

Nonlinear mass transfer and hydrodynamic stability in solubility phenomena*

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Abstract: The dissolution of gases, liquids, or solids in liquids is a heterogeneous reaction, and in many cases, the reaction rate is limited by a diffusive transfer of substance in the boundary layer at the face interphase. In modern industry, intensive interphase mass transfer processes are accomplished by large concentration gradients. This can result in a set of nonlinear effects and the difference between experimental data and predictions of the linear mass transfer theory. One of the main nonlinear effects is a result of the induction of a secondary flow at the interface boundary. This can lead to essential changes of the dissolution rate and the hydrodynamic stability of the system.

INTRODUCTION

A number of ecological problems, related to gas or liquid purification from harmful admixtures and to the development of wasteless technologies, can be solved with the help of the interphase mass transfer. These mass transfer processes are absorption (gas–liquid), extraction (liquid–liquid), dissolution (crystallization), and adsorption (gas/liquid–solid).

A theoretical analysis of nonlinear mass transfer has been developed in ref. [1]. The main idea follows from the nonlinearity of the convection-diffusion equation:

$$\rho(c)\mathbf{W}(c) \mathbf{grad} c = \text{div}[\rho(c)D(c) \mathbf{grad} c] + kc^n. \quad (1)$$

The velocity \mathbf{W} is governed by the hydrodynamic equations. However, the principal nonlinear phenomenon is due to the concentration effects on the velocity $\mathbf{W}(c)$, density $\rho(c)$, viscosity $\mu(c)$, diffusivity $D(c)$ and on the chemical reaction rate kc^n (for $n \neq 1$).

There are a number of processes where u_j , v_j , μ_j , ρ_j , D_j , A_j , and B_j are independent of the concentration c_j ($j = 1, 2$). These situations are the basis of the linear mass transfer theory.

The mathematical model allows the following principle characteristics of the linear mass transfer to be drawn:

- the mass interphase transfer rate J does not depend on the mass transfer direction;
- the mass interphase transfer coefficient K_j does not depend on the concentrations c_{j0} ($j = 1, 2$).

The attempt to decrease the size of the industrial devices necessitates process intensification. The systems with intensive mass transfer are characterized by a behavior that deviates considerably from the characteristics mentioned above. The main feature is a higher mass transfer rate, which differs significantly from the value predicted by the linear mass transfer theory. The nonlinear effects leading to the above have been described [1].

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In systems with high concentrations and large concentration gradients, the deviations from the linear Fick's diffusion law are also significant. Under such conditions, the higher concentrations can affect both the viscosity and the density of the fluid:

$$D_j = D_j(c_j), \mu_j = \mu_j(c_j), \rho_j = \rho_j(c_j), j = 1, 2. \quad (2)$$

The concentration effect introduces a nonlinearity in the convection-diffusion equation discussed in details in refs. [2,3].

The other nonlinear effect due to the nonuniform concentration distributions,

$$A_j = g(\rho_j - \rho_{0j}), \rho_j = \rho_j(c_j) \quad (3)$$

leads to natural convection [4,5].

The next cause that may intensify the mass transfer process is the existence of a chemical reaction with a rate B_j in the bulk of the phase:

$$B_j = B_j(c_j), j = 1, 2. \quad (4)$$

The studies developed in refs. [1,6], show that in gas-liquid systems with a chemical reaction $B_1 = 0$, while $B_2 = kc^n$. Moreover, the chemical reaction rate could significantly affect the interphase mass transfer mechanism between the phases.

The thermal effect of the chemical reactions could lead to temperature nonuniformity on the interface and consequently to surface tension gradients. This calls for new boundary conditions, taking into account the equality of the tangential components of the stress tensor on the interface:

$$y + 0, \mu_1 \frac{\partial u_1}{\partial y} = \mu_2 \frac{\partial u_2}{\partial y} - \frac{\partial \sigma}{\partial x} \quad (5)$$

Investigation of this effect (Marangoni effect) [7,8] has shown that it is negligible when there are no surfactants in the system.

