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INSTABILITY OF MECHANICAL EQUILIBRIUM IN NON-IDEAL GAS MIXTURES

To describe phenomena caused by the spatial heterogeneity of density, as well as the processes of natural gas purification, separation and enrichment of gas mixtures with certain components, it is necessary to take into account not only diffusion processes, but also convective currents that arise in the presence of a concentration gradient. Under certain conditions, in multicomponent gas mixtures, a violation of the stability of mechanical equilibrium is possible, i.e. a transition from a stable diffusion process to a convective one is realized in the systems under consideration. The use of linear stability analysis permits to determine on the plane of partial Rayleigh numbers the boundary of the transition of the diffusion process to convective, as well as the values of the thermophysical and geometric characteristics at which this transition is possible. When using this approach to describe experimental data obtained for gas systems containing components with pronounced non-ideal properties, discrepancies are observed. Therefore, the purpose of this work is to develop a method for determining the boundary of loss of stability of mechanical equilibrium in non-ideal gas mixtures. To achieve this goal, the mathematical model describing the change of regimes uses an equation of state in virial form. Based on the developed approach, stability maps were obtained for the $C_3H_8 + CO_2 - N_2O$ and $C_3H_8 + N_2O - CO_2$ systems. A comparison of the calculation results with experimental data showed that the proposed technique could be used to determine the conditions for changing mixing modes in three-component gas mixtures containing components with real properties.

Key words: diffusion, convection, instability of mechanical equilibrium, stability theory, nonideal gases.

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Идеалды емес газ қоспаларындағы механикалық тең-теңдіктің орнықсыздығы

Тығыздықтың кеңістіктік біркелкі еместігінен туындаған құбылыстарды, сондай-ақ табиғи газды тазарту, газ қоспаларын белгілі бір компоненттермен бөлу және байыту процестерін сипаттау үшін диффузиялық процестерді ғана емес, сонымен қатар концентрация градиенті болған кезде пайда болатын конвективті ағындарды да ескеру қажет. Белгілі бір жағдайларда көпкомпонентті газ қоспаларында механикалық тепе-теңдіктің орнықтылығы бұзылуы мүмкін, яғни қарастырылып отырған жүйелерде тұрақты диффузиялық процестен конвективтіге көшу жүзеге асырылады. Орнықтылыққа сызықтық талдауды қолдану Рэлейдің парциал сандарының жазықтығында диффузиялық процестің конвективтіге өту шекарасын, сондай-ақ осы ауысу мүмкін болатын жылуфизикалық және геометриялық сипаттамалардың мәндерін анықтауға мүмкіндік береді. Құрамында идеалды емес қасиеттерге ие компоненттері бар газ жүйелері үшін алынған тәжірибелік деректерді сипаттау үшін осы тәсілді қолдану кезінде сәйкессіздіктер байқалады. Сондықтан, бұл жұмыстың мақсаты идеалды емес газ қоспаларында механикалық тепе-теңдік орнықтылығының жоғалу шекарасын анықтау әдістемесін жасау болып табылады. Қойылған мақсатқа жету үшін режимдердің өзгеруін сипаттайтын математикалық модельде күй теңдеуі вириалдық түрде қолданылады. Әзірленген тәсілдің негізінде $C_3H_8 + CO_2 - N_2O$ және $C_3H_8 + N_2O - CO_2$ жүйелері үшін орнықтылық карталары алынды. Есептеу нәтижелерін тәжірибелік деректермен салыстыруда ұсынылған әдістемені құрамында нақты қасиеттерге ие компоненттері бар үшкомпонентті газ қоспаларында араласу режимдерін өзгерту шарттарын анықтау үшін қолдануға болатынын көрсетті.

Түйін сөздер: диффузия, конвекция, механикалық тепе-теңдіктің орнықсыздығы, орнықтылық теориясы, идеалды емес газдар.

