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Stochastic simulation of cavitation bubbles formation in the axial valve separator influenced by degree of opening

Anna Kapranova[1] and Adango Miadonye[2]

[1]Faculty of Chemical Technology, Yaroslavl State Technical University, Yaroslavl, Russia

[2]School of Science and Technology, Cape Breton University, Nova Scotia, Canada

Correspondence: Adango Miadonye, School of Science and Technology, Cape Breton University, Nova Scotia, Canada, Email adango_miadonye@cbu.ca

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Abstract

A stochastic modeling of the formation of cavitation bubbles on a specific example is proposed. In this case, the initial stage of hydrodynamic cavitation in the flow part of the axial valve, the separator, was studied. A distinctive feature of this regulating device is the external location of the locking organ. An expression for the differential distribution function of the number of bubbles according to the degree of valve opening is obtained. The model takes into account the design and operating parameters of the axial valve, as well as the physical and mechanical properties of the working environment.

Keywords: axial valve, separator, round throttling holes, cavitation bubbles, model, distribution function, degree of valve opening.

Introduction

In the general case, for pipeline systems, the consequences of the development of cavitation effects can be twofold. Undesirable phenomena include vibrations, noise, erosion of the working surfaces of control valves.[1,2] Cavitation shows a preferred character when cleaning the working surfaces of pipes from sediment, measures to reduce the viscosity of working fluids, for example, oil products, etc.[3,4] Successful solution of problems of designing effective regulatory equipment for pipeline systems is associated with the accounting for cavitation. In particular, hydrodynamic cavitation is usually observed in the flow part of the valves in bubble form. This phenomenon is a rupture of the fluid and its further evolution. This gap occurs under the action of tensile stresses during the flow of this fluid in a critical mode.

As a rule, the design of regulating valves for pipelines has a theoretical basis in the form of mathematical models of characteristic processes. For example, such mathematical descriptions can be models of fluid flow in the flow part of regulatory bodies, the emergence and evolution of hydrodynamic cavitation, etc. According to the analysis of the literature, the modeling of the formation of cavitation bubbles in the conditions of fluid flow in the valve has three directions.[5] The first relates to the deterministic case. It is performed when describing the behavior of a single cavitation bubble using the laws of conservation of momentum, mass, energy, taking into account the conditions at the interface.[6] As a rule, this direction assumes the solution of an equation of the Rayleigh-Plesset type and is limited to the analysis of a boundary-value problem with a free boundary. The second is realized, for example, in the study of the distribution of the number of vapor nuclei with a metastable state in size for two nucleation mechanisms. The first of them is called homogeneous and is implemented in a homogeneous liquid medium. Its description can be found in Volmer and Weber,[7] and Frenkel.[8] The second mechanism is heterogeneous and can be observed in a medium with impurities,[9] or on the wall[10] and its cracks.[11] The third direction of simulation is a combination of deterministic and stochastic. In this case, it is assumed that each phase is described separately. For example, modeling the behavior of the carrier phase-continuum is performed using the laws of a continuous medium in Euler variables. A description of the dispersed phase is produced in Lagrange variables at a fixed point in time.[12]

However, often the construction of the laws of distribution of heterogeneous nucleons is taken from the analysis of the results of experimental studies. According to the analysis of Kapranova et al.,[5,13] it can be noted that with the stochastic approach, the nucleation frequency is determined by an exponential dependence on the Gibbs number in accordance with the theory of Frenkel.[8] However, the proposed modifications of this relationship, including those for heterogeneous nucleation, contain experimental constants,[14] are postulated in the form of normal, lognormal, equiprobable laws,[15] or are reduced to empirical relations.[16] In this case, the combined approach also implies the postulation of the indicated laws for the nucleation frequency.[12]

Thus, to analyze the conditions for the occurrence of cavitation, it is of particular interest to model the differential distribution function of the number of bubbles with respect to a certain selected parameter. Moreover, this parameter should be sufficiently significant and characterize the process of formation of cavitation bubbles in the working volume of a specific technological device.

