

Thermalphysic processes in a reaction zone of electrothermal ore-smelting reactor

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Considered are the features of hydrodynamics and heat and mass transfer during the reduction reaction proceeding in a coke zone of electrothermal ore-smelting reactor, when the process is complicated by gas phase evolving, which bubbles the melt. The gas bubbles provides conditions for intense immixture, which for its turn intensifies target reduction processes.

The peculiarities of the reacting lies in the fact that an active reagent on mixing transfers the reduction process into kinetic area. In that case, the temperature of a reaction zone and reagent concentration in a volume are the governing factors, so the reduction reaction and gas bubbles evolving influence on development of convection currents is thought of as influence of temperature and reagent concentration. Hydrodynamics of the bubbles and liquid interconnection has its peculiar features like a local influence over liquid by means of added mass for example. The effect strength is in direct relation of the gas content gradient. It is shown that the chemical reduction reaction rate determines gas content and hence, an extent of influence on immixture. The effective criteria, which characterize the chemical reaction influence by means of heat and concentration effect, have been introduced as a measure of the gas phase impact on hydrodynamics in filter equation. The coefficients, considering the chemical reaction influence on hydrodynamics of the system are well greater than the influence parameters of free and concentration convection, which actually determines the melt behaviour in a reaction zone. In that case, the problem is reduced by structure to an estimation of influence of the temperature and concentration small perturbations on hydrodynamics of the melt being filtered in a coke layer.

It is deduced that in a reduction process there takes place the formation of dissipative hydrodynamic structures, which determine thermophysical behaviour of a reaction zone, including temperature and reagent concentrations. Synergetic behaviour features of a reaction bulk provide conditions and possibilities of control. It is precisely the situation that should be taken into account when organizing the operating mode of electrothermal ore-smelting reactor.

Key words: electrothermal ore-smelting reactor, reaction zone, layer of disperse particles, filter equations, heat and mass transfer equations, bubbling of gas bubbles, dissipative structures.

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Introduction

On obtaining calcium carbide or phosphorus sublimation in electrothermal ore-smelting reactors, the reduction reactions on carbon particles take place in high-temperature melt with evolving gaseous carbon oxide which bubbles the melt. Rising gas bubbles set up the conditions for intensive liquid immixture. Strengthening of the processes of chemical response is mainly determined by processes of heat and mass transfer, which form temperature condition of the reactor and ensure supply of reagent. Direct experimental study of electrothermal processes is impeded by high temperature and a reaction zone which is difficult of access, etc. Therefore, one should be content with fixing parameters, which are accessible outside on inspecting of operating modes of reactors [1–5] or by investigating the low-temperature zones only. The papers, devoted to computational simulation of the processes

in such reactors are few in number [6–9, 13]. Preliminary analytical estimation of the phenomenon, accompanying target processes is of value for computational simulation. These supporting estimations have been implemented in the papers [10–12]. The present work contains their advancement with more careful taking into account both thermal and hydrodynamic behaviour of reagents.

As for reduction processes with evolving gas-core products into liquid, the hydrodynamic state of a reaction space is often determined by chemical reactions. Below are considered conditions of responding multiple-phase medium, where rate of the energy exchange processes is in many respects determined by the bubbling reaction products in gaseous form.

The qualitative theoretical analysis of hydrodynamic features of a reaction zone of technological reactor with the melt of reagent, which is bubbled by reaction products, is based on the hydrodynamic and heat transfer equations sets.

The simulator of thermophysical processes in a reaction zone of electrothermal reactor

It is thought that the movement of a liquid phase is provoked by difference between the liquid densities owing to temperature, reagent concentration and presence of the gas phase in the form of bubbles. The system being analysed is a two-dimensional structure of height H and width L , filled by dispersed material with percentage of voids ε and by liquid.

The paper is aimed to detection of convection currents, stipulated by density changes, and their influence on the system characteristics.