One of the most interesting nonlinear effects arises from the conditions imposed by high-concentration gradients, which induce secondary flows at the interface. The velocity of these flows is directed normally toward the interface:

$$v^* = -\frac{MD}{\rho_0^*} \left(\frac{\partial c}{\partial y} \right)_{y=0}. \quad (6)$$

This effect has been discussed in details in ref. [1] for a large number of systems taken as examples, and it has been termed "nonlinear mass transfer effect".

All the nonlinear effects influence the velocity fields, which leads to changes in the hydrodynamic stability of the system. The loss of stability could cause an increase of the amplitudes of the random disturbances until a new stable state or a stable periodic process is reached [1]. The latter is a self-organizing dissipative structure with a mass transfer rate growing sharply, which is not the case in the conventional systems. The problem has been discussed in detail in refs. [4,5] in the case of nonstationary absorption of pure gases in immobile liquid layer with flat interface. The velocity of these flows is directed normally to the interface.

NONLINEAR MASS TRANSFER IN THE BOUNDARY LAYER

The kinetics of the nonlinear mass transfer in the approximations of the boundary layer [9-12] will be discussed on the basis of the solution of the equations of hydrodynamics and convection-diffusion, with boundary conditions that take into consideration the influence of the mass transfer on the hydrodynamics. In a rectangular coordinate system, where $y = 0$ corresponds to the interphase surface gas (liquid)-solid, the mathematical description of the nonlinear mass transfer has the form:

$$\begin{aligned}
 u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} &= v \frac{\partial^2 u}{\partial y^2}, & \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} &= 0, & u \frac{\partial c}{\partial x} + v \frac{\partial c}{\partial y} &= D \frac{\partial^2 c}{\partial y^2}; \\
 x = 0, & \quad u = u_0, \quad c = c_0; & y \rightarrow \infty, & \quad u = u_0, \quad c = c_0; \\
 y = 0, & \quad u = 0, \quad v = -\frac{MD}{\rho_0^*} \frac{\partial c}{\partial y}, & c &= c^*;
 \end{aligned}
 \tag{7}$$

where a potential flow, with a velocity u_0 along a plate, and a concentration (c_0) of the transferred substance are assumed. As a result of the rapid establishment of thermodynamic equilibrium, the concentration c^* is constant on the solid surface. The normal component of the velocity at the interphase is determined from eq. 6, as a consequence of intensive interphase mass transfer.

The mass transfer rate for a plate of length L could be determined from the average mass flux:

$$J = Mk(c^* - c_0) = \frac{1}{L} \int_0^L I dx,
 \tag{8}$$

where k is the mass transfer coefficient and I can be expressed from as follows:

$$I = -\frac{MD\rho_0^*}{\rho_0^*} \left(\frac{\partial c}{\partial y} \right)_{y=0}.
 \tag{9}$$

In order to solve the system of eqs. 7, it is necessary to introduce the similarity variables:

$$u = 0.5u_0\varepsilon\phi', \quad v = 0.5\left(\frac{u_0v}{x}\right)^{0.5}(\eta\phi' - \phi), \quad c = c_0 + (c^* - c_0)\psi, \quad y = \eta\left(\frac{u_0}{4Dx}\right)^{-0.5},
 \tag{10}$$

where

$$\varepsilon = Sc^{0.5}, \quad Sc = v/D, \quad \phi = \phi(\eta), \quad \psi = \psi(\eta).
 \tag{11}$$

As a result of these substitutions, eq. 7 takes the following form:

$$\begin{aligned}
 \phi''' + \varepsilon^{-1}\phi\phi'' &= 0, & \psi'' + \varepsilon\phi\psi' &= 0, \\
 \phi(0) = \theta\psi'(0), & \quad \phi'(0) = 0, & \phi'(\infty) = 2\varepsilon^{-1}, & \quad \psi(0) = 1, \quad \psi(\infty) = 0,
 \end{aligned}
 \tag{12}$$

where

$$\theta = \frac{M(c^* - c_0)}{\varepsilon\rho_0^*}.
 \tag{13}$$

θ is a small parameter that reflects the effect of the nonlinear mass transfer. In the linear theory of the diffusion boundary layer, $\theta = 0$.

