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# EFFECT OF HIGH-FREQUENCY VIBRATION ON CONVECTION IN MISCIBLE FLUIDS

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*The effect of high-frequency vibrations of the field of external mass forces on convection in miscible fluids is considered for a system of convection equations obtained by an averaging technique. The structures of flows formed under initial conditions corresponding to physical experiments in microgravity are examined.*

**Key words:** *convection, microgravity, miscible fluids, high-frequency vibrations, averaging technique.*

**Introduction.** It is known that origination of flows in a fluid can depend on processes that occur in regions close to the interface. For instance, capillary forces arising at the interface of immiscible fluids can give rise to convection. In 1901, Korteweg put forward an idea that similar effects can also be observed for miscible fluids with inhomogeneous distributions of density (concentration or temperature). For miscible fluids, the interfaces are characterized by regions with high gradients of concentration, which can exist for a long time with low coefficients of diffusion (it would be more correct to call these regions transitional zones rather than interfaces). As was demonstrated in [1], volume forces arise in these regions; the action of these volume forces on the fluid can be expressed in terms of the effective stress $\sigma$. This stress was estimated in [2] as

$$\sigma = k(\Delta c')^2/\delta,$$

where $k$ is a parameter characterizing the intensity of the arising stress, $c'$ is the concentration of the mass of one of the components, $\Delta c'$ is the characteristic change in concentration inside the transitional zone, and $\delta$ is the transitional zone thickness. Convection in binary systems, induced by the action of such stresses, was studied both experimentally and theoretically [3–7]. Numerical modeling of convective flows in binary systems was performed in [8, 9] to determine an initial distribution of concentration such that it would ensure the formation of a flow structure most convenient for a physical experiment.

It should be noted that volume forces arising in the transitional zone of miscible fluids are very low and, hence, the convective flow induced by these forces is suppressed by natural convection under standard conditions. Therefore, the need to study this phenomenon under microgravity conditions onboard spacecraft is obvious. The optimal configurations for physical research of convection in miscible fluids were considered in [9]. Under these conditions, however, the measurement results can be substantially affected by microaccelerations and microvibrations induced on orbital stations under the action of life-support and attitude-control systems, as well as the activities of the crew. The presence of such vibrations was experimentally confirmed and was considered in [10].

Convection in a binary fluid, which is induced by a combined action of volume forces and high-frequency vibrational fields of external mass forces, is numerically simulated in the present work. The effect of these factors is

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considered by analyzing the system of convection equations derived by an averaging technique with the use of the approach described in [11]. The dependence of the flow structure and properties on initial conditions and vibration intensity is determined.

**Formulation of the Problem and Governing Equations.** In the problems considered below, the physical system is under isothermal conditions and is a weakly compressible viscous fluid consisting of two non-reacting components. The fluid fills a rectangular domain $0 \le x \le L_x$, $0 \le y \le L_y$, whose boundaries $\Gamma$ are solid impermeable walls ($x$ and $y$ are Cartesian coordinates). The system is subject to the action of a variable external force field arising because of periodic vibrations of the volume by the law $af(\Omega' t)/\Omega'$ along the unit vector $\boldsymbol{s} = (\sin\varphi, \cos\varphi)$. Here $a$ is the amplitude of vibration velocities, $\Omega$ is the frequency of vibrations, $t$ is the time, $\varphi$ is the angle of deviation of the vector $\boldsymbol{s}$ from the $y$ axis, and $f$ is a certain periodic function, such that its mean value over one period of vibrations equals zero:

$$\langle f \rangle = \frac{1}{2\pi} \int_0^{2\pi} f(\tau)\, d\tau = 0.$$

The action of vibrations leads to acceleration of external mass forces:

$$\boldsymbol{g} = g' f''(\Omega' t)\boldsymbol{s}, \qquad g' = a\Omega'.$$

If we assume that viscosity and diffusivity are constant, we can write the expression for components of the Korteweg stress tensor $T$ arising in the transitional zone between two components of the fluid [3]:

$$T_{11} = k\Big(\frac{\partial c'}{\partial y}\Big)^2, \qquad T_{12} = T_{21} = -k\,\frac{\partial c'}{\partial x}\,\frac{\partial c'}{\partial y}, \qquad T_{22} = k\Big(\frac{\partial c'}{\partial x}\Big)^2.$$

Taking into account the above-described factors of the action on the system considered, the convection equations in a moving coordinate system can be presented as

$$\rho\Big(\frac{\partial c'}{\partial t} + \boldsymbol{v}' \cdot \nabla c'\Big) = k_c \nabla^2 c',$$

$$\rho\Big(\frac{\partial \boldsymbol{v}'}{\partial t} + \boldsymbol{v}' \cdot \nabla \boldsymbol{v}'\Big) = -\nabla p' + \frac{\mu}{3}\,\nabla(\nabla \cdot \boldsymbol{v})' + \mu \nabla^2 \boldsymbol{v}' + \nabla \cdot T - \rho g' f''(\Omega' t)\boldsymbol{s}, \tag{1}$$

$$\frac{\partial \rho}{\partial t} + \boldsymbol{v}' \cdot \nabla \rho + \rho \,\mathrm{div}\, \boldsymbol{v}' = 0.$$

Here $\boldsymbol{v}' = (v'_x, v'_y)$ is the vector of dimensionless velocity, $p'$ is the pressure, $\rho$ is the density, and $\mu$ is the viscosity; the quantity $k_c$ characterizes molecular diffusion.