The dimensionless form of equations describing the filtered liquid movement as well as mass, heat and gas phase transfer in a form of bubbles is written as follows:

$$\nabla \mathbf{v} = 0,$$

$$\frac{1}{\sigma Pr} \frac{\partial \vec{v}}{\partial t} = -\nabla p + (Ra_\theta \theta + Ra_c c + Ra_\phi \phi_g) \vec{y} - \vec{v} + \frac{Fs}{Pr_p} \vec{v} |\vec{v}|,$$

$$\frac{1}{\sigma} \frac{\partial c}{\partial t} = -\vec{v} \nabla c + Le \nabla^2 c + Da \omega_R(c, \theta), \quad (1)$$

$$\frac{\partial \theta}{\partial t} = -\vec{v} \nabla \theta + \nabla^2 \theta + Da B \omega_R(c, \theta) + Q,$$

$$\frac{\partial N}{\partial t} = -\vec{v} \nabla N + D_N \Delta N + \omega_R(c, \theta) \gamma_{g1} / (\rho_g V_b),$$

Where c is fractional conversion ($c = 1 - C'/C'_0$) with initial and end concentrations C' and C'_0 , respectively; t is dimensionless time ($t = t'a'/H^2\sigma$), t' is time, s; a' is temperature conductivity, m^2/s ; σ is a heat capacity ratio $\sigma = 1 + (\rho_s C_{ps}(1 - \varepsilon))/(\rho_l C_{pl}\varepsilon)$; ρ_s , ρ_l are densities of solid and liquid carrier; C_{ps} , C_{pl} are heat capacities of solid and liquid carrier; ε is percentage of voids; Le is the Lewis' criterion ($Le = D_e/a'$, D_e is an effective diffusion coefficient); Da is the Damkhler criterion: $Da = (k_{0exp}(-\gamma)L^2C_0^{n-1})/(\varepsilon a')$, K_0 is a preexponential, $\gamma = E/RT_0$ is a dimensionless activation energy, T is temperature, R is absolute gas constant, "0" index refers to initial values, n is the reaction order); θ is dimensionless temperature, $\theta = \gamma(T - T_0)/T_0$; B is a dimensionless calorific effect of the reaction, an adiabatic temperature rising: $B = Q_R C_{ps} \gamma / (\rho_l C_{pl} T_0)$; N is a number of bubbles; D_N is the bubbles diffusion coefficient; V_b is volume of bubbles; $p = p'k/(\mu_1 a')$, p' denotes pressure, Pa; k is a permeability ratio; μ_1 denotes the liquid dynamic viscosity, Pa·s; $Pr^* = \nu_1 H^2/(ka')$, Pr^* denotes the Darcy's criterion; $Ra_\theta = \beta_0 g k H (T_0/\gamma)/(va')$, $Ra_c = \beta_c g k H/(va')$, $Ra_\phi = \beta_\phi g k H/(va')$, β_c , β_ϕ , β_0 are mass, thermal and gas-phase expansiveness (density changes due to gas presence).

With boundary condition as follows:

$$c = \theta = 0 \text{ at } y = 0. \quad n \nabla c = n \nabla \theta = 0 \text{ at all boundaries,}$$

where $n \mathbf{v} = 0$ near side wall.

$$\text{At } y = 0, v_z = -Pe; y = 1, v_z = -Pe. \quad (2)$$

Taking into account smallness of the bubbles diffusion coefficient D_N and gradient ∇N , the transport equation for a gas phase one can rewrite as follows:

$$\frac{\partial N}{\partial t} \approx \omega_R(c, \theta) \gamma_{g1} / (\rho_g V_g), \quad N \approx \int \omega_R(c, \theta) \gamma_{g1} / (\rho_g V_g) dt. \quad (3)$$

Whence $\phi_g \approx \omega_R \gamma_g \tau_R / \rho_g$, τ_R is a duration of the bubbles being in a layer.