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Устойчивость механического равновесия в неидеальных газовых смесях

Для описания явлений, обусловленных пространственной неоднородностью плотности, а также процессов очистки природного газа, разделения и обогащения газовых смесей определенными компонентами необходимо учитывать не только диффузионные процессы, но и конвективные течения, возникающие при наличии градиента концентрации. При определенных условиях в многокомпонентных газовых смесях возможно нарушение устойчивости механического равновесия, т.е. в рассматриваемых системах реализуется переход от устойчивого диффузионного процесса к конвективному. Использование линейного анализа на устойчивость позволяет на плоскости парциальных чисел Рэлея определить границу перехода диффузионного процесса на конвективный, а также значения теплофизических и геометрических характеристик, при которых этот переход возможен. При использовании данного подхода для описания экспериментальных данных, полученных для газовых систем, содержащих компоненты с ярко выраженными неидеальными свойствами, наблюдаются расхождения. Поэтому целью данной работы является разработка методики определения границы потери устойчивости механического равновесия в неидеальных газовых смесях. Для достижения поставленной цели в математической модели, описывающей смену режимов, используется уравнение состояния в вириальной форме. На основе разработанного подхода для систем $C_3H_8 + CO_2 - N_2O$ и $C_3H_8 + N_2O - CO_2$ получены карты устойчивости. Сравнение результатов расчета с экспериментальными данными показало, что предложенная методика может быть использована для определения условий смены режимов смешения в трехкомпонентных газовых смесях, содержащих компоненты с реальными свойствами.

Ключевые слова: диффузия, конвекция, неустойчивость механического равновесия, теория устойчивости, неидеальные газы.

Introduction

Solving problems of mass transfer in chemical technology (for example, in the synthesis of ammonia from natural gas, purification of natural gases, separation and enrichment of gas mixtures with certain components), as well as understanding natural phenomena caused by the spatial heterogeneity of density (“salt fingers” in the ocean, the presence of air pockets in the atmosphere, etc.) is associated not only with molecular transport, but also with convective currents that arise during mixing in some multicomponent gas systems.

The mutual influence of components on each other in multicomponent gas mixtures (in particular three-component ones) under certain conditions leads to phenomena that do not occur in ordinary binary diffusion. An example is problems in which molecular diffusion results in the mechanical equilibrium instability of the mixture with the subsequent initiation of natural convection, which noticeably intensifies the total mass transfer [1].

Experiments on studying multicomponent mixing in gases at elevated pressure and the diffusion of a mixture of solution vapors into an inert gas have recorded convective flows leading to a synergistic effect associated with a significant increase in the rate of mixing of the system components. The peculiarity of the observed change in the “diffusion – convection” modes is the fact that it is not realized under traditional conditions corresponding to the thermal problems of Rayleigh-Benard [2-4] and Rayleigh-Taylor [5-7], but occurs with an initial hydrostatically stable stratification, which involves a decrease in the mixture density with height. In this case, the process of diffusion instability depends on a number of conditions and parameters, for example, pressure, concentration, temperature, viscosity, geometric dimensions of the diffusion channel, etc. [1].

Diffusion instability refers to phenomena similar to convection caused by the “double diffusion” [8-10]. To describe this class of phenomena, one can apply linear stability analysis

[11], in which the state of a three-component gas mixture is described by a system of hydrodynamic equations, which includes the Navier-Stokes equation of motion and the conservation equations for the number of mixture particles and components. The indicated system of equations must be supplemented with an equation of medium state in the form $\rho = \rho(c_1, c_2, p)$, $T = \text{const}$. As a result of solving this system of equations for a certain geometry of the diffusion channel and taking into account the corresponding boundary conditions, a boundary relation is obtained for monotonic instability with two critical Rayleigh numbers [12]. In this case, the loss of stability of mechanical equilibrium and the occurrence of diffusion instability is analyzed by the position of the experimental partial Rayleigh numbers relative to the stability lines on the plane of partial Rayleigh numbers (Ra_1 , Ra_2). As a rule, such a comparison shows satisfactory agreement between experimental and theoretical data. However, for mixtures containing components with real properties (for example, CO_2 , N_2O , C_3H_8), discrepancies are observed in the various stages of combined multicomponent mixing. In [13], by experimentally studying the pressure and concentration dependence of the interdiffusion coefficients in the systems $\text{C}_3\text{H}_8 - \text{CO}_2$, $\text{C}_3\text{H}_8 - \text{CH}_4$, it was found that the dependence on pressure differs from traditional kinetic concepts [14]. Similar trends were found for the solubility of CO_2 in aqueous of NaCl [15]. Significant differences were noted in the diffusion coefficient of CO_2 in brines at different NaCl contents compared to Stokes-Einstein predictions [14]. In particular, a significant decrease in the diffusion coefficient was observed at high CO_2 concentrations. It was shown in [16] that as the pressure increases, the density and thermophysical properties of CO_2 change significantly compared to those calculated in the ideal approximation. Other features of combined mixing are reflected in reviews (see, for example, [17, 18]). One of the reasons for the identified inconsistencies is the application of the assumption that gases are ideal.