As the equation of state, we use the density-versus-concentration dependence for the fluid in the form $\rho = \rho_0(1 - \beta(c' - c_0))$, where $\rho_0 > 0$ is the characteristic value of density, $\beta$ is the concentration coefficient of density, and $c_0$ is the constant mean value of concentration. Using the Boussinesq approximation and passing to dimensionless variables with the scales of length, time, velocity, pressure, and characteristic change in concentration being $h$, $h^2/\nu$, $\nu/h$, $\rho_0\nu^2/h^2$, and $c_*$, respectively, we can convert Eqs. (1) to the following system:

$$\frac{\partial c'}{\partial t} + \boldsymbol{v} \cdot \nabla c' = \mathrm{Sh}^{-1}\, \nabla^2 c',$$

$$\frac{\partial \boldsymbol{v}'}{\partial t} + \boldsymbol{v}' \cdot \nabla \boldsymbol{v}' = -\nabla p' + \nabla^2 \boldsymbol{v}' + K_c \nabla \cdot T + G_v c' \Omega f''(\Omega t)\boldsymbol{s}, \tag{2}$$

$$\mathrm{div}\, \boldsymbol{v}' = 0.$$

Here the dimensionless variables are set in the same form as the dimensional ones, and the dimensionless parameters are determined as

$$K_c = \frac{k(c_*)^2}{\rho_0 \nu^2}, \quad \Omega = \frac{\Omega' h^2}{\nu}, \quad G_v = \varepsilon\, \mathrm{Re}, \quad \varepsilon = \beta c_*, \quad \mathrm{Re} = \frac{ah}{\nu}, \quad \mathrm{Sh} = \frac{\nu}{d},$$

where $\nu = \mu/\rho_0$ is the kinematic viscosity, $d = k_c/\rho_0$ is the diffusivity, and $a = g'/\Omega'$ is the amplitude of vibration velocity.

The boundary conditions are the no-slip conditions on the solid walls and the absence of the flux of matter through the boundary:

$$\boldsymbol{v}' = 0, \qquad \nabla c'_n\Big|_\Gamma = 0. \tag{3}$$

**Averaging Technique.** In what follows, we consider the case with a high frequency of vibrations ($\Omega \gg 1$) and $\mathrm{Re} = O(1)$; the latter condition means that the amplitude $a$ of vibration velocity is finite. In addition, we assume that the vibration period is much smaller than the characteristic hydrodynamic time. Under these conditions, we can apply the averaging technique [11, 12] to problem (2), (3). We seek for the unknowns $\boldsymbol{v}'$, $p'$, and $c'$ in the form

$$\boldsymbol{v}' = \boldsymbol{v} + \boldsymbol{v}_f, \qquad p' = p + \Omega p_f, \qquad c' = c + c_f/\Omega, \tag{4}$$

where $(\boldsymbol{v}, p, c)$ and $(\boldsymbol{v}_f, p_f, c_f)$ are the slow and fast components depending on $(x, y, t)$ and $(x, y, t, \tau)$, respectively; $\tau = \Omega t$ is the fast time.

By analogy with [11, 12], we obtain the following problem for fast components:

$$\frac{\partial \boldsymbol{v}_f}{\partial \tau} = -\nabla p_f + G_v c_f f''(\Omega\tau)\boldsymbol{s}, \qquad \frac{\partial c_f}{\partial \tau} + \boldsymbol{v}_f \nabla c_f = 0, \qquad \operatorname{div} \boldsymbol{v}_f = 0. \tag{5}$$

The $2\pi$-periodic solution of this problem in terms of $\tau$ can be written in the form

$$\boldsymbol{v}_f = -G_v \boldsymbol{w}(x, y, t) f'(\tau), \qquad p_f = -G_v \Phi(x, y, t) f''(\tau), \qquad c_f = G_v(\boldsymbol{w}, \nabla c) f(\tau), \tag{6}$$

where the amplitudes $\boldsymbol{w}$ and $\Phi$ satisfy the conditions

$$\boldsymbol{w} = -\nabla\Phi - c\boldsymbol{s}, \qquad \operatorname{div}\ \boldsymbol{w} = 0, \qquad w_n\Big|_\Gamma = 0. \tag{7}$$

