlet diameter D_{in}, m (x_2)	Number of resonators N_{hole} (x_3)
Upper (+1)	3000	0.06	48
Average (0)	2250	0.05	32
Lower (-1)	1500	0.04	16
Interval	750	0.01	16

In the process of numerical modelling, it was determined for each experiment:

– maximum movement speed of the liquid phase of the mixture in the inlet $V_{in\,max}$;

– maximum movement speed of the liquid phase of the mixture in the diffuser $V_{rot\,max}$;

– maximum pressure of the liquid phase of the mixture in the inlet $P_{in\,max}$;

– maximum pressure of the liquid phase of the mixture in the diffuser $P_{rot\,max}$;

– minimum pressure of the liquid phase of the mixture in the diffuser $P_{rot\,min}$.

The qualitative criterion for evaluating the cavitation phenomenon in the developed equipment is the maximum and minimum cavitation number X_{max} and X_{min}, which is calculated using the equations (1-2):

$$X_{max} = \frac{2(P_{rotmax} - P_s)}{\rho V_{rotmax}}, \qquad (1)$$

$$X_{min} = \frac{2(P_{rotmin} - P_s)}{\rho V_{rotmin}}, \qquad (2)$$

where: P_{rot} – hydrostatic pressure of the incoming flow in the diffuser, Pa; P_s – saturated vapour pressure of the liquid (for water vapour $P_s = 2314.4$ Pa); ρ – density of the medium (for water $\rho = 997$ kg/m^3); V_{rot} – flow rate in the diffuser, m/s.

When the flow of a two-phase medium reaches the maximum velocity, at the moment when the pressure in the flow becomes equal to the pressure of vaporisation (saturated vapours), the cavitation phenomenon occurs. The specified velocity corresponds to the value of the cavitation criterion X, which determines the type of flow:

– at $X > 1$ – continuous (single-phase) flow;

– at $X \approx 1$ – two-phase cavitation flow;

– at $X < 1$ – film flow;

– at $X << 1$ – supercavitation.

The criterion for the dispersion productivity is the value of the mass flow of the mixture, which is calculated using the equation (3):

$$Q = V_{in\,max}\rho S_{in} = V_{in\,max}\rho\pi D_{in}^2, \qquad (3)$$

where S_{in} – area of the entrance opening, m^2.

The higher the value of Q, the greater the mass of the mixture per unit time to be dispersed. Rational design and mode parameters of the cavitation disperser-homogeniser can be achieved if the productivity of the dispersing process is maximised while minimising the value of the cavitation number.

The simulation was performed by iterating through all levels of factors. The total number was 27 experiments. After that, a second-order regression model was calculated using the Mathematica software.

RESULTS AND DISCUSSION

Based on the results of numerical modelling, the distribution of the velocity of movement of the liquid phase in the working chamber of a rotary cavitation disperser-homogeniser is obtained (Fig. 5). This visualisation shows that the entire mixture is captured by the rotor in the through-hole of the stator and passes through diffusers and resonators, in which the dispersion process takes place.

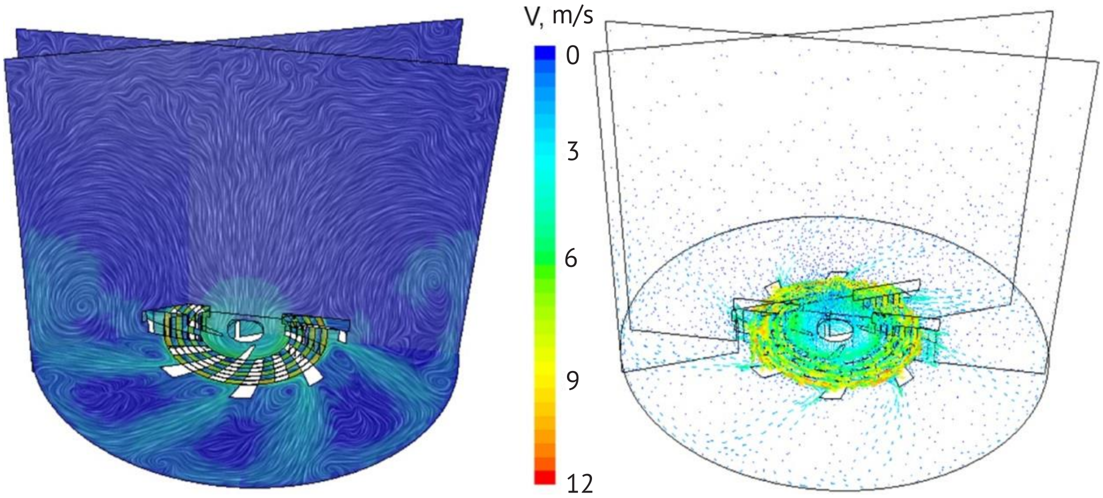

***Figure 5**. Distribution of movement velocity of the liquid phase of the mixture in the working chamber of the rotary cavitation disperser-homogeniser*