Considering the new variables and eq. 8, one obtains:

$$Sh = \frac{kL}{D} = -\frac{\rho_0^*}{\rho_0^*} Pe^{0.5}\psi'(0), \quad Pe = \frac{u_0L}{D}.
 \tag{14}$$

It is seen from eq. 14, that mass transfer kinetics is determined by the dimensionless diffusion flux $\psi'(0)$, which can be obtained by solving eq. 12. The solution has been found utilizing a perturbation method after presenting ϕ and ψ as a power series of the small parameter θ [13]:

$$\phi = \phi_0 + \theta\phi_1 + \theta^2\phi_2 + \dots, \quad \psi = \psi_0 + \theta\psi_1 + \theta^2\psi_2 + \dots
 \tag{15}$$

The dimensionless diffusion flux, expressed by the Sherwood number (eq. 14) is obtained directly from eqs. 12 and 16:

$$\psi'(0) = -\frac{2}{\varepsilon \varphi_0} + \theta \frac{2\varphi_3}{\varphi_0^3} + \theta^2 \left(-\frac{4\varepsilon \varphi_3^2}{\varphi_0^5} + \frac{\varepsilon \varphi_{33}}{\varphi_0^4} + \frac{4\bar{\varphi}_{33}}{\varepsilon \varphi_0^4} \right). \quad (16)$$

In Table 1, results of the asymptotic theory $\psi'(0)$ are compared with the results of the numerical experiment $\psi'_N(0)$.

Table 1 Comparison of the results of the asymptotic theory $\psi'(0)$ with the results of the numerical experiment.

θ	$\varepsilon = 1$		$\varepsilon = 2$		$\varepsilon = 10$		$\varepsilon = 20$	
	$-\psi'_N(0)$	$-\psi'(0)$	$-\psi'_N(0)$	$-\psi'(0)$	$-\psi'_N(0)$	$-\psi'(0)$	$-\psi'_N(0)$	$-\psi'(0)$
0.00	0.664	0.664	0.535	0.535	0.314	0.305	0.250	0.246
+0.03	0.650	0.650	0.515	0.516	0.270	0.265	0.190	0.199
-0.03	0.679	0.679	0.553	0.555	0.384	0.365	0.406	0.363
+0.05	0.641	0.641	0.503	0.504	0.248	0.250	0.166	0.205
-0.05	0.689	0.689	0.572	0.570	0.459	0.415	–	0.479
+0.10	0.620	0.620	0.475	0.478	0.207	0.250	–	0.355
-0.10	0.716	0.7162	0.616	0.611	–	0.581	–	0.903
+0.20	0.581	0.584	0.429	0.442	0.160	0.418	–	1.229
-0.20	0.779	0.776	0.736	0.707	–	1.080	–	2.325
+0.30	0.548	0.555	0.393	0.425	–	0.808	–	2.868
-0.30	0.855	0.843	0.936	0.822	–	1.800	–	4.512

The results show that the direction of the intensive mass transfer significantly influences the mass transfer kinetics, and this cannot be predicted in the approximations of the linear theory ($\theta = 0$). When the mass transfer is directed from the volume toward the phase boundary ($\theta < 0$), the increasing of the concentration gradient in the diffusion boundary layer ($c^* - c_0$) leads to an increase in diffusion mass transfer. When the mass transfer is directed from the phase boundary towards the volume ($\theta > 0$), the increasing of the concentration gradient leads to a decrease in the diffusion mass transfer.

NONLINEAR MASS TRANSFER IN GAS AND LIQUID BOUNDARY LAYER

Industrial gas absorption is most frequently accomplished in packed-bed columns. Since the size of packings used is small, the interphase transfer of the absorbed material is affected through the thin layers bordering the phase boundary between the gas and the liquid. The main change in the absorbed material concentration takes place in these layers, which allows the theoretical analysis of the kinetics of nonlinear interphase mass transfer to be performed, making use of the approximation of the diffusion boundary layer.