Substituting (4) into (2) with allowance for (6) and (7) and averaging over the fast time $\tau$, we obtain the problem for the smooth components $\boldsymbol{v}$, $p$, and $c$:

$$\begin{gathered}\frac{\partial c}{\partial t} + \boldsymbol{v} \cdot \nabla c = \mathrm{Sh}^{-1}\,\nabla^2 c,\\ \frac{\partial \boldsymbol{v}}{\partial t} + \boldsymbol{v} \cdot \nabla \boldsymbol{v} = -\nabla p + \nabla^2 \boldsymbol{v} + K_c \nabla \cdot T + F_v,\\ \operatorname{div} \boldsymbol{v} = 0, \qquad \boldsymbol{w} = -\nabla\Phi - c\boldsymbol{s}, \qquad \operatorname{div} \boldsymbol{w} = 0.\end{gathered} \tag{8}$$

Here $F_v = G_v^2((\boldsymbol{w}, \nabla)\nabla\Phi)\langle (f')^2 \rangle$ is the vibrational force.

The boundary conditions (3) for the averaged system of convection equations (8) can be written as follows:

$$\begin{aligned} x = 0, L_x&: \quad \frac{\partial c}{\partial x} = 0, \quad \boldsymbol{v} = 0, \quad w_x = 0, \quad \frac{\partial \Phi}{\partial x} = -c\sin\varphi;\\ y = 0, L_y&: \quad \frac{\partial c}{\partial y} = 0, \quad \boldsymbol{v} = 0, \quad w_y = 0, \quad \frac{\partial \Phi}{\partial y} = -c\cos\varphi.\end{aligned} \tag{9}$$

For the numerical solution, system (8) is considered in the variables of vorticity $\omega$, stream function $\psi$, and concentration $c$, where

$$\omega = \frac{\partial v_y}{\partial x} - \frac{\partial v_x}{\partial y}, \qquad v_x = \frac{\partial \psi}{\partial y}, \qquad v_y = -\frac{\partial \psi}{\partial x}.$$

In this case, Eqs. (8) can be presented as

$$\begin{gathered}\frac{\partial c}{\partial t} + \boldsymbol{v} \cdot \nabla c = \mathrm{Sh}^{-1}\,\nabla^2 c,\\ \frac{\partial \omega}{\partial t} + \boldsymbol{v} \cdot \nabla \omega = \nabla^2 \omega + K_c\{c, \nabla^2 c\} + \frac{1}{2} G_v^2 \Big( \sin\varphi \Big( \frac{\partial c}{\partial y} \frac{\partial^2 \Phi}{\partial x^2} - \frac{\partial c}{\partial x} \frac{\partial^2 \Phi}{\partial x\,\partial y} \Big) + \cos\varphi \Big( \frac{\partial c}{\partial y} \frac{\partial^2 \Phi}{\partial x\,\partial y} - \frac{\partial c}{\partial x} \frac{\partial^2 \Phi}{\partial y^2} \Big) \Big),\\ \nabla^2 \psi = -\omega, \qquad \nabla^2 \Phi = -\nabla c\boldsymbol{s},\end{gathered} \tag{10}$$

where $\{g, h\} = \dfrac{\partial g}{\partial x} \dfrac{\partial h}{\partial y} - \dfrac{\partial g}{\partial y} \dfrac{\partial h}{\partial x}$.

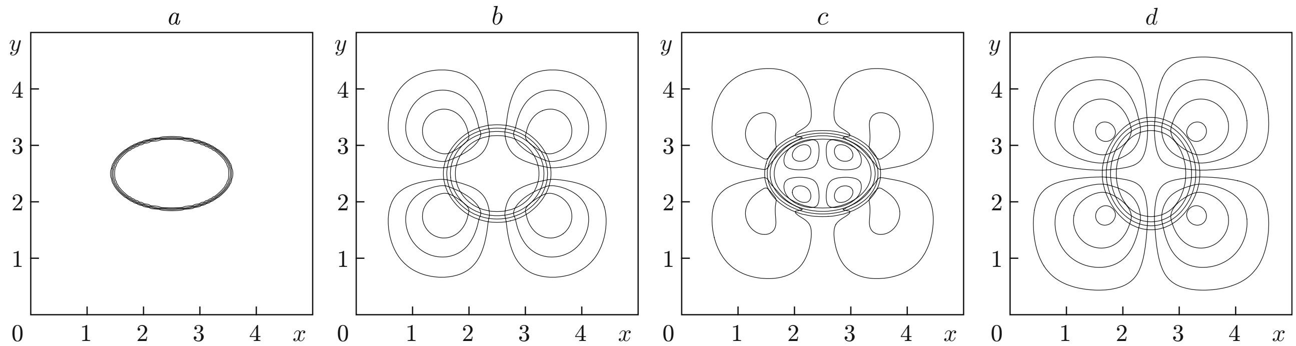


Fig. 1. Lines of the averaged concentration and stream function for Problem 1: (a) initial distribution of concentration ($t = 0$); (b) flow in the absence of vibrational forces (hereinafter, $t = 750$ sec); (c) vibrations aligned with the $x$ axis; (d) vibrations aligned with the $y$ axis.