Figure 6 shows the distribution and dynamics of pressure in the diffuser of a rotary cavitation disperser-homogeniser. This visualisation shows that the average difference between the maximum and minimum pressure values in the diffuser is more than 90 kPa. At the same time, such a pressure change occurs in 0.004 seconds. This allows stating that the phenomenon of hydraulic shock occurs in the diffuser, which contributes to the dispersion process.

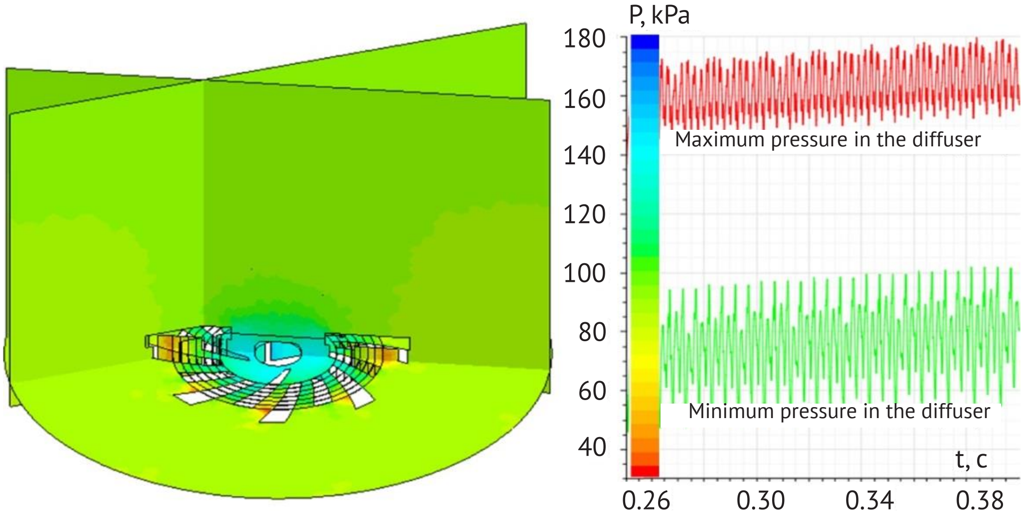

***Figure 6**. Pressure distribution and dynamics in the diffuser of a rotary cavitation disperser-homogeniser*

Based on the results of simulation and processing of the obtained data in the Mathematica software, regularities of changes in the value of the maximum velocity of movement of the liquid phase of the mixture in the inlet are obtained from research factors in encoded form (4):

$$V_{in\,max} = 4.72 + 1.00333\,x_1 - 3.03551\cdot10^{-15}\,x_1^{\,2} + 1.09667\,x^2 - 5.2384\cdot10^{-16}\,x_1\,x_2 + 0.1\,x_2^{\,2} - 0.271667\,x_3 - 0.01\,x_1\,x_3 - 0.0275\,x_2\,x_3 + 0.085\,x_3^{\,2} \quad (4)$$

Statistical processing of equation (4) is presented in Table 2. As a result of the analysis of Table 2, corresponding reduction of insignificant coefficients according to the Student's t-test and decoding of equation (4), the study has finally obtained the dependence of the change in the maximum velocity of the liquid phase of the mixture in the inlet on the research factors (5):

$$V_{in\,max} = -0.665 + 15.1667\,D_{in} + 1000\,D_{in}^{\,2} + 0.00133778\,n - 0.0296354\,N_{hole} - 0.171875\,D_{in}\,N_{hole} + 0.000332031\,N_{hole}^{\,2} \quad (5)$$