$$\omega_R(c, \theta) = \frac{\partial c}{\partial t} = k_0 S (1 - c)^n \exp \left[\frac{\theta}{1 + \theta/\gamma} \right] \quad (4)$$

Further we consider the first-order reaction. Let us decompose the exponent into a series up to first order.

$$\begin{aligned} \omega_R(c, \theta) &= \frac{\partial c}{\partial t} \approx k_0 S (1 - c)(a + b\theta) = \\ &= k_0 S(a - ac + b\theta - bc\theta). \end{aligned} \quad (5)$$

Then $\phi_g \approx (k_0 S \gamma_g \tau_R / \rho_g)(a - ac + b\theta - bc\theta)$.

Solving such a problem even numerically presents certain difficulty.

To make an analytical investigation, let us do some simplification. We consider a layer between horizon planes with temperatures T_0 and T_1 . We believe the problem two-dimensional and stationary and the liquid seepage velocities low; we also neglect non-linearity in the equation of motion. We consider small deviations of all quantities, involved in the equations:

$v = v_0 + v_1$, $\theta = \theta_0 + \theta_1$, $c = c_0 + c_1$, in which connection we suppose $v = 0$ in equilibrium.

The filter equation may be written as:

$$0 = -\nabla p + (Ra_\theta \theta + Ra_c c + Ra_\phi (k_0 S \gamma_g \tau_R / \rho_g) \times (a - ac + b\theta - bc\theta)) \vec{y} - \vec{v},$$

Or by using the perturbed and linearized forms:

$$0 = -\nabla p_1 + ((Ra_\theta + Ra_\phi (k_0 S \gamma_g \tau_R / \rho_g) \omega_\theta) \theta_1 + (Ra_c + Ra_\phi (k_0 S \gamma_g \tau_R / \rho_g) \omega_c) c_1) \vec{y} - \vec{v}. \quad (6)$$

Applying operator *rot* to the equation of motion in the medium equilibrium conditions, when velocity equals to zero, one can show that the temperature and concentration distribution are one-dimensional along the y axis. The tempe-

rature and concentration distribution in equilibrium turns out an exponential one, within the temperature range from T_0 to T_1 . The temperature and concentration field in tranquillity we approximate by linear dependence; for temperature, as an example, we have: $T = T_1 - \beta y$, $\beta = (T_1 - T_0)/H$.

Following the use of perturbed components, the linearized equations become:

$$\nabla v = 0$$

$$0 = -\nabla p_1 + ((Ra_\theta + Ra_\varphi R_\varphi \omega_\theta)\theta_1 + (Ra_c + Ra_\varphi R_\varphi \omega_c)c_1)\vec{y} - \vec{v}_1$$

$$0 = -\vec{v}_0 \vec{\nabla} c_1 - \vec{v}_1 \vec{\nabla} c_0 + Le \nabla^2 c_1 + (Fk/B)(\omega_\theta \theta_1 + \omega_c c_1) \quad (7)$$

$$0 = -\vec{v}_0 \vec{\nabla} \theta_1 + \vec{v}_1 \vec{\nabla} \theta_0 + \nabla^2 \theta_1 + Fk(\omega_\theta \theta_1 + \omega_c c_1)$$

$R_\varphi = (k_0 S \gamma_g \tau_R / \rho_g)$, ω_θ , ω_c are coefficients of expansion in a series.

Method of solution of the problem

Let us define the flow function ψ as follows:

$$v_x = \frac{\partial \psi}{\partial y}, v_y = -\frac{1}{\alpha} \frac{\partial \psi}{\partial x},$$