The boundary no-slip conditions for velocity on the solid walls (9), as applied to the stream function $\psi$, have the form

$$x = 0, L_x,\ y = 0, L_y: \qquad \psi = 0, \quad \frac{\partial \psi}{\partial n} = 0. \tag{11}$$

The system is integrated by a numerical method for calculating two-dimensional flows in the vorticity–stream function variables, which was described, e.g., in [13], and generalized to the case of system (10).

**Results of Numerical Simulations.** Let us consider the results obtained by the numerical solution of system (10) and boundary conditions (9) and (11). The following physical parameters of the fluid were used in the calculations: $k = 10^{-9}$ N, $\rho_0 = 10^3$ kg/m$^3$, $d = 10^{-10}$ m$^2$/sec, $\nu = 10^{-5}$ m$^2$/sec, $\beta = 0.2$, $c_* = 1$, and $h = 10^{-2}$ m, which corresponds to the dimensionless parameters $\mathrm{Sh} = 10^5$ and $K_c = 10^{-2}$.

The initial conditions correspond to setting into contact of two quiescent media with different constant concentrations, which are divided by a transitional zone of thickness $\delta$: $\omega = \psi = 0$ and $c = c(x, y)$. Two variants of initial conditions for the concentration distribution $c$ are considered.

**Problem 1.** In this problem, the transitional zone has the form of an ellipse extended along the $x$ axis. The thickness of the transitional zone is $\delta = 1$ mm. The problem is considered in a square domain $L_x = L_y = 5$ cm. The initial conditions for concentration $c$ are

$$c(x, y) = \begin{cases} 1 & \text{for} \quad F(x, y, a_1, b_1) < 1, \\ 0 & \text{for} \quad F(x, y, a_2, b_2) > 1, \\ 1 - (D^4 - 4(D^3 - D^2)) & \text{for} \quad F(x, y, a_1, b_1) \geq 1 \text{ and } F(x, y, a_2, b_2) \leq 1, \end{cases}$$

where $a_1 = 1$, $b_1 = 0.6$, $a_2 = 1.1$, $b_2 = 0.66$, and

$$F(x, y, a, b) = \frac{x^2}{a^2} + \frac{y^2}{b^2}, \qquad D = \frac{F(x, y, a_1, b_1) - 1}{a_2^2/a_1^2 - 1}.$$

The distribution of concentration $c$ at the initial time is shown in Fig. 1a.

The convective flow formed by volume forces induced by the Korteweg stresses was considered for such initial conditions in [8, 9], where it was shown that the action of such forces in their nature is similar to surface tension forces, which try to confer a circular shape to an elliptic drop. The flow structure in the absence of vibrational actions consists of four vortices and is shown in Fig. 1b.

To estimate the change in the concentration field with time, we introduce the parameter

$$S = \int_0^{L_y} c\, dy$$

at $x = L_x/2$, which characterizes the change in the amount of matter in the mean flow of the computational domain (Fig. 2a). An increase in the parameter $S$ means that the drop becomes extended in the vertical direction (i.e., along the $y$ axis). The maximum velocity in the computational domain $W$ is plotted in Fig. 2b.