This paper proposes a technique for solving the problem of stability in isothermal three-component gas mixtures containing components with real properties based on the use of a virial equation of state with one virial coefficient.

Materials and methods

Consider an isothermal three-component gas system $\text{C}_3\text{H}_8 + \text{CO}_2 - \text{N}_2\text{O}$ or $\text{C}_3\text{H}_8 + \text{N}_2\text{O} - \text{CO}_2$, containing components with real properties. The gases under consideration are characterized by the different types of symmetry [19], which affects their

diffusion properties during the mixing process, as well as the change in the density of pure gas depending on pressure [20], which is shown in Figure 1. In accordance with Figure 1, the densities of the gases under study change nonlinear as pressure increases. Up to a pressure of 1.6 MPa, CO_2 is the lightest in the system under consideration. At pressures above 1.6 MPa, CO_2 becomes heavier compared to N_2O . Nitrous oxide has the highest density up to a pressure of 0.65 MPa, and above this pressure the heaviest component is propane. This behavior of the density of the real gases under consideration affects the nature of the occurrence of convective flows.

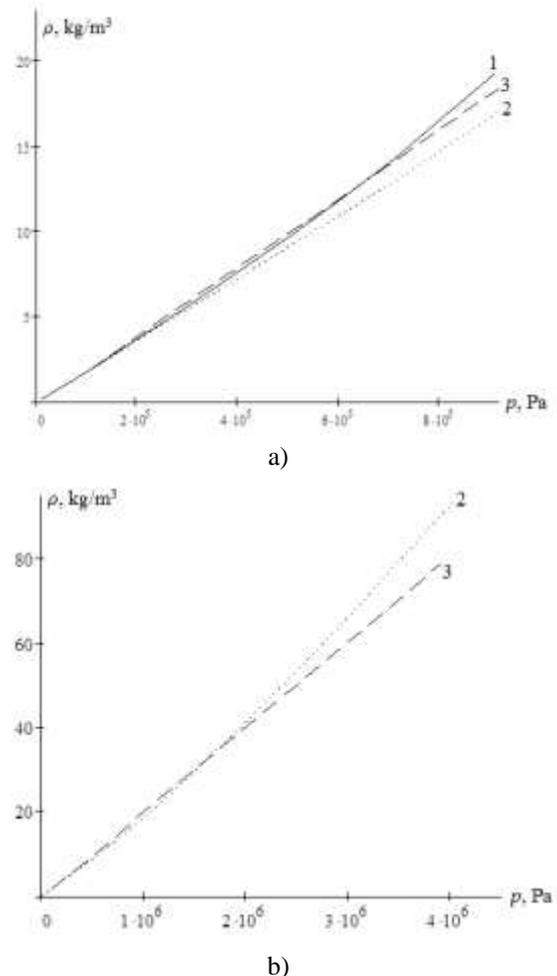


Figure 1 – Dependence of the density of C_3H_8 , CO_2 and N_2O on pressure at $T = 298.0$ K:
1 – C_3H_8 , 2 – CO_2 , 3 – N_2O

To describe the behavior of real gases, we will use the virial equation in powers of volume [21]:

$$\frac{pV}{RT} = 1 + \frac{B_0}{V} + \frac{C_0}{V^2} + \frac{D_0}{V^3} + \dots, \quad (1)$$

where B_0 , C_0 , D_0 are the virial coefficients depending on temperature, p is the pressure, V is the volume, R

is the universal gas constant, T is the temperature.

Equation (1) can be converted in terms of number density to the following form:

$$\frac{p}{nkT} = 1 + Bn + Cn^2 + Dn^3 + \dots, \quad (2)$$

where $B = \frac{B_0}{N_0}$, $C = \frac{C_0}{N_0}$, $D = \frac{D_0}{N_0}$, ..., N_0 is the Avogadro number. When only the first virial coefficient is taken into account, Equation (2) is transformed into the following form:

$$n^2 + \frac{n}{B} - \frac{p}{kTB} = 0. \quad (3)$$

Solving Equation (3), one can obtain:

$$n = \frac{p}{kT} - \frac{p^2 B}{(kT)^2} = n_0 \left(1 - \frac{pB}{kT} \right), \quad (4)$$

where $n_0 = p/kT$.

The component density can be determined using the following formula:

$$\rho = nm_0 = \left(\frac{p}{kT} - \frac{p^2 B}{(kT)^2} \right) m_0, \quad (5)$$

where m_0 is the mass of one molecule.