The simplified form of the motion equations will be written in the following form:

$$\frac{\partial v_x}{\partial x} + \frac{\partial v_y}{\partial y} = 0,$$

$$-\frac{\partial p}{\partial x} - v_x = 0,$$

$$-\frac{\partial p}{\partial y} + ((Ra_\theta + Ra_\varphi R_\varphi \omega_\theta)\theta_1 + (Ra_c + Ra_\varphi R_\varphi \omega_c)c_1) -$$

$$-v_y = 0,$$

And upon eliminating the pressure, the system of equations will be presented in the following form:

$$\frac{\partial^2 \psi}{\partial x^2} + \frac{\partial^2 \psi}{\partial y^2} + \frac{1}{\alpha} ((Ra_\theta + Ra_\varphi R_\varphi \omega_\theta) \frac{\partial \theta_1}{\partial x} + (Ra_c + Ra_\varphi R_\varphi \omega_c) \frac{\partial c_1}{\partial x}) = 0,$$

$$\frac{\partial^2 \theta_1}{\partial x^2} + \frac{\partial^2 \theta_1}{\partial y^2} - \frac{1}{\alpha} \frac{\partial \psi}{\partial x} + Fk(\omega_\theta \theta_1 + \omega_c c_1) = 0, \quad (8)$$

$$\frac{\partial^2 c_1}{\partial x^2} + \frac{\partial^2 c_1}{\partial y^2} - \frac{1}{Le\alpha} \frac{\partial \psi}{\partial x} + (Fk/LeB)(\omega_\theta \theta_1 + \omega_c c_1) = 0.$$

Taking into account that perturbations are damping on borders and don't penetrate outside the area, the boundary conditions may be written as:

$$\bar{x} = 0, 0 < y < 1, \theta_1 = 0, c_1 = 0, \psi = 0;$$

$$\bar{x} = 1, 0 < y < 1, \theta_1 = 0, c_1 = 0, \psi = 0;$$

$$y = 0, 0 < x < +1, \theta_1 = 0, c_1 = 0, \psi = 0;$$

$$y = 1, 0 < x < +1, \theta_1 = 0, c_1 = 0, \psi = 0. \quad (9)$$

Let us study the behaviour of solutions of the system (8) with respect to small perturbations. We will look for a solution, which meets boundary conditions in the form as follows:

$$\psi = \sum_{n=1}^{\infty} \psi_n \sin n\pi y, \theta_1 = \sum_{n=1}^{\infty} \theta_n \sin n\pi y, \\ c_1 = \sum_{n=1}^{\infty} c_n \sin n\pi y, \quad (10)$$

where ψ_n, θ_n, c_n are the functions of x .

Substituting the expressions (10) into equations (8), we obtain:

$$\frac{d^2 \psi_n}{dx^2} - n^2 \pi^2 \psi_n + \frac{1}{\alpha} \left((Ra_\theta + Ra_\varphi R_\varphi \omega_\theta) \frac{d\theta_n}{dx} + (Ra_c + Ra_\varphi R_\varphi \omega_c) \frac{dc_n}{dx} \right) = 0;$$

$$\frac{d^2 \theta_n}{dx^2} - n^2 \pi^2 \theta_n - \frac{d\psi_n}{dx} + Fk(\omega_\theta \theta_n + \omega_c c_n) = 0; \quad (11)$$

$$\frac{d^2 c_n}{dx^2} - n^2 \pi^2 c_n - \frac{1}{Le\alpha} \frac{d\psi_n}{dx} + (Fk/LeB)(\omega_\theta \theta_n + \omega_c c_n) = 0.$$

With the boundary conditions

$$\psi_n(0) = \psi_n(1) = 0; \theta_n(0) = \theta_n(1) = 0; \\ c_n(0) = c_n(1) = 0. \quad (12)$$

Let us form a differential equation of the fourth order relative to ψ_n out of initial system of equations (11). For that, the first equation of the system (11) we will differentiate on x twice and obtain:

$$\frac{d^4 \psi_n}{dx^4} - n^2 \pi^2 \frac{d^2 \psi_n}{dx^2} + \frac{1}{\alpha} \left((Ra_\theta + Ra_\varphi R_\varphi \omega_\theta) \frac{d^3 \theta_n}{dx^3} + (Ra_c + Ra_\varphi R_\varphi \omega_c) \frac{d^3 c_n}{dx^3} \right) = 0. \quad (13)$$