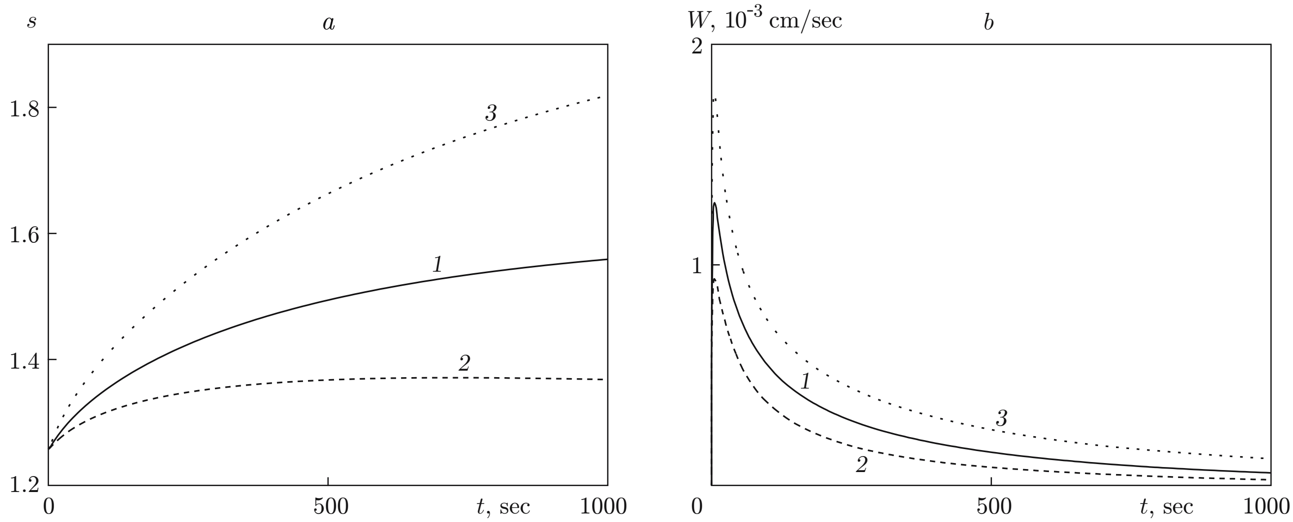


Fig. 2. Time evolution of the parameter $S$ (a) and the maximum velocity $W$ (b) for different variants of the vibrational action: 1) flow in the absence of vibrational forces; 2) vibrations aligned with the $x$ axis; 3) vibrations aligned with the $y$ axis.

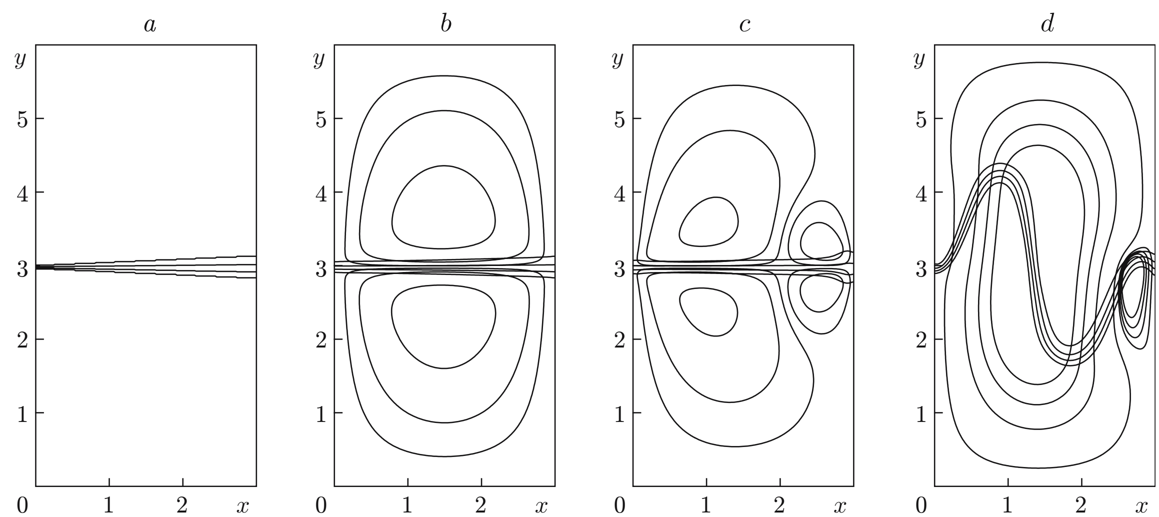


Fig. 3. Lines of the averaged concentration and the stream function for problem 2: (a) initial distribution of concentration ($t = 0$); (b) flow in the absence of vibrational forces (hereinafter $t = 750$ sec); (c) vibrations aligned with the $x$ axis; (d) vibrations aligned with the $y$ axis.

**Problem 2.** The second computational problem deals with convective flows with the transitional zone thickness $\delta = \delta(x)$ increasing linearly from 0.5 to 4.5 mm along the $x$ axis. The problem is considered in a rectangular domain: $L_x = 3$ cm and $L_y = 6$ cm. The initial conditions for concentration $c$ are

$$c(x, y) = \begin{cases} 0 & \text{at} \quad 0 \le y < 3 - \delta/2, \\ 0.5 - 1,5(3 - y)/\delta + 2(3 - y)^3/\delta^3 & \text{at} \quad 3 - \delta/2 \le y \le 3 + \delta/2, \\ 1 & \text{at} \quad 3 + \delta/2 < y \le 6. \end{cases}$$

The distribution of concentration $c$ at the initial time is shown in Fig. 3a.

The flow structure was considered for the same initial conditions as those used in [8, 9]. It was shown that volume forces inducted by the Korteweg stresses arise only in the transitional zone whose thickness is nonuniform, which leads to emergence of two symmetric vortices here (Fig. 3b). The intensity of these vortices decreases with time owing to an increase in the transitional zone thickness under the action of convection and diffusion. The rate