In the cases where the rate of the interphase mass transfer is limited by the diffusion resistance in the gas phase, the Sherwood number can be expressed [14–16] in the form:

$$Sh_1 = \frac{\rho_1^*}{\rho_{10}^*} Pe_1^{0.5} \left(\frac{2}{\varepsilon_1 \varphi_{10}} + \frac{2\theta_1}{\varepsilon_1 \alpha \varphi_{10}^2} + 2\theta_3 \frac{\varphi_{13}}{\varphi_{10}^3} \right). \quad (17)$$

When the process is limited by the diffusion resistance in the liquid phase

$$Sh_2 = \frac{\rho_2^*}{\rho_{20}^*} Pe_2^{0.5} \left(\frac{2}{\sqrt{\pi}} + 8\theta_2 \frac{\alpha \varepsilon_2 \bar{\varphi}_2}{\sqrt{\pi}} - 8\theta_4 \frac{\varepsilon_2}{\pi \sqrt{\pi}} \right). \quad (18)$$

CONCENTRATION EFFECTS

The theoretical analysis of the influence of the diffused substance concentration on the density, viscosity, and diffusivity shows that in a number of cases, these effects can be considered small [17] (first-order approximation):

$$\rho = \rho_0(1 + \bar{\rho}C), \quad \mu = \mu_0(1 + \bar{\mu}C), \quad D = D_0(1 + \bar{D}C), \quad C = \frac{c - c_0}{c^* - c_0}, \quad (19)$$

where $\bar{\rho}$, $\bar{\mu}$, and \bar{D} are small parameters defined from the experimental data for the dependence of ρ , μ , and D from c .

The mass transfer rate in gases can be determined from

$$Sh = \frac{kL}{D_0} = -2 \frac{\rho^*}{\rho_0} Pe^{1/2} F'(0), \quad Pe = \frac{u_0 L}{D_0} \quad (20)$$

where $F'(0)$ is shown on Fig. 1.

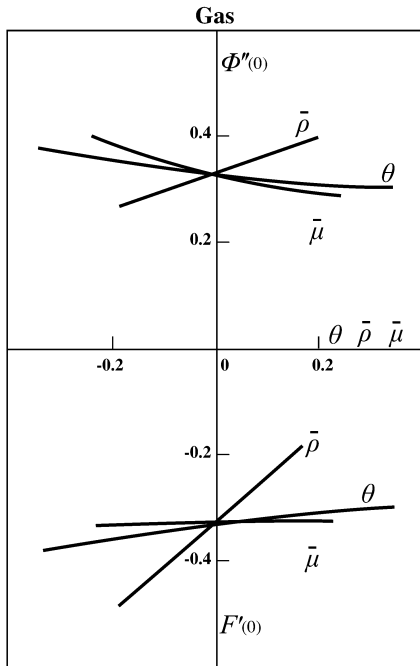


Fig. 1 Influence of high concentrations through the viscosity ($\bar{\mu}$), density ($\bar{\rho}$), and large concentration gradients (θ) on the hydrodynamics [$\phi''(0)$] and the mass transfer [$F'(0)$] in gases.

The mass transfer rate in liquids can be determined from

$$Sh = -2 \frac{\rho^*}{\rho_0} (1 + \bar{D}) Pe^{1/2} F'_2(0) \quad (21)$$

where $F'_2(0)$ is shown on Fig. 2.