The second-order equations for θ_n and c_n of the system (11) we differentiate on x :

$$\frac{d^3\theta_n}{dx^3} - n^2\pi^2 \frac{d\theta_n}{dx^2} - \frac{d^2\psi_n}{dx^2} + Fk \left(\omega_\theta \frac{d\theta_n}{dx} + \omega_c \frac{dc_n}{dx} \right) = 0;$$

$$\frac{d^3c_n}{dx^3} - n^2\pi^2 \frac{dc_n}{dx} - \frac{1}{Le\alpha} \frac{\partial^2\psi_n}{\partial x^2} + (Fk/LeB) \left(\omega_\theta \frac{d\theta_n}{dx} + \omega_c \frac{dc_n}{dx} \right) = 0.$$

We put the expressions of derivatives of the third order to the equation for flow function (13):

$$\begin{aligned} & \frac{d^4\psi_n}{dx^4} - n^2\pi^2 \frac{d^2\psi_n}{dx^2} + \frac{1}{\alpha} \left((Ra_\theta + Ra_\phi R_\phi \omega_\theta) \times \right. \\ & \times \left(n^2\pi^2 \frac{d\theta_n}{dx} + \frac{d^2\psi_n}{dx^2} - Fk \left(\omega_\theta \frac{d\theta_n}{dx} + \omega_c \frac{dc_n}{dx} \right) \right) + \\ & + (Ra_c + Ra_\phi R_\phi \omega_c) \left(n^2\pi^2 \frac{dc_n}{dx} + \frac{1}{Le\alpha} \frac{\partial^2\psi_n}{\partial x^2} - \right. \\ & \left. - (Fk/LeB) \left(\omega_\theta \frac{d\theta_n}{dx} + \omega_c \frac{dc_n}{dx} \right) \right) = 0. \end{aligned}$$

Or uniting the factors, we obtain:

$$\begin{aligned} & \frac{d^4\psi_n}{dx^4} - n^2\pi^2 \frac{d^2\psi_n}{dx^2} + \frac{1}{\alpha} \left((Ra_\theta + Ra_\phi R_\phi \omega_\theta) \frac{d^2\psi_n}{dx^2} + \right. \\ & + \frac{1}{\alpha} (Ra_c + Ra_\phi R_\phi \omega_c) \frac{1}{Le\alpha} \frac{\partial^2\psi_n}{\partial x^2} + \\ & + \left(\frac{1}{\alpha} (Ra_\theta + Ra_\phi R_\phi \omega_\theta) n^2\pi^2 - \right. \\ & - \frac{1}{\alpha} (Ra_\theta + Ra_\phi R_\phi \omega_\theta) Fk\omega_\theta - \\ & - \frac{1}{\alpha} (Ra_c + Ra_\phi R_\phi \omega_c) (Fk/LeB)\omega_\theta \left. \right) \frac{d\theta_n}{dx} + \\ & + \left(\frac{1}{\alpha} (Ra_c + Ra_\phi R_\phi \omega_c) n^2\pi^2 - \right. \\ & - \frac{1}{\alpha} (Ra_\theta + Ra_\phi R_\phi \omega_\theta) Fk\omega_c - \\ & - \frac{1}{\alpha} (Ra_c + Ra_\phi R_\phi \omega_c) (Fk/LeB)\omega_c \left. \right) \frac{dc_n}{dx} = 0. \end{aligned} \quad (14)$$