The purpose of this work is stochastic modeling of the formation of cavitation bubbles on a specific example. It is proposed to consider the initial stage of hydrodynamic cavitation in the flow part of the axial valve - in the separator, depending on the degree of its opening. The constructive novelty of this regulating device consists in the external arrangement of the locking organ. The construction of the corresponding model involves consideration of the design and operating parameters of the axial valve, as well as the physical and mechanical properties of the working environment. It uses the assumption of the random nature of the process of formation of cavitation bubbles, as the process Ornshten-Uhlenbeck.[17] The latter refers to a variety of processes by Markov A. A.[18,19]

Basic assumptions of the stochastic model

The random Ornstein-Uhlenbeck process, which characterizes diffusion and fluctuation changes in the state of a selected system, assumes a linear dependence of the transition frequency moment on the state of the system while keeping the second moment constant.[20] It is assumed that the system of formed cavitation bubbles in the flow part of the axial valve forms the macrosystem of spheres, which is energetically closed in the Gibbs ensemble with micro-parameters in the form of Hamilton coordinates and pulses.[17,21] This energy closure of the macrosystem of cavitation bubbles reflects an increase with the subsequent preservation of the entropy at its equilibrium state according to the principle of its maximum.[17] According to this principle, during the evolution of a closed system of bubbles to equilibrium, the Boltzmann entropy increases and persists when the equilibrium state of the specified macrosystem is reached.[17]

Unlike the previously proposed modeling,[13,22,23] and in accordance with the description,[24,25] the set of phase variables is determined by the radius of the cavitation sphere r, the speed of its center of mass v, and the degree of valve opening ζ, defined by the ratio of this position ζ' for the moving gate along its axis to the conventional position L. Here L is the length of the perforated part of the fixed cylindrical separator with round choke holes, which are overlapped with the help of an external movable cylindrical shell of an axial valve.[26] Then for the element of the phase space we have

$$d\Psi = dv dr d\zeta \ . \tag{1}$$

Taking into account the adopted approximations for the considered Ornstein-Uhlenbeck random process, we write the energy representation of the Fokker-Planck equation[17] for the equilibrium distribution function $\varphi(t,E)$ for the state of the cavitation spheres formed depending on time t and energy E for stochastic motion of bubble

$$\frac{\partial \varphi}{\partial t} = \left.\frac{dE}{dt}\right|_{t_0} \left[\frac{\partial}{\partial E}\left(E \frac{\partial \varphi}{\partial E} \right) + \frac{1}{E_0} \frac{\partial (E\varphi)}{\partial E} \right], \tag{2}$$

where $E_0 = E(t_0)$ is the energy parameter corresponding to the energy of the system at the moment of its stochastization t_0.

For the stationary case, the construction of solving the kinetic equation (2) in the form $\varphi(t_0, r, v, \zeta) = f(r, v, \zeta)$ or in the form $\varphi(t_0, \xi, \eta, \zeta) = f(\xi, \eta, \zeta)$ after the introduction of dimensionless variables according to the characteristic values of the radius and velocity r_k, v_L

$$\xi = r / r_k, \qquad \eta = v / v_L, \qquad \zeta = \zeta' / L \tag{3}$$

leads to an expression

$$f(\xi,\eta,\zeta) = A_0 \exp\left[-\frac{E(\xi,\eta,\zeta)}{E_0} \right] \tag{4}$$

whose explicit form is determined by the function $E(\xi,\eta,\zeta)$ for the energy of the stochastic bubble motion, energy parameter $E_0 = E(t_0)$ and normalization coefficient A_0.

The last coefficient is given by the normalization equation

$$\int_{\Psi} f d\Psi = 1 \ . \tag{5}$$

The function $E(\xi,\eta,\zeta)$ indicated in (4) is modeled similarly to the approach proposed by Kapranoval et al.[25] according to the main stages of the formation of a single cavitation bubble. These include: the formation of a liquid rupture in a rarefied region; the design of the sphere with the coefficient of surface tension σ; gas percolation through its surface and vapor condensation inside the bubble when saturated vapor pressure is reached P_s; the motion of both the bubble itself in the fluid flow density ρ_L, and its internal gas-vapor system with volume fractions α_g, α_s at corresponding densities for gas and vapor ρ_g, ρ_s. Therefore, the sum of the corresponding energy terms leads to the equation[25]

$$E(\xi,\eta,\zeta) = v_L^2 \eta^2 \left[w_{11}(\xi) + w_{12}(\xi)\zeta_{12}(\zeta) \right] + w_{22}(\xi) \ . \tag{6}$$