***Table 2**. Statistical processing of equation (4)*

Coefficient	Value	Error	Student's t-test	Probability
a_{00}	4.72	0.0193396	244.059	$1.41494\cdot10^{-31}$
a_{10}	1.00333	0.00895249	112.073	$7.81436\cdot10^{-26}$
a_{20}	1.09667	0.00895249	122.499	$1.7257\cdot10^{-26}$
a_{30}	-0.271667	0.00895249	-30.3454	$3.01715\cdot10^{-16}$
a_{12}	$-5.2384\cdot10^{-16}$	0.0109645	$-4.7776\cdot10^{-14}$	1
a_{13}	-0.01	0.0109645	-0.912033	0.374504
a_{23}	-0.0275	0.0109645	-2.50809	0.0225708
a_{11}	$-3.03551\cdot10^{-15}$	0.0155062	$-1.95762\cdot10^{-13}$	1
a_{22}	0.1	0.0155062	6.44905	$5.99957\cdot10^{-6}$
a_{33}	0.085	0.0155062	5.48169	0.00004052

The maximum movement speed of the liquid phase of the mixture in the inlet $V_{in\,max} = 7.3$ m/s is achieved at $n = 3000$ rpm., $D_{in} = 0.06$ m, $N_{hole} = 16$. Graphical interpretations of dependency (5) are shown in Figure 7.

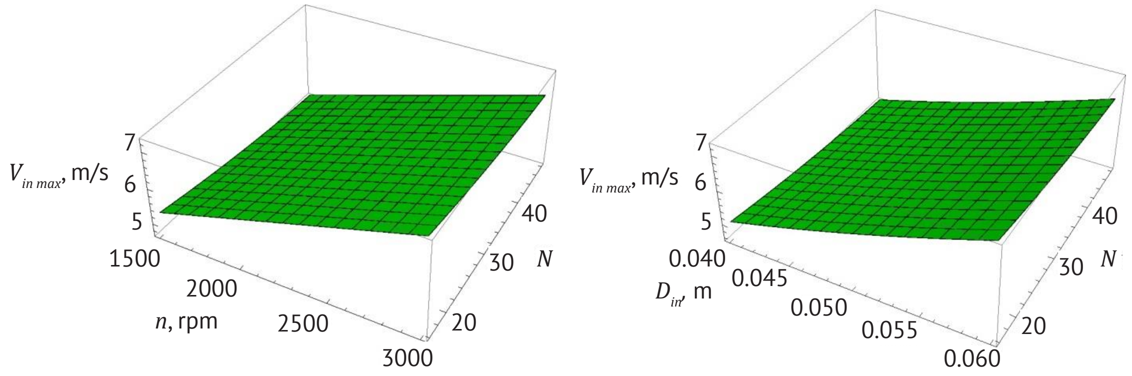

***Figure 7**. Dependence of the maximum movement speed of the liquid phase of the mixture in the inlet $V_{in\,max}$ on the rotation speed of the rotor n, the diameter of the inlet Din and the number of resonators N_{hole}*

Based on the results of simulation and processing of the obtained data in the Mathematica software, regularities of changes in the value of the maximum velocity of movement of the liquid phase of the mixture in the diffuser are obtained from research factors in encoded form (6):

$$V_{rot\,max} = 17.2533 + 6.31667\,x_1 - 2.34467\cdot 10^{-14}\,x_1^2 + 0.178333\,x_2 - 4.13185\cdot 10^{-15}\,x_1 x_2 + 0.135\,x_2^2 + 2.33333\,x_3 + 1.11\,x_1 x_3 - 0.1525\,x_2 x_3 + 0.36\,x_3^2 \quad (6)$$

Statistical processing of equation (6) is presented in Table 3. As a result of the analysis of Table 3, corresponding reduction of insignificant coefficients according to the Student's t-test and decoding of equation (6), the study has finally obtained the dependence of the change in the maximum velocity of the liquid phase of the mixture in the diffuser on the research factors (7):

$$V_{rot\,max} = 0.845 + 17.8333\,D_{in} + 0.00546222\,n - 0.152292\,N_{hole} + 0.0000925\,n\,N_{hole} + 0.00140625\,N_{hole}^2 \quad (7)$$