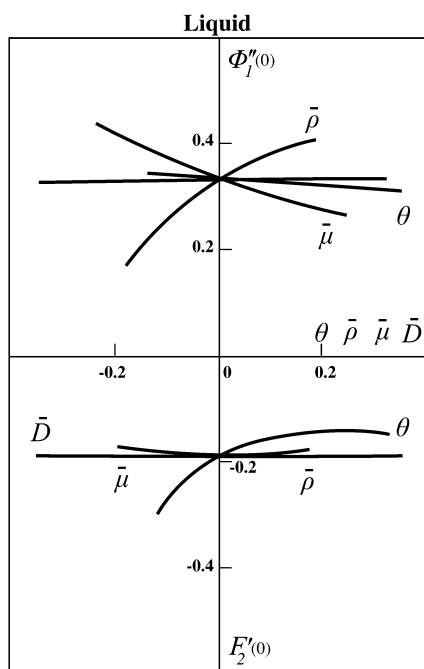


Fig. 2 Influence of high concentrations through the viscosity ($\bar{\mu}$), density ($\bar{\rho}$) and large concentration gradients (θ) on the hydrodynamics [$\phi_I''(0)$] and the mass transfer [$F_2'(0)$] in liquids.

NONLINEAR MASS TRANSFER AND THE MARANGONI EFFECT

Intensification of the mass transfer in industrial gas–liquid systems is obtained quite often by creation of large-concentration gradients. This can be reached in a number of cases as a result of a chemical reaction of the transferred substance in the liquid phase. The thermal effect of the chemical reactions creates high-temperature gradients. The temperature and concentration gradients created can affect considerably the mass transfer kinetics in gas–liquid systems. Hence, the experimentally obtained mass transfer coefficients differ significantly from those predicted by the linear theory of mass transfer.

As shown in a number of papers [1], the temperature and concentration gradients on the gas–liquid or liquid–liquid interphase surface can create an interfacial tension gradient. As a result, a secondary flow is induced. The velocity of the induced flow is directed tangentially to the interface. It leads to a change in the velocity distribution in the boundary layer and, therefore, to a change in the mass transfer kinetics. These effects are thought to be of the Marangoni type and provide an explanation for all experimental deviations from the prediction of the linear theory of the mass transfer, where the hydrodynamics of the flow does not depend on the mass transfer.

The studies of gas–liquid and liquid–liquid systems with intensive interphase mass transfer as a result of large-concentration gradients show [1] that under these conditions the induced secondary flow is directed normally to the interface. It leads to “injection” or “suction” of a substance in the boundary layer, therefore to a change in the velocity distribution in the layer and the in-mass transfer kinetics. This effect of nonlinear mass transfer can explain a number of experimental deviations from the linear theory of mass transfer that have been explained with the Marangoni effect.

The above-mentioned two effects (the Marangoni effect and the effect of the nonlinear mass transfer) can manifest themselves separately as well as in combination. That is why their influence on the mass transfer kinetics has to be assessed.

The comparative analysis of the nonlinear mass transfer effect and the Marangoni effect in gas–liquid and liquid–liquid systems show, that the Marangoni effect does not affect the heat and mass transfer kinetics, because in real systems this effect is very small.

LINEAR STABILITY ANALYSIS IN GAS (LIQUID)–SOLID SYSTEMS

Theoretical studies [18] of the influence of the suction (injection) from (to) the boundary layer on the hydrodynamics and hydrodynamic stability have been carried out in cases where the normal component of the velocity on the phase boundary is constant along the interface. In cases of nonlinear mass transfer, the rate of the suction (injection) effects on the local diffusion flux and changes from ∞ to 0 when x changes from 0 to ∞ . The latter leads to a significant change in the flow stability. The linear stability analysis considers a nonstationary flow (U, V, P, C), obtained as a combination of a basic stationary flow (u, v, c) and two-dimensional periodic disturbances (u_1, v_1, p_1, c_1) with small amplitudes ($\omega \ll 1$):

$$\begin{aligned} U(x, y, t) &= u(x, y) + \omega u_1(x, y, t), \quad V(x, y, t) = v(x, y) + \omega v_1(x, y, t), \\ P(x, y, t) &= \omega p_1(x, y, t), \quad C(x, y, t) = c(x, y) + \omega c_1(x, y, t). \end{aligned} \quad (22)$$