Here, the auxiliary dependencies on the chosen dimensionless variable of the specific radius ξ for the cavitation sphere are given by equations $w_{11}(\xi) \equiv \lambda_1 r_k^3 \xi^3$; $w_{12}(\xi) \equiv \rho_L / (4 r_k \xi)$; $w_{22}(\xi) \equiv \lambda_3 M^2 / (r_k^{\ 5} \xi^5) + r_k^2 \xi^2 (\lambda_4 + \lambda_5 r_k \xi)$ where $\lambda_1 \equiv 2\pi(\alpha_g \rho_g + \alpha_s \rho_s)/3$; $\lambda_3 \equiv 5\lambda_1/8$; $\lambda_4 \equiv 4\pi\sigma$; $\lambda_5 \equiv 8\pi P_s / 3$. In Equation (6), the following are also indicated: $\zeta_{12}(\zeta)$ the function for the hydraulic resistance coefficient[27] for the transition zone of fluid flow $(10 < \mathrm{Re} < 10^4)$ through the axial valve separator,[26] depending on the degree of opening of the axial valve ζ from Equation (3); s_ζ coefficient of proportionality; M the random component of the angular momentum for the internal gas-vapor bubble system. In this case, the modeling of the form both for $M(\zeta)$ and for the energy parameter $E_0(\zeta)$ from Equation (4) is discussed in Kapranova et al.[25]

$$M(\zeta) = \left\{ \frac{r_k^{\ 5}}{5\lambda_3} \left[3(2q_1^{\ 1/3} - 1)E_0(\zeta) - \gamma_2 \right] \right\}^{1/2}, \tag{7}$$

$$E_0(\zeta) = q_0(\zeta) \frac{f_1(\zeta)[3\gamma_2 + (\gamma_2 - \gamma_3 r_k) f_2(\zeta) + 15\gamma_0 r_k^{\ 3}] + 60 f_3(\zeta) f_4(\zeta)}{2\pi^2 f_1(x)\{2(q_1^{\ 1/3} - 1)[3 + f_2(x)]\gamma_2\} - 20 r_k [1 + f_3(\zeta)]} \ . \tag{8}$$

In Equations (7) and (8), the functions $f_j(\zeta)$, $j = \overline{1,4}$ are determined by different values for the following dependencies $w_{11}(\xi)$, $w_{12}(\xi)$, $w_{22}(\xi)$ from Equation (6); $\gamma_2 \equiv (2\lambda_4 + 3\lambda_5 r_k) r_k^{\ 2}$, $\gamma_3(\zeta) \equiv 3 r_k [5\lambda_4 + r_k \gamma_0(\zeta)$; $\gamma_0(\zeta) \equiv 32\pi^{1/2} / \{3[D_y(\zeta)]^2\} - \lambda_5$; the coefficient $q_1 \equiv r_k^3 \left(P_{\max} / P_s \right)^{1/k}$ is taken at reaching $r_k = r_{\min}$ with the

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maximum value of pressure $P_{\max}$ in the center of the bubble and the adiabatic index k; the values of the function $q_0(\zeta)$ are calculated using the dependence $K_{vy}(\zeta)=K_{vy}[\zeta_{12}(\zeta)]$ for the conditional throughput of the axial valve (m³/h) in accordance with the specified diameter of the nominal flow area $D_y(\zeta)$, which is calculated through the radius of the throttle holes of the separator.

Note that in formula (6), according to [27], the expression

$$\zeta_{12}(\zeta)=\mu_2+\mu_1 g_1(\zeta)+\mu_4[g_2(\zeta)]^2 \quad (9)$$

is accepted as a reflection of the principle of superposition of pressure losses in elementary local resistances, where the functions $g_1(\zeta),\ g_2(\zeta)$ and constants $\mu_2,\ \mu_1,\ \mu_4$ are determined by the design and operating parameters of the axial valve[21] and are given in Kapranova etl al.[27]

Simulation of the kinetic equation solution

Using the explicit form Equation (6) for the energy $E(\xi,\eta,\zeta)$ of the stochastic motion of the cavitation sphere, the solution of the kinetic equation of the Fokker-Planck type Equation(2) in the described stationary case Equation (4) allows us to calculate the number of bubbles of the macrosystem

$$N=A_0\int_{\Psi}\exp\left[-\frac{E(\xi,\eta,\zeta)}{E_0}\right]dN. \quad (10)$$