In this system, let us single out the coefficients

$$\begin{aligned} a_{11} = & \left(\frac{1}{\alpha} (Ra_\theta + Ra_\phi R_\phi \omega_\theta) n^2\pi^2 - \right. \\ & - \frac{1}{\alpha} (Ra_\theta + Ra_\phi R_\phi \omega_\theta) Fk\omega_\theta - \end{aligned}$$

$$- \frac{1}{\alpha} (Ra_c + Ra_\phi R_\phi \omega_c) (Fk/LeB)\omega_\theta \left. \right),$$

$$\begin{aligned} a_{12} = & \left(\frac{1}{\alpha} (Ra_c + Ra_\phi R_\phi \omega_c) n^2\pi^2 - \right. \\ & - \frac{1}{\alpha} (Ra_\theta + Ra_\phi R_\phi \omega_\theta) Fk\omega_c - \\ & - \frac{1}{\alpha} (Ra_c + Ra_\phi R_\phi \omega_c) (Fk/LeB)\omega_c \left. \right). \end{aligned}$$

$$\begin{aligned} b_1 = & - \frac{d^4\psi_n}{dx^4} - n^2\pi^2 \frac{d^2\psi_n}{dx^2} + \\ & + \frac{1}{\alpha} \left((Ra_\theta + Ra_\phi R_\phi \omega_\theta) \frac{d^2\psi_n}{dx^2} + \right. \\ & + \frac{1}{\alpha} (Ra_c + Ra_\phi R_\phi \omega_c) \frac{1}{Le\alpha} \frac{\partial^2\psi_n}{\partial x^2} \left. \right). \end{aligned}$$

From the first equation (11)

$$\begin{aligned} & \frac{d^2\psi_n}{dx^2} - n^2\pi^2\psi_n + \frac{1}{\alpha} \left((Ra_\theta + Ra_\phi R_\phi \omega_\theta) \frac{d\theta_n}{dx} + \right. \\ & + (Ra_c + Ra_\phi R_\phi \omega_c) \frac{dc_n}{dx} \left. \right) = 0. \end{aligned}$$

the coefficients are also following:

$$a_{21} = \frac{1}{\alpha} (Ra_\theta + Ra_\phi R_\phi \omega_\theta),$$

$$a_{22} = \frac{1}{\alpha} (Ra_c + Ra_\phi R_\phi \omega_c),$$

$$b_2 = - \left(\frac{d^2\psi_n}{dx^2} - n^2\pi^2\psi_n \right),$$

As a result, we have the system of linear second-order equations with respect to derivatives $\frac{d\theta_n}{dx}, \frac{dc_n}{dx}$.

In such a way, two considered equations allow to obtain expressions for first derivatives of temperature and concentration, which being substituted for example into the first equation for flow function will produce the differential equation of the fourth order of the flow function, giving an indication of the behaviour of the flow function of x and y .

$$\frac{d^4\psi_n}{dx^4} + f_1 \frac{d^2\psi_n}{dx^2} + f_2 \psi_n = 0. \quad (15)$$

Presenting solution (15) as $\psi_n \sim e^{px}$, we will get the characteristic equation in the following form:

$$p^4 + f_1 p^2 + f_2 = 0.$$

Thus, partial solutions in the form of harmonic functions are true for the flow function.

Let us write down the solution for ψ as:

$$\psi = C \sin(px) \sin(\pi ny), \quad (16)$$

where C is a constant.

Analysis of hydrodynamic conditions of a reaction zone of the reactor

With definitions for flow function, we find the expressions for velocity component:

$$v_x = \partial\psi/\partial y = \pi n C \sin(px) \cos(\pi ny), \quad (17)$$

$$v_y = -\partial\psi/\partial x = -p C \cos(px) \sin(\pi ny). \quad (18)$$

Movement of a separate gas element is described by trajectories, mathematical representation of which have the following form: $\frac{dx}{d\tau} = v_x$, $\frac{dy}{d\tau} = v_y$, and the motion path is deduced from the expression:

$$\frac{dx}{dy} = -\frac{\pi n C}{p C} \operatorname{tg}(px) \cdot \operatorname{ctg}(\pi ny). \quad (19)$$

Solution of the last equation gives:

$$\sin(px) \cdot \sin(\pi ny) = Tr, \quad (20)$$

where Tr is the constant, defined by initial conditions.