The nonstationary flow thus obtained satisfies the full system of Navier–Stokes equations. After linearizing about small disturbances, we have the following system of equations:

$$\begin{aligned} \frac{\partial u_1}{\partial t} + u \frac{\partial u_1}{\partial x} + v \frac{\partial u_1}{\partial y} + u_1 \frac{\partial u}{\partial x} + v_1 \frac{\partial u}{\partial y} &= -\frac{1}{\rho} \frac{\partial p_1}{\partial x} + v \left(\frac{\partial^2 u_1}{\partial x^2} + \frac{\partial^2 u_1}{\partial y^2} \right), \\ \frac{\partial v_1}{\partial t} + u \frac{\partial v_1}{\partial x} + v \frac{\partial v_1}{\partial y} + u_1 \frac{\partial v}{\partial x} + v_1 \frac{\partial v}{\partial y} &= -\frac{1}{\rho} \frac{\partial p_1}{\partial y} + v \left(\frac{\partial^2 v_1}{\partial x^2} + \frac{\partial^2 v_1}{\partial y^2} \right), \\ \frac{\partial u_1}{\partial x} + \frac{\partial v_1}{\partial y} &= 0; \quad x=0, \quad u_1=0, \quad v_1=0, \quad p_1=p_0; \\ y=0, \quad u_1=0, \quad v_1=0, \quad p_1=p_0; \quad y \rightarrow \infty, \quad u_1=0, \quad v_1=0. \end{aligned} \quad (23)$$

The differentiation on y and x of the first two equations provides the opportunity to exclude the pressure p_1 . The stability of the basic flow will be examined considering periodic disturbances of the form:

$$u_1 = F'(y) \exp i(\alpha x - \beta t), \quad v_1 = -i\alpha F(y) \exp i(\alpha x - \beta t), \quad (24)$$

where $F(y)$ is the amplitude of an one-dimensional disturbance (regarding y); α and β/α are its wave number and phase velocity, respectively:

$$\alpha = \frac{2\pi}{\lambda}, \quad \beta = \beta_r + i\beta_i. \quad (25)$$

In eq. 25, λ is the wave length, β_r is the circle frequency, and β_i is the increment factor. Obviously, the condition for stability of the flow is $\beta_i < 0$.

In the case of $\beta_i > 0$, the basic flow is unstable (the amplitude grows with time).

Introducing eq. 24 into eqs. 23 leads to Orr–Sommerfeld-type equations [19–22] for the amplitude of the disturbances (in similarity variables):

$$\begin{aligned}
 & (f' - C)(\varphi'' - A^2\varphi) - f'''\varphi = \\
 & = -\frac{i}{A\text{Re}} \left\{ (\varphi'^{\vee} - 2A^2\varphi'' + A^4\varphi) - \frac{1}{2}(\xi f' - f)\varphi''' + \left[\frac{1}{2}(\xi f''' + f'') + \frac{A^2}{2}(\xi f' - f) \right] \varphi' \right\}, \quad (26) \\
 & \varphi(0) = 0, \quad \varphi'(0) = 0, \quad \varphi(\infty) = 0, \quad \varphi'(\infty) = 0,
 \end{aligned}$$

where

$$\begin{aligned}
 & 2f''' + ff'' = 0, \quad f(0) = a, \quad f'(0) = 0, \quad f''(0) = \frac{\varepsilon^2}{4}b; \\
 & A = \alpha\delta, \quad C = \frac{\beta}{\alpha u_0} = C_r + iC_i, \quad \text{Re} = 1.72 \frac{u_0\delta}{\nu}. \quad (27)
 \end{aligned}$$

The linear analysis of the hydrodynamic stability of a laminar boundary layer at the conditions of intensive interphase mass transfer is finally reduced to determining C_r and $\varphi(\xi)$ at $C_i = 0$, when Re and A are given. The minimum Reynolds number, i.e., the critical Reynolds number Re_{cr} , at which the flow becomes unstable, can be obtained from the dependence $C_r(\text{Re})$.

The critical Reynolds numbers Re_{cr} , corresponding to the wave velocities C_r , and wave numbers are shown in Table 2 in dependence on the magnitude and on the direction of the concentration gradient at the conditions of a intensive interphase mass transfer.