Equation (10) leads to the calculation of the differential distribution function of the number of cavitation spheres formed in the initial stage of hydrodynamic cavitation as the fluid flows through a separator of axial valve with circular orifices, depending on its opening, according to the definition

$$F(\zeta)\equiv\frac{1}{N}\frac{dN}{d\zeta}. \quad (11)$$

So, from Equations (6), (10), (11) taking into account Equations (7) - (9) for the random component of the angular momentum M for the internal gas-bubble pair system, energy parameter E_0, coefficient of hydraulic resistance for the transition zone of fluid flow ζ_{12}, and the normalization equation (5) for the parameter should be the type of the desired function $f_\zeta(\zeta)$

$$f_\zeta(\zeta)=\frac{\theta_0\theta_1(\zeta)\sigma_2[\zeta(u_2)]}{L[\theta_2(\zeta)]^{\Delta+1/2}}\frac{[\theta_3\sigma_0(\zeta)+\theta_4\sigma_1(\zeta)]}{[\theta_3\sigma_{01}(\zeta)+\theta_4\sigma_{11}(\zeta)]}, \quad (12)$$

where L is the length of the perforated part of the cylindrical separator. The resulting Equation (12) includes the following notation for the coefficients $\theta_0\equiv[\gamma_0/(2\pi B)]^2$; $B\equiv r_k(\beta_1+\beta_2/2+\beta_3/3)$; $\beta_1\equiv(\sigma_0'-\sigma_1')(\sigma_2'-\sigma_3')$; $\beta_2\equiv\sigma_3'(\sigma_0'-\sigma_1')+\sigma_1'(\sigma_2'-\sigma_3')$; $\beta_3\equiv\sigma_3'\sigma_1'$ where at the task $\gamma_4\equiv v_L^2(\lambda_1 r_k^4+\lambda_2)$; $w_1(\xi)=(\lambda_1 r_k^4\xi^4+\lambda_2)/(r_k\xi)$; $w_2(\xi)\equiv\lambda_3 M_1^2/(r_k^5\xi^5)+r_k^2\xi^2(\lambda_4+\lambda_5 r_k\xi)$; $\gamma_5\equiv 3\lambda_1 r_k^4-\lambda_2$ and

$$\sigma_0'\equiv\left[\frac{E_{01}}{w_1(1)}\right]^{1/2}\operatorname{erf}\left\{v_L\left[\frac{w_1(1)}{E_{01}}\right]^{1/2}\right\},$$

$$\sigma_1'\equiv\frac{\gamma_5 v_L^2}{\gamma_4}\left[\frac{v_L}{\pi^{1/2}}\exp\left(-\frac{\gamma_4^{1/2}}{E_{01}r_k}\right)-\frac{\sigma_0'}{2}\right], \quad (13)$$

$$\sigma_2'\equiv\exp\left[-\frac{w_2(1)}{E_{01}}\right],\quad \sigma_3'\equiv\frac{\sigma_0'}{E_{01}}\left(5\frac{\lambda_3 M^2}{r_k^5}-\gamma_2\right) \quad (14)$$

are accepted. In this case, the value M_1 of $w_2(\xi)$ and the energy parameter E_{01} included in Equations (13) and (14) are calculated in Kapranova et al.[13]

The functions $\theta_1(\zeta)$ and $\theta_2(\zeta)$, determining the form of dependence Equation (12) for $f_\zeta(\zeta)$ are

$$\theta_1(\zeta)\equiv\frac{1}{2}\left(\frac{D_{y\max}}{D_y(\zeta)}\right)^{1/4}\left\{\pi^4\left(2^{1/2}-\frac{1}{3}\right)\left(\frac{K_{vy\max}}{K_{vy}(\zeta)}\right)^{1/2}\right\}^{-1}. \quad (15)$$

$$\theta_2(\zeta)\equiv 2^{5/2}\left(\frac{\pi}{3}\right)^2\left\{1+\frac{3^{3/2}\pi^4}{4}\left[1-\frac{K_{vy\max}}{K_{vy}(\zeta)}\left(\frac{D_y(\zeta)}{D_{y\max}}\right)^2\right]\right\}\times$$
$$\times\left[1-\frac{r_k}{D_y(\zeta)}\left(\frac{K_{vy}(\zeta)}{Q_{1\max}}\right)^{1/2}\right]\left[\frac{K_{vy}(\zeta)}{K_{vy\max}}\left(\frac{D_{y\max}}{D_y(\zeta)}\right)^2\right]^{3/2}, \quad (16)$$