The density for a three-component mixture is found according to the formula:

$$\rho_{mix} = \left(\frac{p}{RT} - \frac{p^2}{(RT)^2} B_{mix} \right) * \quad (6)$$

$$* [c_1 m_1 + (1 - c_1 - c_3) m_2 + c_3 m_3]$$

where m_i is the molar mass of the i -th component, c_i is the concentration of the i -th component, index 1 corresponds to CO_2 , 2 – N_2O , 3 – C_3H_8 ,

$$B_{mix} = c_1^2 B_1 + (1 - c_1 - c_3)^2 B_2 + c_3^2 B_3 + 2c_1 c_3 B_{13} + 2(1 - c_1 - c_3)(c_1 B_{12} + c_3 B_{23}). \quad (7)$$

The dependence of the interdiffusion coefficient (IDC) of gases on density can be presented in the following form:

$$D_{ij} = D_{ij}^0 \frac{\rho^0}{\rho}, \quad (8)$$

where D_{ij}^0 is the interdiffusion coefficient under normal conditions, ρ^0 and ρ is the density of the mixture under normal conditions and experimental pressure, respectively. Taking into account formula (6), the expression for the IDC subject to the real

properties of the components is written in the following form:

$$D_{ij} = D_{ij}^0 \frac{p}{p_0} \left(\frac{T}{T_0} \right)^{3/2} \frac{1}{1 - \frac{B_{mix}}{RT}}, \quad (9)$$

where p , p_0 , p , T are the pressure and temperature under normal and experimental conditions.

The mathematical description of the occurrence of convection is based on the analysis of a system of equations of continuum mechanics for multicomponent systems with respect to small perturbations [4]. The macroscopic motion of the isothermal ternary gas mixture is described by the general system of hydrodynamic equations, which includes the Navier-Stokes equation, the conservation equations of the number of mixture particles and components.

Taking into account the condition of independent diffusion, in which for the isothermal gas mixture $\sum_{i=1}^3 \vec{j}_i = 0$; $\sum_{i=1}^3 c_i = 1$, this system of equations has the following form [11, 12]:

$$\rho \left[\frac{\partial \vec{u}}{\partial t} + (\vec{u} \nabla \vec{u}) \right] =$$

$$= -\nabla p + \eta \nabla^2 \vec{u} + \left(\frac{\eta}{3} + \zeta \right) \nabla \text{div} \vec{u} + \rho \vec{g},$$

$$\frac{\partial n}{\partial t} + \text{div}(n \vec{v}) = 0,$$

$$\frac{\partial c_i}{\partial t} + \vec{v} \nabla c_i = -\text{div} \vec{j}_i, \quad (10)$$

$$\vec{j}_1 = -(D_{11}^* \nabla c_1 + D_{12}^* \nabla c_2),$$

$$\vec{j}_2 = -(D_{21}^* \nabla c_1 + D_{22}^* \nabla c_2).$$

Here \vec{u} is the vector of weight-average velocity; \vec{v} is the vector of number-average velocity; ρ is the density; p is the pressure; η and ζ are the shear and bulk viscosity coefficients; \vec{g} is the free fall acceleration vector; n is the number density; t is the time; c_i is the concentration of the i -th component; \vec{j}_i is the vector of the diffusion flux density of the i -th component; D_{ij}^* are the practical diffusion coefficients, which are determined through the interdiffusion coefficients (IDC):

$$\begin{aligned}
 D_{11}^* &= \frac{D_{13} [c_1 D_{32} + (c_2 + c_3) D_{12}]}{D}, \\
 D_{12}^* &= -\frac{c_1 D_{23} (D_{12} - D_{13})}{D}, \\
 D_{22}^* &= \frac{D_{23} [c_2 D_{13} + (c_1 + c_3) D_{12}]}{D}, \\
 D_{21}^* &= -\frac{c_2 D_{13} (D_{12} - D_{23})}{D}, \\
 D &= c_1 D_{23} + c_2 D_{13} + c_3 D_{12}.
 \end{aligned}$$

Equations (10) are supplemented with the equation of medium state:

$$\rho = \rho(c_1, c_2, p), \quad T = \text{const.}$$

When solving the system of Equations (10), the method of small perturbation was used [4], which assumed the concentration of the i -th component c_i and the pressure p to be represented as follows:

$$c_i = \langle c_i \rangle + c_i', \quad p = \langle p \rangle + p',$$

where $\langle c_i \rangle$, $\langle p \rangle$ are the constant average values taken as a reference point.