***Table 3**. Statistical processing of equation (6)*

Coefficient	Value	Error	Student's t-test	Probability
a_{00}	17.2533	0.164711	104.749	$2.46127\cdot 10^{-25}$
a_{10}	6.31667	0.0762462	82.8457	$1.31798\cdot 10^{-23}$
a_{20}	0.178333	0.0762462	2.33891	0.0318103
a_{30}	2.33333	0.0762462	30.6026	$2.6202\cdot 10^{-16}$
a_{12}	$-4.13185\cdot 10^{-15}$	0.0933821	$-4.42467\cdot 10^{-14}$	1
a_{13}	1.11	0.0933821	11.8866	$1.16332\cdot 10^{-9}$
a_{23}	-0.1525	0.0933821	-1.63307	0.120836
a_{11}	$-2.34467\cdot 10^{-14}$	0.132062	$-1.77543\cdot 10^{-13}$	1
a_{22}	0.135	0.132062	1.02225	0.320993
a_{33}	0.36	0.132062	2.72599	0.0143729

The maximum movement speed of the liquid phase of the mixture in diffuser $V_{rot\,max}$ = 27.5 m/s is achieved at n = 3000 rpm., D_{in} = 0.06 m, N_{hole} = 48. Graphical interpretations of dependency (5) are shown in Figure 8.

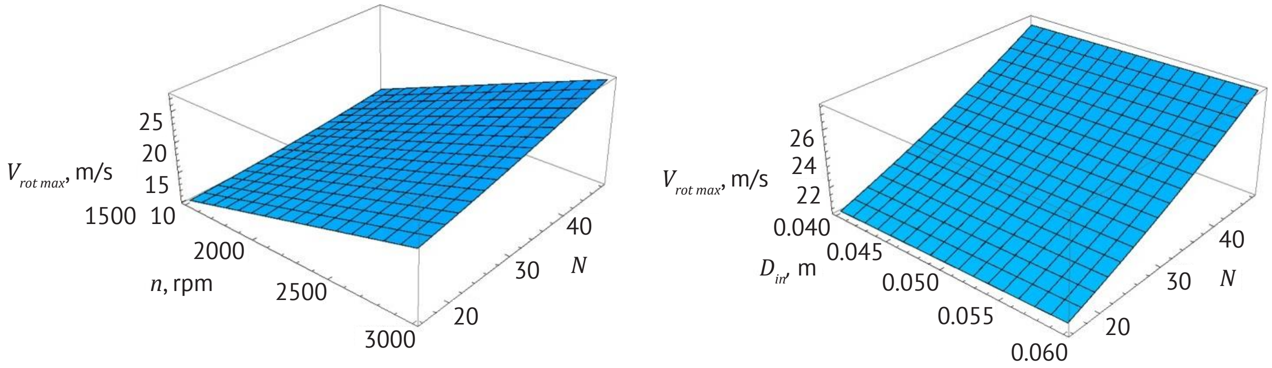

***Figure 8**. Dependence of the maximum movement speed of the liquid phase of the mixture in the diffuser $V_{rot\,max}$ on the rotation speed of the rotor n, the diameter of the inlet D_{in} and the number of resonators N_{hole}*

Based on the results of simulation and processing of the obtained data in the Mathematica software, regularities of changes in the value of the maximum pressure of the liquid phase of the mixture in the inlet are obtained from research factors in encoded form (8):

$$P_{in\,max} = 124.551 + 15.6894\,x_1 - 1.81164\,x_1^2 + 5.46905\,x_2 + 0.524858\,x_1 x_2 - 0.323984\,x_2^2 + 5.3878\,x_3 + 0.04055\,x_1 x_3 + 1.21828\,x_2 x_3 + 3.88243\,x_3^2. \quad (8)$$

Statistical processing of equation (8) is presented in Table 4. As a result of the analysis of Table 4, corresponding reduction of insignificant coefficients according to the Student's t-test and decoding of equation (8), the dependence of the change in the maximum pressure of the liquid phase of the mixture in the inlet on the research factors (9) was found:

$$P_{in\,max} = 50.7694 + 303.249\,D_{in} + 0.0354123\,n - 3.22069\cdot 10^{-6}\,n^2 - 1.01458\,N_{hole} + 7.61425\,D_{in}\,N_{hole} + 0.0151657\,N_{hole}^2 \quad (9)$$

The maximum pressure of the liquid phase of the mixture in the inlet $P_{in\,max}$ = 154.4 kPa is reached at n = 3000 rpm., D_{in} = 0.06 m, N_{hole} = 48. Graphical interpretations of equation (9) are shown in Figure 9.