where $Q_{1\max}$ (m³/h) is the maximum flow rate of the working fluid at a temperature t_1 (⁰C); the maximum conditional throughput for an axial valve is equal to $K_{vy\max}=K_{vy}(1)$ and corresponds to its full opening. The values of the coefficients included in Equation (12)

$$\theta_3\equiv U_0-U_1/2,\quad \theta_4\equiv 4U_1/3-U_0/2 \quad (17)$$

are calculated according to the equations

$$U_0\equiv\exp\left[-\frac{w_{22}(1)}{E_0}\right],\quad U_1\equiv\frac{U_0}{E_0}\left(5\frac{\lambda_3 M^2}{r_k^5}-\gamma_2\right). \quad (18)$$

For the remaining functions included in Equation (12), the notation

$$\sigma_0(\zeta)\equiv\left[\frac{E_0 r_k}{\Omega_1(\zeta)}\right]^{1/2}\operatorname{erf}\left\{v_L\left[\frac{\Omega_1(\zeta)}{E_0}\right]^{1/2}\right\}, \quad (19)$$

$$\sigma_1(\zeta)\equiv\frac{\Omega_2(\zeta)v_L^2}{\Omega_1(\zeta)}\left[\frac{v_L}{\pi^{1/2}}\exp\left(-\frac{[\Omega_1(\zeta)]^{1/2}}{E_0 r_k}\right)-\frac{\sigma_0(\zeta)}{2}\right], \quad (20)$$

$$\sigma_{01}(\zeta)\equiv\int_\zeta^1\sigma_0(\zeta)d\zeta,\quad \sigma_{11}(\zeta)\equiv\int_\zeta^1\sigma_1(\zeta)d\zeta, \quad (21)$$

$$\sigma_2[\zeta(u_2)]\equiv 3^2\left(3^{1/2}-\frac{1}{2}\right)\left(2\frac{1}{2}\frac{\zeta(u_2)}{\zeta(1)}\right)^{1/2}\left(\frac{\zeta(u_2)}{2\zeta(1)}-2\right)\left(3-\frac{\zeta_{12}[\zeta(u_2)]}{\zeta_{12}[\zeta(1)]}\right) \quad (22)$$

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where $\Omega_1(\zeta) \equiv r_k[w_{11}(1) + \zeta_{12}(\zeta) w_{12}(1)]$; $\Omega_2(\zeta) \equiv r_k[3w_{11}(1) - \zeta_{12}(\zeta) w_{12}(1)]$; $\Delta = \zeta(u_2) - \zeta(1)$; $\zeta(n_2) \equiv [n_2(l_0 + d_0) + l_0]/L$; $n_2 = 1, ..., u_2$ the value u_2 is the number of rows of round throttle holes with a diameter d_0 at a distance l_0 from each other in the separator axial valve. Note that Equations (13) and (19) contain the error function, the general form of which for the argument $\varepsilon = 2^{-1} x^{1/2}$ is given by the formula

$$\mathrm{erf}(\varepsilon) = 2\pi^{-1} \int_0^{\varepsilon} \exp(-x^2) dx . \quad (23)$$

Thus, the proposed Equation (12) to estimate the desired distribution function $f_\zeta(\zeta)$.

Results and discussion

Taking the following values for the parameters of the model of the formation of cavitation spheres in the flow part of the axial valve, depending on its opening, let us analyze the results obtained. Physical and mechanical characteristics of the working environment are for gas ρ_g =1,205 kg/m^3; for steam ρ_s = 1,44×10^{-2} kg/m^3; $P_{\max}$ =1,3×10^8 Pa; r_k =10^{-3} m; for liquid P_s =10^3 kg/m^3;σ=7,284×10^{-4} H/m; for bubbles P_s =10^{-3} Pa. The main design parameters for an axial valve include: diameter of round throttle holes d_0 = 3,5×10^{-3} m; the number of holes in the same row u_1 =16; number of rows with these holes u_2 =5; separator thickness H =0,15×10^{-2} m; separator diameter d_{id} =3,4×10^{-2} m; diameters of the inner and outer surfaces of the casing d_{is} =5,3×0^{-2} m and d_{es} =6,5×10^{-2} m; the length of the perforated part L =2,35×10^{-2} m. The values of the operating parameters are t_1 = 30,0 ° C; $\Delta P_{\min}$ =1.5 kPa; $Q_{1\max}$ =0.5 m^3/h. The specified input parameters of the proposed stochastic model correspond to the following range of Reynolds number Re=(1.5-7.0)×10^4.