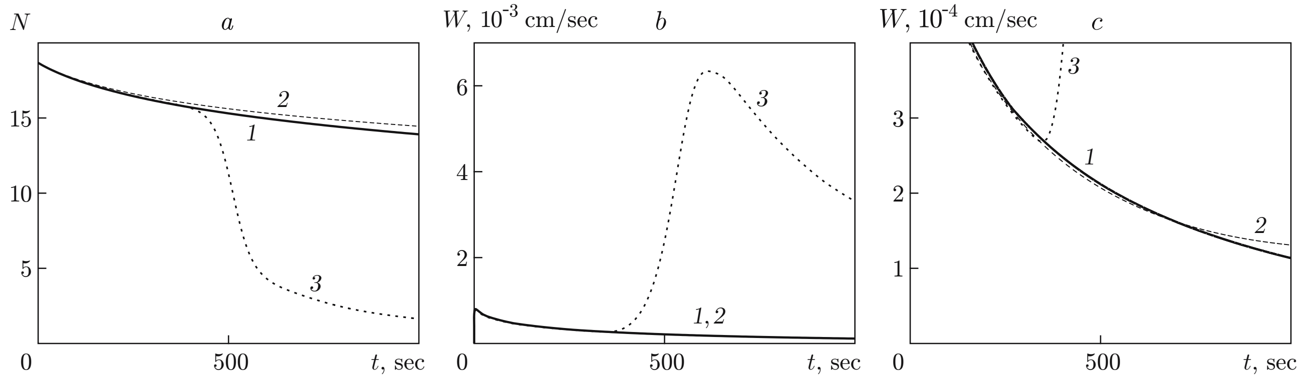


Fig. 4. Time evolution of the parameter $N$ (a) and the maximum velocity $W$ (b and c) for different variants of the vibrational action: 1) flow in the absence of vibrational forces; 2) vibrations aligned with the $x$ axis; 3) vibrations aligned with the $y$ axis.

variation of flow intensity with time can be estimated from Fig. 4b and c, which shows the maximum velocity $W$ in the computational domain. Figure 4a shows the time evolution of the parameter $N$, which characterizes the changes in the concentration field. The value of $N$ is calculated in the mid-section $y = L_y/2$ of the computational domain:

$$N = \int_0^{L_x} c_y \, dx.$$

In the absence of high-frequency vibrations of the field of external forces, the flow dynamics is identical in both problems: initial drastic increase in velocity and subsequent relaxation with simultaneous expansion of the transitional region.

In studying the flow structure arising under the action of rapidly oscillating external force fields together with the volume forces induced by the Korteweg stresses, the basic parameter of the problem is the vibration amplitude $g'$ determining the intensity of the vibrational action. The value of $g'$ in the calculations is varied: $g' = (10^{-4}–10^{-1})g_0$, where $g_0 = 9.8$ m/sec$^2$ is the acceleration of gravity.

**Comparison of Results Obtained for the Full and Averaged Systems of Equations.** Before the calculations, we performed a study to determine the vibration frequency $\Omega$ at which it is possible to use the averaging technique and the solution reaches an asymptotic value. For this purpose, we performed a series of calculations for the non-averaged system (2) with time-dependent vibrations of the variable external force field. The results calculated for the non-averaged system (2) for different values of $\Omega$ obtained for Problem 1 with vibrations of the external force fields directed along the $y$ axis are plotted in Fig. 5. With increasing $\Omega$, we can observe an asymptotic dependence for both the field of concentrations (parameter $S$ in Fig. 5a) and the field of velocity (maximum value of velocity in Fig. 5b). The value of the parameter $\Omega = 600$ at which the asymptotic solution of the non-averaged system (2) is reached corresponds to the vibration frequency $\Omega' = 60$ Hz close to the results measured onboard the spacecraft [10]. Therefore, we used $\Omega = 600$ in all variants of calculations for the averaged system (10).

Figure 6 shows the maximum velocity as a function of time. For the non-averaged system (2), there are periodic oscillations of velocity (curve 1 in Fig. 6). Solving the averaged system (10) yields the slow component of velocity $\boldsymbol{v}$ (curve 3 in Fig. 6). The total velocity $\boldsymbol{v}'$ for the averaged system (curve 2 in Fig. 6) is determined from Eq. (4), where the fast component of velocity $\boldsymbol{v}_f$ is obtained from Eq. (6). The results agree with each other, especially for the lower boundary of oscillations of the solution of the non-averaged system (2) and for the values of slow velocity $\boldsymbol{v}$.

Thus, it is shown that the averaging technique can yield results close to those reached in solving the full system (2). The solution of system (2), however, requires a larger computational time, which is caused by a significant decrease in the integration step in time necessary for exact discretization of the change in the external mass force with a high frequency of its vibrations.