***Table 4**. Statistical processing of equation (8)*

Coefficient	Value	Error	Student's t-test	Probability
a_{00}	124.551	0.666684	186.821	$1.328 \cdot 10^{-29}$
a_{10}	15.6894	0.308615	50.8382	$5.14025 \cdot 10^{-20}$
a_{20}	5.46905	0.308615	17.7213	$2.13958 \cdot 10^{-12}$
a_{30}	5.3878	0.308615	17.458	$2.72515 \cdot 10^{-12}$
a_{12}	0.524858	0.377974	1.38861	0.182879
a_{13}	0.04055	0.377974	0.107282	0.915821
a_{23}	1.21828	0.377974	3.22318	0.0049921
a_{11}	-1.81164	0.534536	-3.38918	0.00348852
a_{22}	-0.323984	0.534536	-0.606104	0.552454
a_{33}	3.88243	0.534536	7.26317	$1.3255 \cdot 10^{-6}$

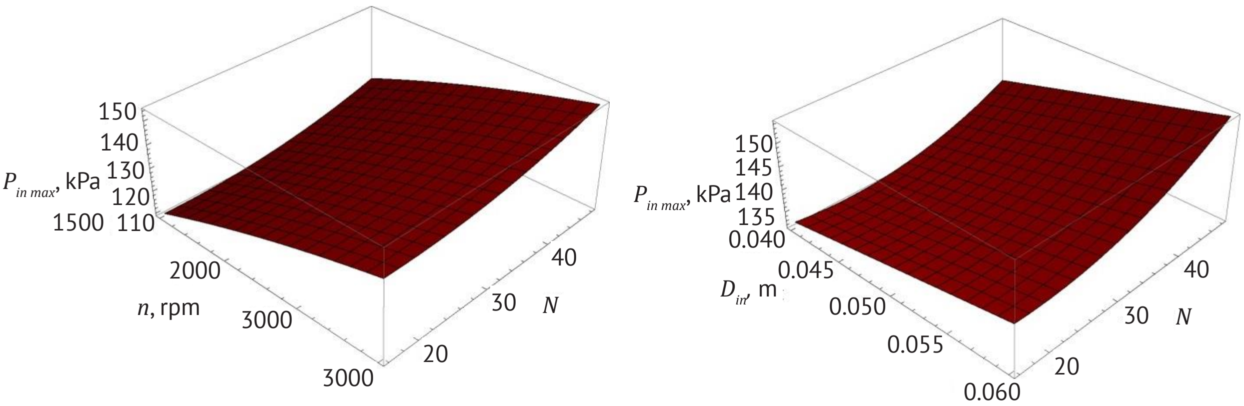

***Figure 9**. Dependence of the maximum pressure of the liquid phase of the mixture in the inlet $P_{in\ max}$ on the rotation speed of the rotor n, the diameter of the inlet D_{in} and the number of resonators N_{hole}*

Based on the results of simulation and processing of the obtained data in the Mathematica software, regularities of changes in the value of the maximum pressure of the liquid phase of the mixture in the diffuser are obtained from research factors in encoded form (10):

$$P_{rot\ max} = 171.763 + 19.3513\ x_1 - 3.90839\ x_1^2 + 3.98246\ x_2 - 0.357417\ x_1 x_2 - 0.0684029\ x_2^2 + 6.15596\ x_3 + 0.0130833\ x_1 x_3 - 1.56583\ x_2 x_3 + 2.63001\ x_3^2 \quad (10)$$

Statistical processing of equation (10) is presented in Table 5. As a result of the analysis of Table 5, the corresponding reduction of insignificant coefficients according to the Student's t-test and decoding of equation (10), the dependence of the change in the maximum pressure of displacement of the liquid phase of the mixture in the diffuser on the research factors was obtained (11):

$$P_{rot\ max} = 41.1716 + 711.412\ D_{in} + 0.0570688\ n - 6.94825 \cdot 10^{-6}\ n^2 + 0.216568\ N_{hole} - 9.78644\ D_{in} N_{hole} + 0.0102735\ N_{hole}^2 \quad (11)$$