Analysis of surfaces for the function in Figure 1 shows that in the first stages of opening the throttle holes, the maximum number of cavitation spheres accumulates in the end zone of the separator (Figure 1, a and b), gradually, with an increase in the degree of valve opening, some equalization of the number of bubbles in the end zone occurs when the smoothed maximum for $f_\zeta(\zeta, d_0)$ is displaced into the region of the initial throttle holes (Figure 1, c and d).

At the same time, a constructive parameter of the separator – the diameter d_0 of the throttle holes – significantly affects the value of the function $f_\zeta(\zeta, d_0)$, when an increase d_0 of 1,6 times with other fixed parameters reduces the number of cavitation bubbles by a factor of 2 in the extreme range of its opening degree (for example, see Figure 1, a, when for $d_{01} = 3,0 \times 10^{-3}$ m value $f_\zeta(0,25; d_{01}) = 0,20$, and for $d_{02} = 5,0 \times 10^{-3}$ m we have $f_\zeta(0,25; d_{02}) = 0,10$).

Comparison of theoretical results according to expression (12) and experimental data obtained on a pilot plant by Lebedev et al.[28] is shown in Figure 2. The analysis was performed with the degree of valve opening ζ=0,6, when the values of the model parameters are equal to: E_0 = 1,97×10^{-8}J; M = 2,01×10^{-12}kg×m^2/c; Re$_y$=9,8×10^4. The diameter of the throttle holes of the separator corresponds to the value d_0=3,5×10^{4}m. The relative calculation error was 13%. The deviation of the theoretical curve from the experimental values for the last rows of the throttle holes is explained by the limitation of the model's application area for the initial stage of hydrodynamic cavitation, when Re=(1,5-10,0)×10^4. The proposed stochastic model does not take into account such consequences of the evolution of cavitation bubbles as possible splicing of bubbles, growth of their size, collapse, etc.

Conclusion and Significance

The main result of the proposed stochastic model of the formation of cavitation bubbles on the example of an axial valve separator is the expression (12). The simulation was performed on the basis of the Ornstein-Uhlenbeck process[17] using the stationary solution (4) for the Fokker-Planck type equation (2) when calculating the number of cavitation bubbles using the expression (10). The resulting expression (12) models the differential distribution function of the number of bubbles according to the degree of opening of the axial valve. The last parameter is one of the main characteristics affecting the intensity of the development of hydrodynamic cavitation. The model takes into account the design and operating parameters of the axial valve, as well as the physicomechanical properties of the working environment. Here, the design parameters include the parameters of a cylindrical fluid flow divider providing the throttling process: the diameter of the throttle orifices, their number in one row, the number of such rows, the characteristic diameters of the separator and the housing, the thickness of their walls, etc. Note that the feature of modeling the desired function in the form of (12) is the dependence (6) for the energy of the stochastic bubble motion. Expression (6) takes into account the characteristic energies for each stage of bubble formation from the formation of a liquid rupture to the description of the vortex motion of the internal gas-vapor system using expression (7).

An example of calculating the desired differential distribution function of the number of bubbles according to the degree of opening of an axial valve with an equal ratio of gas and vapor fractions inside the cavitation bubble (Figure 1) is considered. Moreover, for each value of the valve opening degree, when the Reynolds number varies within limits Re=(1,5-7,0)×10^4, the model parameters are calculated.The ranges of variation of these quantities are equal: for the energetic parameter E_0 =(1,9-3,9)×10^{-8} J and for the random component of the angular momentum of the internal gas-vapor system M= (2,0-4,4)×10^{-12} kg×m^2/c. It was found that, in addition to the degree of opening of the valve, the diameter of the throttle orifices significantly affects the intensity of blistering. So, in the extreme area of the valve opening degree, a decrease in the number of bubbles by a factor of 2 is observed only with an increase in the diameter of the throttle orifices by a factor of 1.6 (Figure 1, a). The calculation showed that the shift to the region of the initial choke holes of the smoothed maximum for the function occurs with an increase in the valve opening degree, which is reflected in Figure 1, c and Figure 1, d. The described nature of the formation of cavitation bubbles makes it possible to predict the region of their most significant accumulation in the separator, which contributes to the effective consideration of the conditions for the manifestation of hydrodynamic cavitation even at its initial stage of evolution when forming the engineering methodology for calculating the axial valve fluid flow divider with an external blocking organ. So, the completed stochastic modeling of the formation of cavitation bubbles at the initial stage of the development of hydrodynamic cavitation can be used in the design of new regulatory equipment.