It can be seen from Table 3 that the intensive interphase mass transfer directed toward the phase boundary ($\theta < 0$) (the effect of "suction") stabilizes the flow. In the case of intensive interphase mass transfer directed from the phase boundary toward the volume ($\theta > 0$) (the effect of "injection"), a destabilization of the flow is observed.

Table 2 Values of the critical Reynolds number Re_{cr} corresponding to the wave velocities C_r , wave number A and $C_{r\min}$, A_{\min} obtained.

ε	θ	Re_{cr}	A	C_r	A_{\min}	$C_{r\min}$
1	-0.30	1619	0.259	0.3281	0.301	0.3310
	-0.20	1014	0.285	0.3587	0.322	0.3599
	-0.10	689	0.290	0.3816	0.340	0.3848
	0.0	501	0.305	0.4035	0.359	0.4067
	0.10	386	0.309	0.4196	0.373	0.4243
	0.20	310	0.320	0.4351	0.387	0.4396
	0.30	258	0.331	0.4488	0.398	0.4526
10	-0.05	555	0.300	0.3960	0.351	0.3990
	0.0	501	0.305	0.4035	0.359	0.4067
	0.05	476	0.305	0.4062	0.360	0.4097
	0.10	459	0.305	0.4085	0.361	0.4124
	0.20	437	0.310	0.4123	0.367	0.4155
20	-0.05	558	0.305	0.3959	0.351	0.3978
	-0.03	528	0.305	0.4010	0.354	0.4037
	0.0	501	0.305	0.4035	0.359	0.4067
	0.03	488	0.305	0.4064	0.362	0.4099

Table 3 Values of the critical Reynolds numbers Re_{cr} , wave velocities C_r , wave numbers A and $C_{r\ min}$, A_{\min} obtained (in the gas phase).

θ	Re_{cr}	A	C_r	A_{\min}	$C_{r\ min}$
-0.3	2511	0.270	0.3863	0.304	0.3878
-0.2	1605	0.285	0.4095	0.325	0.4108
-0.1	1078	0.295	0.4264	0.341	0.4281
0.0	795	0.305	0.4469	0.356	0.4493
0.3	397	0.330	0.4866	0.398	0.4902
0.2	483	0.320	0.4749	0.386	0.4786
0.1	605	0.315	0.4620	0.373	0.4645

STABILITY IN THE GAS-LIQUID SYSTEM

Essential interaction between flows in gas and liquid will be observed if a movable liquid surface replaces the unmovable solid surface. There will also be the induction of secondary flows as a result of intensive interphase mass transfer in the gas-liquid systems, but this effect is superposed on the hydrodynamic interaction between the above-mentioned two phases. Stability at these conditions is not only theoretical, but also of practical interest in view of the fact that it defines the rate of a number of industrial absorption and desorption processes.

The critical Reynolds numbers, corresponding wave numbers, and phase velocities are presented in Table 3.

The direction of the intensive interphase mass transfer influences the hydrodynamic stability of the flow in the gas-phase boundary layer analogously to the case of the solid face boundary. Hence, in the case of absorption ($\theta_3 > 0$), the rise of stability is observed. In the opposite case of desorption ($\theta_3 < 0$), the stability increases the motion of the interface [$f'(0) > 0$] leads to the decrease of the velocity gradients, which is the cause of flow stabilization in all cases (increase of Re_{cr}).

EFFECT OF CONCENTRATION AND TEMPERATURE

The influence of the concentration and its gradient on the hydrodynamic stability in the laminar boundary layer are shown in ref. [23].

The results obtained in ref. [24] give the opportunity to define the influence of the nonlinear mass transfer and the Marangoni effect on the hydrodynamic stability of the flow in the boundary layer.

The numerical analysis shows that the Marangoni effect is insignificant in gas-liquid systems with a movable phase boundary.

CONCLUSION

The investigations of the solubility phenomena, limited by the nonlinear mass transfer and hydrodynamic stability in systems with intensive interphase mass transfer, can explain a number of experimental deviations from the linear mass transfer theory, which have been explained with the Marangoni effect.

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