***Table 5**. Statistical processing of equation (10)*

Coefficient	Value	Error	Student's t-test	Probability
a_{00}	171.763	0.780301	220.125	$8.17623 \cdot 10^{-31}$
a_{10}	19.3513	0.361209	53.5736	$2.11995 \cdot 10^{-20}$
a_{20}	3.98246	0.361209	11.0254	$3.63528 \cdot 10^{-9}$
a_{30}	6.15596	0.361209	17.0427	$4.01849 \cdot 10^{-12}$
a_{12}	-0.357417	0.442389	-0.807924	0.430295
a_{13}	0.0130833	0.442389	0.0295743	0.976751
a_{23}	-1.56583	0.442389	-3.53949	0.00251884
a_{11}	-3.90839	0.625632	-6.2471	$8.84795 \cdot 10^{-6}$
a_{22}	-0.0684029	0.625632	-0.109334	0.914218
a_{33}	2.63001	0.625632	4.20376	0.000596762

The maximum pressure of the liquid phase of the mixture in the inlet $P_{in\ max}$ = 154.4 kPa is reached at n = 3000 rpm., D_{in} = 0.06 m, N_{hole} = 48. Taking into account the research factors alternately at the specified level, graphical interpretations of the dependence (11) are shown in Figure 10.

Based on the results of simulation and processing of the obtained data in the Mathematica software, regularities of changes in the value of the minimum pressure of the liquid phase of the mixture in the diffuser are obtained from research factors in encoded form (12):

$$P_{rot\ min} = 54.5321 - 19.3513\ x_1 + 3.90839\ x_1^2 + 2.097\ x_2 + 0.357417\ x_1 x_2 + 0.47866\ x_2^2 - 2.45528\ x_3 - 0.0130833\ x_1 x_3 - 0.401844\ x_2 x_3 - 2.22782\ x_3^2 \quad (12)$$

Statistical processing of equation (12) is presented in Table 6. As a result of the analysis of Table 6, the corresponding reduction of insignificant coefficients according to the Student's t-test and decoding of equation (12), the dependence of the change in the minimum pressure of displacement of the liquid phase of the mixture in the diffuser on the research factors was obtained (13):

$$P_{rot\ min} = 133.276 + 209.7\ D_{in} - 0.0570688\ n + 6.94825 \cdot 10^{-6}\ n^2 + 0.403501\ N_{hole} - 0.00870244\ N_{hole}^{\ 2}. \quad (13)$$

The maximum pressure of the liquid phase of the mixture in the inlet $P_{in\ max}$ = 37.2 kPa is reached at n = 3000 rpm., D_{in} = 0.06 m, N_{hole} = 16. Taking into account the research factors alternately at the specified level, graphical interpretations of the dependence (13) are shown in Figure 10.

***Table 6**. Statistical processing of equation (12)*

Regression coefficient	Value of regression coefficient	Standard error	t-statistic	P-Value
a_{00}	54.5321	0.641455	85.0131	$8.50496 \cdot 10^{-24}$
a_{10}	-19.3513	0.296936	-65.1699	$7.69801 \cdot 10^{-22}$
a_{20}	2.097	0.296936	7.06212	$1.90842 \cdot 10^{-6}$
a_{30}	-2.45528	0.296936	-8.26873	$2.32092 \cdot 10^{-7}$
a_{12}	0.357417	0.363671	0.982803	0.339486
a_{13}	-0.0130833	0.363671	-0.0359758	0.971721
a_{23}	-0.401844	0.363671	-1.10497	0.284567
a_{11}	3.90839	0.514308	7.59932	$7.29443 \cdot 10^{-7}$
a_{22}	0.47866	0.514308	0.930687	0.365044
a_{33}	-2.22782	0.514308	-4.33169	0.000453011