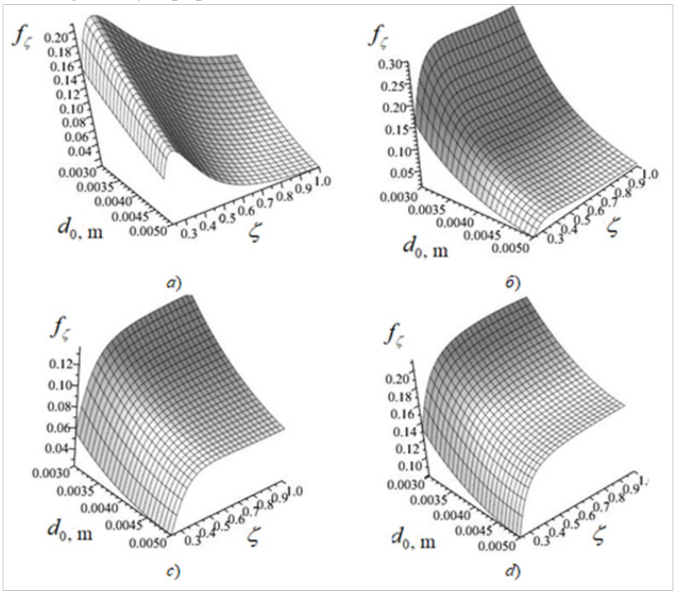

Figure 1 Dependence for $f_\zeta(\zeta, d_0)$ an axial valve with an external location of the locking member: $\alpha_g = \alpha_s = 0,5$;

a) $\zeta = 0,2340$; E_0 = $1,0159\times10^{-8}$ J; M= $1,9154\times10^{-12}$ kg×m^2/c; $\mathrm{Re}_{y1} = 1,5564\times10^4$;

b) $\zeta = 0,6170$; E_0 = $1,9733\times10^{-8}$ J; M = $2,0129\times10^{-12}$ kg×m^2/c; $\mathrm{Re}_{y2} = 9,8438\times10^4$;

c) $\zeta = 0,8085$; E_0 = $2,9066\times10^{-8}$ J; M = $3,4026\times10^{-12}$ kg×m^2/c; $\mathrm{Re}_{y3} = 7,7822\times10^4$;

d) $\zeta = 1,0$; E_0 = $3,8560\times10^{-8}$ J; M = $4,3856\times10^{-12}$ kg×m^2/c; $\mathrm{Re}_{y4} = 6,9606\times10^4$

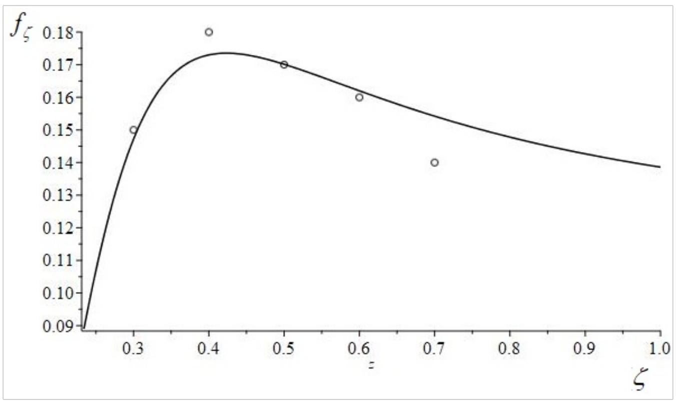

Figure 2 Comparison of theoretical and experimental data for dependencies $f_\zeta(\zeta)$ with varying degrees of opening of the axial valve: line - theory; points - experimental data;[28] $\alpha_g = \alpha_s = 0,5$; $d_0 = 3,5\times10^{-3}$ m; $u_1 = 16$; $u_2 = 5$; E_0 = $1,97\times10^{-8}$ J; M = $2,01\times10^{-12}$ kg×m^2/c; $\mathrm{Re}_y = 9,8\times10^4$.

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