Considering that for $L \gg r$ (L and r are the length and radius of the diffusion channel, respectively), the differences between the perturbations of the number-average and weight-average velocities in the Navier-Stokes equation will be insignificant [12], and also assuming that the non-stationary disturbances of mechanical equilibrium are small, neglecting quadratic members in terms of the perturbations, and choosing the appropriate scales of measurement units (the distance is d , the time is d^2/ν , the velocity is D_{22}^*/d , the concentration of the i -th component is $A_i d$, the pressure is $\rho_0 \nu D_{22}^*/d^2$), one can obtain a system of equations of gravitational concentration convection for the perturbed values in dimensionless quantities (primes are omitted):

$$\begin{aligned}
 \text{Pr}_{22} \frac{\partial c_1}{\partial t} - (\vec{u} \vec{e}_z) &= \tau_{11} \nabla^2 c_1 + \frac{A_2}{A_1} \tau_{12} \nabla^2 c_2, \\
 \text{Pr}_{22} \frac{\partial c_2}{\partial t} - (\vec{u} \vec{e}_z) &= \frac{A_1}{A_2} \tau_{21} \nabla^2 c_1 + \nabla^2 c_2, \\
 \frac{\partial \vec{u}}{\partial t} &= -\nabla p + \nabla^2 \vec{u} + (\text{Ra}_1 \tau_{11} c_1 + \text{Ra}_2 c_2) \vec{e}_z, \\
 \text{div} \vec{u} &= 0,
 \end{aligned} \quad (11)$$

where \vec{e}_z is the unit vector in the z -axis direction; $\text{Pr}_{ii} = \nu/D_{ii}^*$ is the diffusion Prandtl number; $\text{Ra}_i = g \beta_i A_i d^4 / \nu D_{ii}^*$ is the partial Rayleigh number; $\tau_{ij} = D_{ij}^*/D_{22}^*$ are the parameters determining the relationship between the practical diffusion coefficients; $\beta_i = -\frac{1}{\rho_0} \left(\frac{\partial \rho}{\partial c_i} \right)_{p,T}$; $A_i \vec{e}_z = -\nabla c_{i0}$ (subscript 0 refers to the average values).

Solving the system of Equations (11) for a flat channel with mass-impermeable walls made it possible to obtain, in terms of Rayleigh numbers, a boundary relation that determines the change in the "diffusion – convection" modes in the form [12]:

$$\begin{aligned}
 \tau_{11} \left(1 - \frac{A_2}{A_1} \tau_{12} \right) \text{Ra}_1 + \left(\tau_{11} - \frac{A_1}{A_2} \tau_{21} \right) \text{Ra}_2 &= \\
 = \gamma^4 (\tau_{11} - \tau_{12} \tau_{21}), & \quad (12)
 \end{aligned}$$

where $\gamma = \text{Ra}^{1/4}$, i.e. $\gamma = (\text{Ra}_1 \tau_{11} K_1 + \text{Ra}_2 K_2)^{1/4}$;

$$K_1 = \frac{\left(1 - \frac{A_2}{A_1} \tau_{12} \right)}{(\tau_{11} - \tau_{12} \tau_{21})}, \quad K_2 = \frac{\left(\tau_{11} - \frac{A_1}{A_2} \tau_{21} \right)}{(\tau_{11} - \tau_{12} \tau_{21})};$$

A_i is the partial concentration gradient of the i -th component.

In accordance with Equation (11), the partial Rayleigh numbers for the flat channel with mass-impermeable walls can be determined as follows:

$$\begin{aligned}
 \text{Ra}_1 &= \frac{g a^3 b}{\nu D_{11}^*} \frac{1}{\rho} \left(\frac{\partial \rho}{\partial c_1} \right) \left(\frac{\partial c_1}{\partial z} \right), \\
 \text{Ra}_2 &= \frac{g a^3 b}{\nu D_{22}^*} \frac{1}{\rho} \left(\frac{\partial \rho}{\partial c_2} \right) \left(\frac{\partial c_2}{\partial z} \right). \quad (13)
 \end{aligned}$$

where a and b are the thickness and width of the diffusion channel.