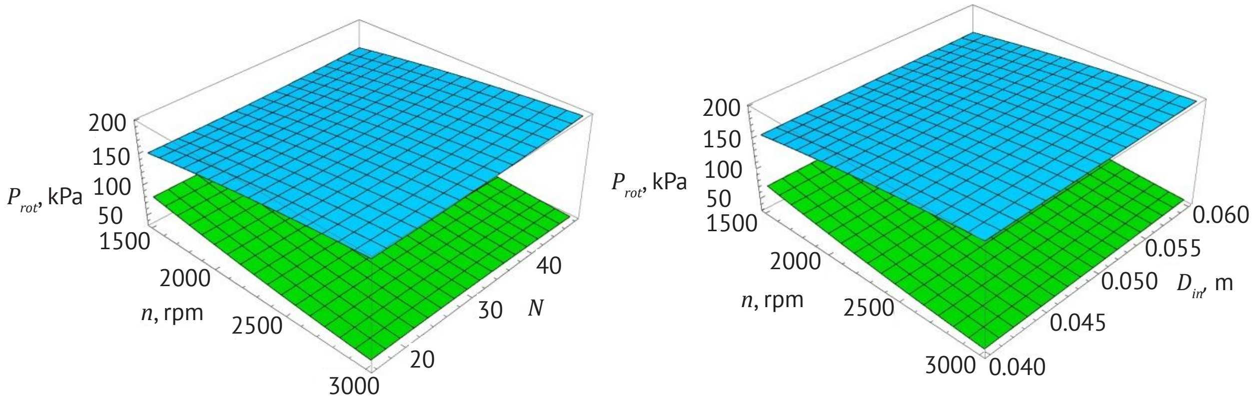

***Figure 10**. Dependence of the maximum and minimum pressures of the liquid phase of the mixture in the diffuser $P_{rot\ max}$, $P_{rot\ min}$ on the rotation speed of the rotor n, the diameter of the inlet D_{in} and the number of resonators N_{hole}*

As a result of calculating the maximum and minimum cavitation numbers using equations (1) and (2), the corresponding regression equations (14-15):

$$X_{max} = 8.85738 - 0.0046054\ n + 6.90585 \cdot 10^{-7}\ n^2 - 0.0626404\ N_{hole} + 0.0000113792\ n\ N_{hole} + 0.000297945\ N_{hole}^{\ 2} \quad (14)$$

$$X_{min} = 6.00697 - 0.00363865\ n + 5.73414 \cdot 10^{-7}\ n^2 - 0.0385963\ N_{hole} + 0.0000106933\ n\ N_{hole} + 0.0000802344\ N_{hole}^{\ 2} \quad (15)$$

The value of the cavitation number X_{min} = 0.08 and X_{max} = 0.57 is achieved at n = 2725 rpm., D_{in} = 0.049 m, N_{hole} = 48. Taking into account the research factors alternately at the specified level, graphical interpretations of dependencies (14)-(15) are shown in Figure 11.

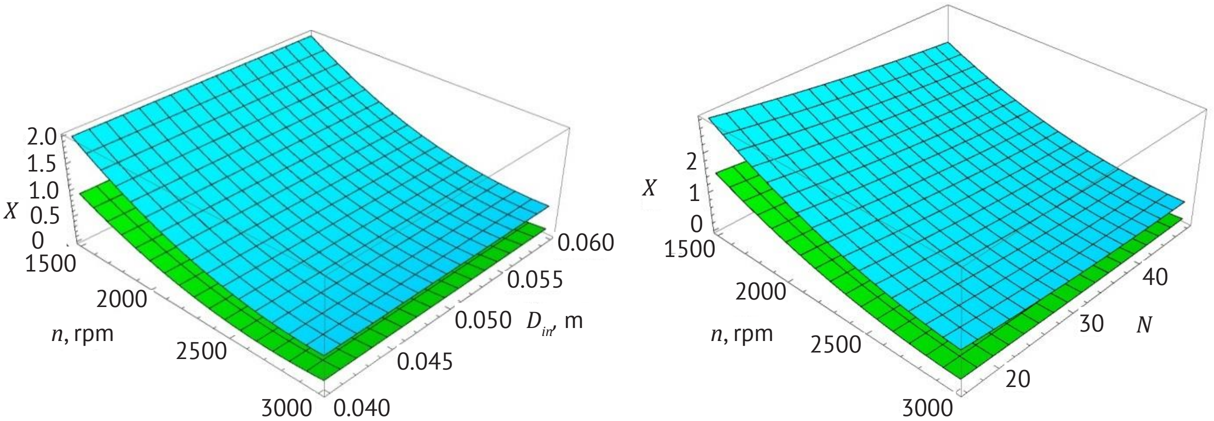

***Figure 11**. Dependence of the maximum and minimum cavitation numbers $X_{max,}$ X_{min} on the rotor speed n, the inlet diameter D_{in}, and the number of resonators N_{hole}*

CONCLUSIONS

As a result of modelling the action of a rotary cavitation disperser-homogeniser in the Star CCM+ software, the distributions and dynamics of velocities of the liquid phase of the mixture and the pressure and concentration of the gaseous phase of liquid in the diffuser are established, which indicates the presence of cavitation. This confirms the operability of the developed design and technological facilities for the preparation of liquid feed and indicates the expediency of further research to substantiate its technological parameters.