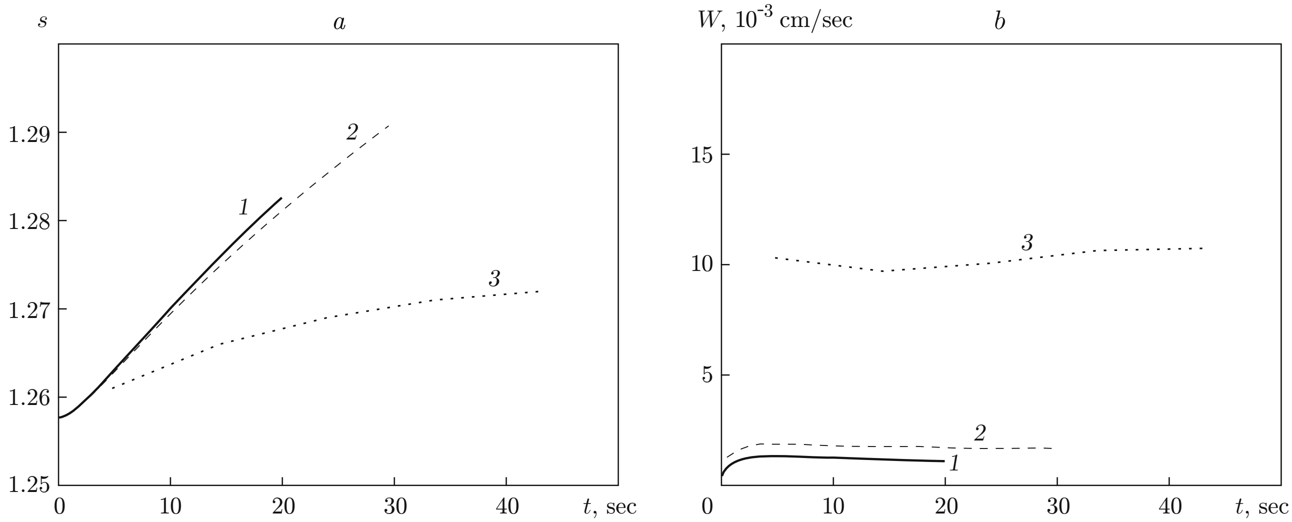


Fig. 5. Time evolution of the parameter $S$ (a) and the maximum velocity $W$ (b) averaged over the vibration period $g'$ for different values of $\Omega$ in the numerical solution of the problem without using the averaging technique: 1) $\Omega = 600$ and $G_v = 4.9 \cdot 10^{-3}$; 2) $\Omega = 60$ and $G_v = 4.9 \cdot 10^{-2}$; 3) $\Omega = 6$ and $G_v = 4.9 \cdot 10^{-1}$.

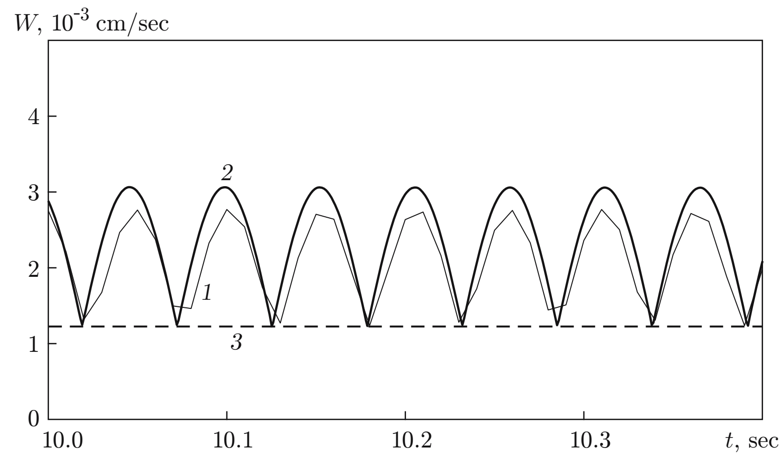


Fig. 6. Time evolution of the maximum velocity: curve 1 is obtained by solving system (2); curve 2 is the total velocity $\boldsymbol{v}' = \boldsymbol{v} + \boldsymbol{v}_f$; curve 3 is the "slow" component of velocity $\boldsymbol{v}$ obtained by solving system (10); $\Omega = 600$ and $G_v = 4.9 \cdot 10^{-2}$ ($g' = 0.015 g_0$).

**Analysis and Discussion of Results.** The vibrational action can (depending on vibration intensity and direction) enhance or attenuate convection. Figure 1c and d shows the results of solving Problem 1 with a vibration amplitude $g' = 0.015 g_0$. It is seen that the flow structure changes under the action of vibrations. If vibration occurs in the $x$ direction ($\varphi = \pi/2$), the action of vibrational forces leads to emergence of additional vortices. The direction of rotation of these vortices located in the center of the drop is opposite to the direction of peripheral vortices induced by the Korteweg stresses, i.e., vibration here is a counter-acting factor. The results are the lower convection, the drop changes its shape slower, and the maximum velocity $W$ becomes lower than that in the absence of vibrations (see Fig. 2).

In contrast to the case described above, vibrations in the $y$ direction ($\varphi = 0$) enhance the convective flow: the maximum velocity $W$ becomes higher, and the drop changes its shape faster (Fig. 2). When the drop acquires a circular shape, its extension along the $y$ axis begins (Fig. 1d). This occurs under the action of vibrational forces only, whereas the volume forces induced by the Korteweg stresses are a factor that constrain this extension.