For the case under consideration, the partial concentration gradient of the i -th component can be represented as $A_i = -\frac{\partial c_i}{\partial z}$. Then the ratio A_1/A_2 , taking into account Formulas (13), is determined as follows:

$$\frac{A_1}{A_2} = \frac{\text{Ra}_1 \tau_{11} \partial \rho / \partial c_2}{\text{Ra}_2 \partial \rho / \partial c_1}. \quad (14)$$

After substituting Equation (14) into (12), one can obtain:

$$\begin{aligned} & \text{Ra}_1 \left(1 - \tau_{21} \frac{\partial \rho / \partial c_2}{\partial \rho / \partial c_1} \right) + \\ & + \text{Ra}_2 \left(1 - \frac{\tau_{12}}{\tau_{11}} \frac{\partial \rho / \partial c_1}{\partial \rho / \partial c_2} \right) =, \quad (15) \\ & = \gamma^4 \left(1 - \frac{\tau_{12} \tau_{21}}{\tau_{11}} \right) \end{aligned}$$

The mixture density, taking into account equations (4), (6) and (7), can be represented as:

$$\begin{aligned} \rho = n_0 \left[1 - n_0 \left(\begin{aligned} & c_1^2 B_1 + c_2^2 B_2 + c_3^2 B_3 + \\ & + 2c_1 c_2 B_{12} + 2c_1 c_3 B_{13} + \\ & + 2c_2 c_3 B_{23} \end{aligned} \right) \right]^* \quad (16) \\ * (c_1 \Delta m_1 + c_2 \Delta m_2 + m_3) \end{aligned}$$

where $\Delta m_1 = m_1 - m_3$, $\Delta m_2 = m_2 - m_3$. Since the gases under consideration have almost equal molecular masses, we assume that $\Delta m_1 = \Delta m_2 = 0$.

Differentiating expression (16) with respect to c_1 and c_2 and taking into account that $c_3 = 1 - c_1 - c_2$, one can obtain:

$$\begin{aligned} \frac{\partial \rho}{\partial c_1} &= n_0^2 m_3 (B_3 - B_1), \\ \frac{\partial \rho}{\partial c_2} &= n_0^2 m_3 (B_3 - B_2). \quad (17) \end{aligned}$$

Substituting Equations (17) into (15), one can obtain the following expression for the stability line:

$$\begin{aligned} & \text{Ra}_1 \left(1 - \tau_{21} \frac{B_3 - B_2}{B_3 - B_1} \right) + \\ & + \text{Ra}_2 \left(1 - \frac{\tau_{12}}{\tau_{11}} \frac{B_3 - B_2}{B_3 - B_1} \right) =, \quad (18) \\ & = \gamma^4 \left(1 - \frac{\tau_{12} \tau_{21}}{\tau_{11}} \right) \end{aligned}$$

The second virial coefficients depend on pressure, therefore, in contrast to the consideration of the stability problem for ideal gases, the position of the stability line (18) will also depend on pressure.

Results and discussion

Figure 2 shows the stability map at $p = 0.28$ MPa for the system $0.804 \text{ CO}_2 + 0.196 \text{ C}_3\text{H}_8 - \text{N}_2\text{O}$, experimentally studied in [22]. The *MM* line corresponds to the first perturbation mode $n = 1$, and the M_1M_1 line was obtained for the $n = 3$ mode, which characterizes a change in the type of convective flow. The region lying below the *MM* line corresponds to diffusion I, and the area above this line refers to convection II with the different types of motion. In the area between the *MM* and M_1M_1 lines, a current-countercurrent movement is observed, and above the M_1M_1 line there are two currents and two countercurrents.

In Figure 2, the sign “x” marks the point corresponding to a pressure of 0.28 MPa, at which, as experimental studies have shown, a violation of the stability of mechanical equilibrium is observed in the system under consideration and subsequently a convective process is realized in the system. According to experimental data, at a pressure of 1.20 MPa, the maximum intensity of the convective process is observed in the system under consideration. In Figure 2, point 8, corresponding to this pressure, lies near the line M_1M_1 . Thus, the calculation results for the system $0.804 \text{ CO}_2 + 0.196 \text{ C}_3\text{H}_8 - \text{N}_2\text{O}$ are consistent with the experimental data given in [22].

Figure 3 shows the calculation results for the system $0.812 \text{ N}_2\text{O} + 0.188 \text{ C}_3\text{H}_8 - \text{CO}_2$. The stability lines shown in Figure 3 were obtained at a pressure $p = 0.3$ MPa. According to Figure 3, the points displaying experimental data for the system $0.812 \text{ N}_2\text{O} + 0.188 \text{ C}_3\text{H}_8 - \text{CO}_2$ are located in the first quadrant of the stability map. This indicates that the density of the mixture $0.812 \text{ N}_2\text{O} + 0.188 \text{ C}_3\text{H}_8$ is greater than the density of the pure CO_2 component. Point 5, corresponding to a pressure $p = 0.8$ MPa, lies near the M_1M_1 line, which corresponds, as experimental studies have shown [23], to maximum mass transfer.