As a result of numerical modelling of the operation of a rotary cavitation disperser-homogeniser, the dependences of the maximum (max) and minimum (min) movement speed of the liquid phase of the mixture in the inlet V_{in} and in the diffuser V_{rot} on the rotation speed of the rotor n, the diameter of the inlet D_{in} and the number of resonators N_{hole} are determined. The maximum movement speed of the liquid phase of the mixture in the inlet $V_{in\ max}$ = 7.3 m/s is achieved at n = 3000 rpm., D_{in} = 0.06 m, N_{hole} = 16. In turn, the maximum movement speed of the liquid phase of the mixture in the diffuser $V_{rot\ max}$ = 27.5 m/s is achieved at n = 3000 rpm., D_{in} = 0.06 m, N_{hole} = 48. As a result of numerical modelling of the operation process of a rotary cavitation disperser-homogeniser, the dependences of the maximum (max) and minimum (min) pressures of the liquid phase of the mixture in the Inlet P_{in} and in the diffuser P_{rot} on the rotor speed n, the diameter of the inlet D_{in} and the number of resonators N_{hole} are determined. The maximum pressure of the liquid phase of the mixture in the inlet $P_{in\ max}$ = 154.4 kPa and in the diffuser $P_{rot\ max}$ = 154.4 kPa is reached at n = 3000 rpm., D_{in} = 0.06 m, N_{hole} = 48.

The qualitative criterion for evaluating the cavitation phenomenon in the developed equipment is the maximum and minimum cavitation number X_{max} and X_{min}, which depends on the rotation speed of the rotor n, the inlet diameter D_{in} and the number of resonators N_{hole}. The value of the cavitation number X_{min} = 0.08 and X_{max} = 0.57 is achieved at n = 2725 rpm, D_{in} = 0.049 m, N_{hole} = 48, which corresponds to a film flow of liquid with a stable separation of the cavitation cavity from the rest of the continuous flow (film cavitation).

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СИМУЛЯЦІЯ ПРОЦЕСУ КАВІТАЦІЙНОЇ ОБРОБКИ РІДКИХ КОРМІВ

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Анотація. Однаковий фракційний склад та однорідність розподілу компонентів сировини рослинного походження у суміші є основними критеріями якості рідкого корму. Це забезпечується процесами гомогенізації та диспергування компонентів кормів із застосуванням кавітаційної обробки. Метою досліджень є проведення симуляції процесу кавітаційної обробки рідких кормів роторним кавітаційним диспергатор-гомогенізатором і обґрунтування його раціональних конструктивно-технологічних параметрів. Поставлено задачу створення такого роторного кавітаційного диспергатор-гомогенізатора, який дозволяє одночасно виконувати технологічні процеси диспергування, емульгування та гомогенізації компонентів суміші в рідкому середовищі з більш високою продуктивністю, якістю і меншими енерговитратами. У результаті симуляції роторного кавітаційного диспергатор-гомогенізатора в програмі Star CCM+ встановлено розподіли і динаміки швидкостей руху рідкої фази суміші, тиску та концентрації газоподібної фази рідини в дифузорі, що свідчить про наявність кавітації. Це підтверджує працездатність конструктивно-технологічної схеми розробленого технічного засобу для приготування рідких кормів і свідчить про доцільність подальших його досліджень з обґрунтування конструктивно-технологічних параметрів. У результаті чисельного моделювання процесу роботи роторного кавітаційного диспергатор-гомогенізатора визначено залежності максимальної (max) і мінімальної (min) швидкості переміщення рідкої фази суміші у вхідному отворі V_{in} і у дифузорі V_{rot} від частоти обертання ротора n, діаметра вхідного отвору D_{in} і кількості резонаторів N_{hole}. Якісним критерієм оцінки явища кавітації у розробленому обладнанні є максимальне і мінімальне число кавітації X_{max} і X_{min}, яке залежить від частоти обертання ротора n, діаметра вхідного отвору D_{in} і кількості резонаторів N_{hole}. Значення числа кавітації X_{min} = 0,08 і X_{max} = 0,57 досягається при n = 2725 об/хв., D_{in} = 0,049 м, N_{hole} = 48, що відповідає плівковому потоку рідини зі стійким відділенням кавітаційної порожнини від решти суцільного потоку (плівкова кавітація)

Ключові слова: кормовиробництво, кавітація, диспергатор-гомогенізатор, чисельне моделювання, параметри, швидкість, тиск