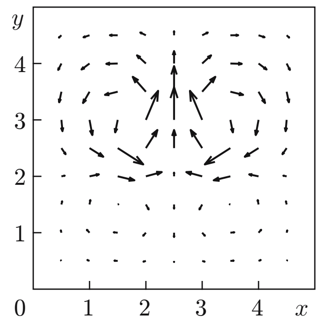


Fig. 7. Field of total velocity for vibrations directed along the $y$ axis for $\Omega = 600$, and $G_v = 4.9 \cdot 10^{-3}$ ($g' = 0.0015 g_0$).

If the vibration amplitude $g'$ increases, the action of convective flows formed by vibrational forces only on the drop becomes dominating.

In Problem 2, as in Problem 1, the effect of vibrations is noticeable on both the qualitative and quantitative level. Figure 3c shows the results calculated for vibrations aligned with the $x$ axis ($\varphi = \pi/2$), which have a vibration amplitude $g' = 0.07 g_0$. Two symmetric vortices appear near the right boundary; the direction of rotation of these vortices is opposite to the direction of the main vortices induced by the action of the Korteweg stresses. Differences in the values of $N$ and the maximum velocity $W$ are also observed; they are most pronounced at $t > 800$ sec (Fig. 4a and c) when the intensity of the main vortices is already attenuated.

If vibrations are directed along the $y$ axis ($\varphi = 0$), a significant deformation of the transitional zone is observed at $t > 750$ sec (Fig. 3d). The flow structure at the initial time consists of two symmetric vortices and is similar to that shown in Fig. 3b. The intensity of the lower vortex gradually increases with time, and then the centers of the vortices are rapidly shifted inward the transitional zone and the maximum velocity $W$ drastically increases (see Fig. 4). Under the action of the dominating vortex, the transitional zone is stratified, which is visible in Fig. 3d and by the changes in the parameter $N$ (Fig 4a). We can assume that such dynamics of the flow structure is caused by the loss of stability associated with the effect of vibrations.

Understanding of the processes in Problem 2 can be improved by analyzing a similar problem with a constant mass force instead of a rapidly varying one. If the vector of this force is perpendicular to mass fluxes, the convective flow arises independent of the force intensity. This configuration corresponds to the above-considered variant where vibrations are directed along the $x$ axis. If the action of buoyancy forces is parallel to the mass fluxes, convection is generated only under certain conditions of the loss of stability of the equilibrium position. Such a loss of stability is observed in problem 2 if vibrations are directed along the $y$ axis.

Comparing the results obtained in solving Problems 1 and 2, we should note that the results presented for Problem 2 were obtained for the vibration amplitude $g' = 0.07 g_0$, which is several times higher than that for Problem 1. The calculations in Problem 2 with lower values of $g'$ show that either vibrations do not affect the flow structure in this case or the effects associated with vibrations are manifested much later. This allows us to conclude that the curvature of the transitional zone is one of the governing parameters in such problems.

Note that the flow structure is analyzed in the present work for averaged velocities and concentrations. The values of the total velocity in numerical simulations can be obtained from Eq. (4) by summing the averaged (slow) and fast components. According to Eq. (6), if the term $f'(\Omega t) = \cos(\Omega t)$ is taken into account, the value of the fast component will periodically change its sign. Thus, the flow structure will oscillate in the field of total velocity. Figure 7 shows the total velocity field for Problem 1 with vibrations directed along the $y$ axis. Comparing the flow structures in Fig. 7 and Fig. 1d, we can see that one pair of vortices (corresponding to the upper pair of vortices in Fig. 1d) dominates at this time in the total velocity field. The pairs of dominating vortices alternate with time (from the upper to the lower pair), and thus the drop becomes extended along the $y$ axis. The fields of total and averaged concentrations are only little different because the factor $1/\Omega$ in Eq. (4) with $\Omega = 600$ is rather small.

It should be noted that it is rather difficult to measure rapidly varying but small quantities in a physical experiment, which refers to velocity fields under microgravity conditions, where the maximum values are only slightly above 10 $\mu$m/sec. Thus, it seems more reasonable to analyze the processes whose measurement and observation are less difficult. In this sense, the averaged velocity and concentration are of great importance for practice, because the effect of vibrations will become pronounced only when significant changes occur in the fields of averaged quantities. Therefore, the present research was aimed at determining the threshold values of vibration amplitude at which it starts dominating over the forces induced by the Korteweg stresses.

**Conclusions.** The influence of high-frequency vibrations on the flow in a miscible fluid is considered by means of numerical simulations for a system of convection equations obtained by an averaging technique. The structure of the flows formed are analyzed, and the intensity of rapidly varying fields of external forces are determined, at which vibrations exert a significant qualitative and quantitative effect on the convective flow. It is shown that the effect of vibrations in physical experiments performed under microgravity conditions in miscible fluids with the above-considered initial distributions of components of the fluid can be reduced by decreasing the amplitude of oscillations of the mass force or by minimizing the curvature of the transitional zone.

The conclusions drawn in the present work can be used for planning physical experiments under microgravity conditions.

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