Comparison of the calculation results shown in Figures 2 and 3 indicates that when nitrous oxide is located at the top, a change in the type of convective flow occurs at a lower pressure than when a mixture of propane and carbon dioxide is located at the top.

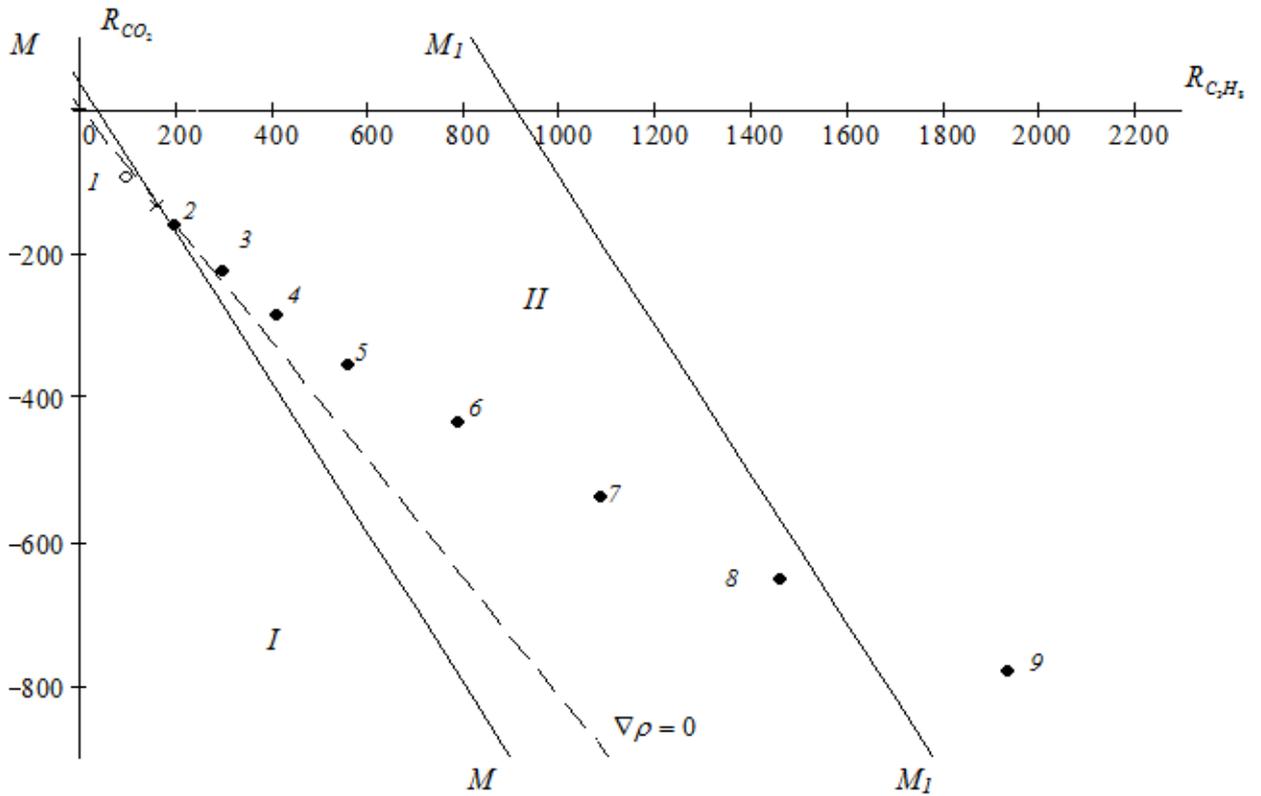


Figure 2 – Regions of diffusion I and convective mixing II for the system $0.804 \text{ CO}_2 + 0.196 \text{ C}_3\text{H}_8 - \text{N}_2\text{O}$.
 The points correspond to the following pressure values:
 1 – 0.23; 2 – 0.30; 3 – 0.40; 4 – 0.50; 5 – 0.60; 6 – 0.80; 7 – 1.00; 8 – 1.20; 9 – 1.40 MPa