The lines for which $Tr=0$ are of particular importance. Position of these lines is characterized by the equations

$$\frac{\pi ny}{H} = \pi m_1, \quad y = \frac{H}{n} \cdot m_1, \quad p \frac{x}{L} = \pi m_2, \quad x = \frac{\pi L}{p} m_2, \quad (21)$$

where m_1, m_2 are whole numbers.

These straight lines divide the reaction zone into separate cells. The liquid moves inside the cells, not exceeding their bounds, since normal components of velocity at cell bounds equal to zero, i.e. the liquid doesn't overstep the limits (Fig. 1). Such cells are analogues to the Bénard ones.

Inside each cell, an element of the liquid moves over closed trajectory around the centre, where liquid is at rest. Such approximate description of the liquid movement in a reaction zone of technological reactor allows qualitatively describe an appearance of hydraulic dissipative structures and dependences for estimating modes of operation, which form vortical structures, arising on impact of gas bubbles, bubbling the liquid phase medium of the reaction zone. Formation of circulation cells provides an intensive immixture of the liquid and hence intensifies mass exchanged processes and chemical response. In that

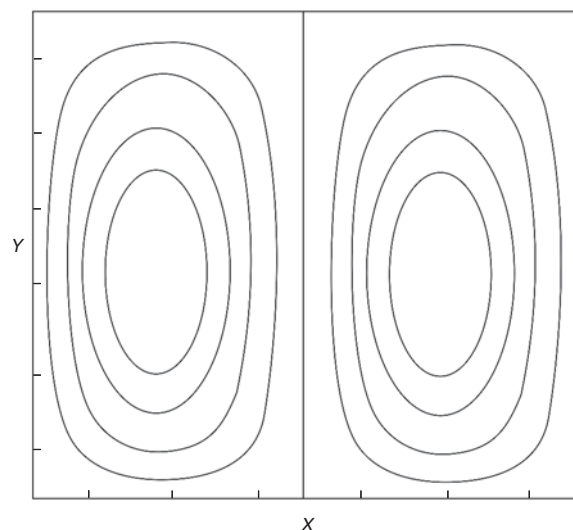


Fig. 1. The motion path of the liquid

case, diffusion is not an inhibitory factor in the response process, and the assumption of the first order of a reaction is quite sound. The higher is vortex frequency, the better is immixture quality.

Conclusion

It has been obtained that additional factors appear in the reaction zone of reduction reactor owing to formation of a gas phase. They are influencing on the liquid phase density change and modifications of an Archimedean constituent, the value of which is vastly superior to the concentration and temperature ones. Since the rate of bubbles formation and their number depend on temperature and concentration, the immixture and energy exchange processes are interrelated. Immixture is a way of the reagent mass supply and enhancement of the target processes efficiency. Hence, providing conditions for micro-vortex formation is just the way to intensification of mass exchange and target physical and chemical processes.

As equivalent Rayleigh numbers rise, new types of convective movement are developing. This leads to violation of well-ordered stream movement during convection and finally makes convectational liquid movement unsteady, which cause confused or turbulent nature of the liquid movement even with the system placed in a closed space. Taking into consideration the synergetic possibilities in such systems allow to programme control action and more correctly guarantee an effective impact on target processes.

Resume:

1. Showed is a mechanism of affecting the reaction zone hydrodynamics by the bubbles of the gas phase, arising on the reduction reaction proceeding.

2. The reaction rate for linearized exponent, presented for the perturbed components, brings the

resulting action to a sum of the temperature and concentration actions.

3. It is ascertained that the gas phase impact is reduced to the temperature and concentration influence, but that is much more effective.

4. It has been analytically demonstrated an existence of hydrodynamic dissipative structures, which provides the reacting melt immixture in a reaction zone.

5. Consequently, an intensifying effect on the mass transfer processes lies mainly in the reduction reaction itself, so given mechanism of affecting, there is a possibility to efficiently control such processes.

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