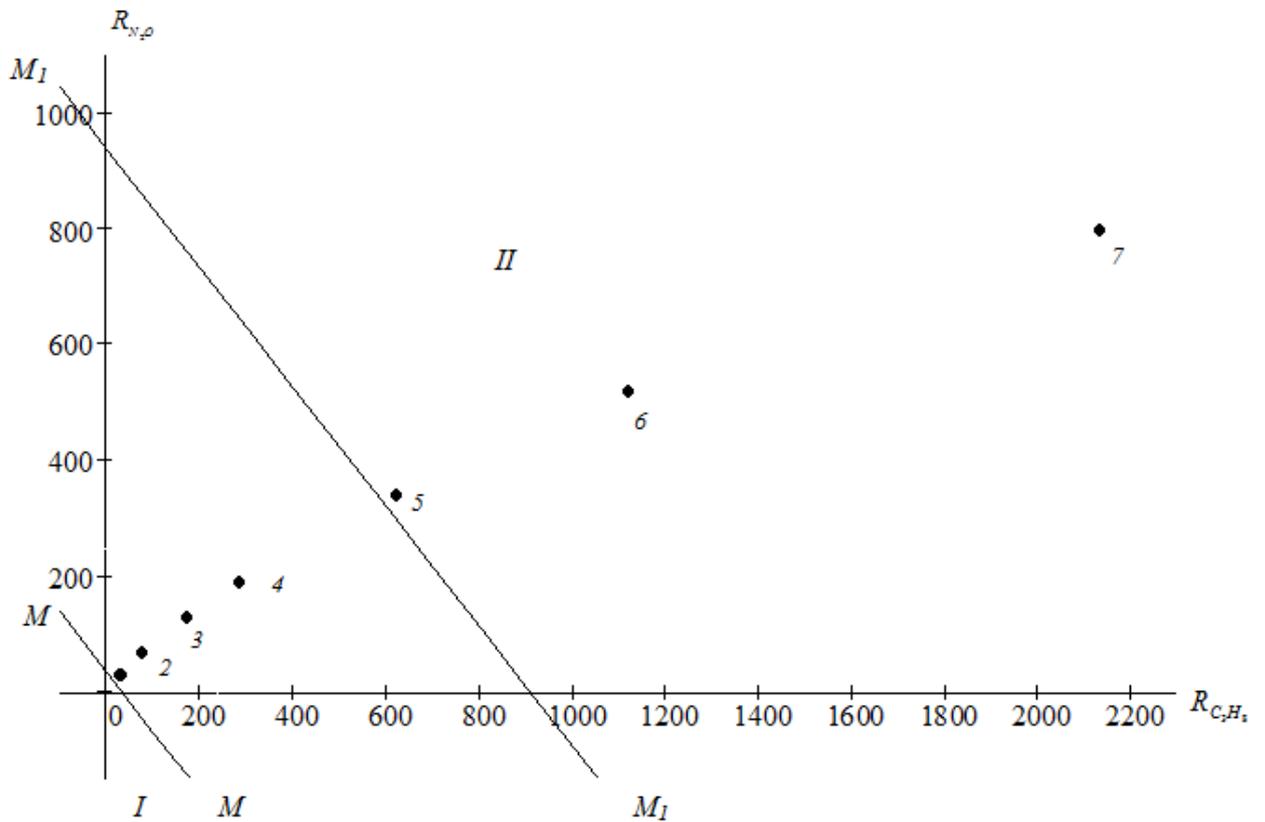


Figure 3 – Areas of diffusion I and convective mixing II for the system $0.812 \text{ N}_2\text{O} + 0.188 \text{ C}_3\text{H}_8 - \text{CO}_2$.
 The points correspond to the following pressure values:
 1 – 0.30; 2 – 0.40; 3 – 0.50; 4 – 0.60; 5 – 0.80; 6 – 1.00; 7 – 1.50 MPa

Conclusion

The stability of mechanical equilibrium in isothermal three-component gas mixtures containing components with real properties is studied numerically. It is shown that to determine the areas of stable diffusion and convection, as well as the conditions under which the stability of mechanical equilibrium is violated when non-ideal gases are mixed, it is possible to use the equation of state in virial form with one virial coefficient in the mathematical model that describes the occurrence of convection. For the flat diffusion channel with mass-impermeable walls, a method for determining the

position of the stability line has been developed. Analysis of the obtained stability maps and their correlation with experimental data shows that the proposed technique can be used to study changes in the nature of convective flows when mixing nonideal gases.

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