

## TRANSIENT PROCESS OF THE MASS TRANSFER OF THE GASEOUS COMPONENT BETWEEN GAS AND LIQUID

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**Abstract.** The exchange of the gas component between liquid and gas phase at a constant pressure of the gas is described. The transient process by the change of the parameters of the gas phase and the flow of the gas component through the interfacial surface are discussed. The dependence of the transient process on the diffusional characteristics of the liquid's surface layer was established.

**Key words:** mass transfer, diffusional flow, gas transient process, interfacial surface.

The exchange of the gas component between the atmosphere and hydrosphere depends to a considerable extent on the state of the interfacial surface between liquid and gas. The determination of the diffusional characteristics of the gas–liquid surface layer gives essential information on the influence of the surface-active pollutants on the exchange of the gaseous component between gas and liquid. The gas exchange in turn determines the content of gaseous component in the liquid phase, which influences biochemical processes in the natural water bodies and water treatment systems.

The methods of the determination of the diffusional characteristics can be classified on the basis of the stationary and nonstationary regime of diffusion. The latter was introduced later and it is more effective. For instance, it is successfully used in the dynamic determination of the diffusional characteristics of the polymer's membrane for oxygen using the Clark type sensor [1].

In the present paper the determination of diffusional characteristics of the liquid surface layer by the transient process of the gaseous component between gas and liquid is considered. This transient process is realized under the following conditions:

the gas phase is located in the separated variable volume  $V$ ;  
 the total pressure of the gas  $p_V$  is constant;  
 the area of the interfacial surface  $S$  between the gas and the liquid is constant;  
 the concentration of the gas component  $c_S$  in the liquid phase is constant.

When the gas phase occurs on both sides of the liquid layer, the flow of the gaseous component  $J_S$  from the gas volume  $V$  through the layer is proportional to the difference of the partial pressures:

$$J_S = k_S(p - p_S), \quad (1)$$

where  $k_S$  is the coefficient of the diffusional conductivity of the studied liquid layer,  $p$  is the partial pressure of the gaseous component in the volume  $V$ , and  $p_S$  is the partial pressure of the gaseous component on the other side of the liquid layer.

As the content of the gaseous component in the gas phase is expressed through its partial pressure or concentration and the content of the solute in the diluted solutions through its concentration, the analytical concentration of the gaseous component in the heterogeneous systems has a break in its values on the interfacial surface due to the different physical state of the gaseous component in gas and liquid. Therefore, in the mathematical description of the transient process in the heterogeneous system equations with boundary conditions are used. These take into account the difference of the state of the examined gaseous component in different phases. To simplify the solution of the system of mathematical equations, we used the effective value of the concentration of the gaseous component – "the effective concentration" [2]. This quantity is universal for all phases of the heterogeneous system.

The effective concentration of the gaseous component in the volume  $V$  of the gas phase can be expressed [2]:

$$c_e = mRT/V, \quad (2)$$

where  $m$  is the number of moles of gas in volume  $V$ ;  $R$  is the universal gas constant; and  $T$  stands for temperature. In the gas phase  $c_e$  is quantitatively equal to the partial pressure of the gaseous component.

The effective concentration of the gaseous component  $c_{eS}$  in the liquid can be expressed by

$$c_{eS} = k_h \cdot c_S, \quad (3)$$

where  $k_h$  is Henry's coefficient;  $c_S$  is the analytical concentration of the gaseous component in the liquid.

In the observed system the gas flow  $J_S$  through the interfacial surface from the volume  $V$  to the liquid is proportional to the difference between the effective concentrations of the gaseous component in the volume  $V$  and the liquid phase:

$$J_s = k_s(c_e - c_{es}). \quad (4)$$

The gas flow  $J_s$  at the constant pressure  $p_V$  of the gaseous mixture changes the amount of the examined gas  $m$  in the gas phase and the volume  $V$ , which is given as follows:

$$V = (m + m_n)(RT/p_V), \quad (5)$$

where  $m_n$  is the amount of the other gases in the volume  $V$ .

The velocity of the change of the amount of the gaseous component  $m$  in the volume  $V$  is determined by the flow  $J_s$ :

$$dm/dt = -J_s. \quad (6)$$

By substituting the corresponding quantities from Eqs. (2), (4), and (5) in Eq. (6) we get:

$$\frac{dm}{dt} = -\frac{RT}{V_0} k_s \left( \frac{m_0 + m_n}{m + m_n} m - c_{es} \frac{V_0}{RT} \right), \quad (7)$$

where  $V_0$  and  $m_0$  are the volume of the gas and the number of the moles of the gaseous component at  $t = t_0$ .

By the integration of Eq. (7) in the paths from  $[t_0, m_0]$  to  $[t, m]$  we can write:

$$\ln \left( \frac{m - m_\infty}{m_0 - m_\infty} \right) - \frac{m_0 - m}{m_n + m_\infty} = -\frac{t - t_0}{t_s}, \quad (8)$$

where  $m_\infty = m_n \frac{c_{es}}{p_V - c_{es}}$  is the value of  $m$  at  $t \rightarrow \infty$ ;  $t_s = \frac{m_n + m_\infty}{k_s (p_V - c_{es})}$

is the time constant of the transient process ( $m = f(t)$ ).

Under the given conditions, if the volume  $V$  is a function of the amount of the gaseous component  $m$  and time  $t$ , the effective concentration of the gaseous component  $c_e$  is given as:

$$c_e = \frac{m}{m + m_n} p_V. \quad (9)$$

By replacing Eq. (9) into Eq. (8) we can write:

$$\ln \left( \frac{p_V - c_{e0}}{p_V - c_e} \times \frac{c_e - c_{e\infty}}{c_{e0} - c_{e\infty}} \right) - \frac{c_{e0} - c_e}{p_V - c_e} \times \frac{p_V - c_{e\infty}}{p_V - c_{e0}} = -\frac{(t - t_0)}{t_s}, \quad (10)$$

where  $c_{e0}$  is the value of  $c_e$  at  $t = t_0$ ;  $c_{e\infty} = c_{es}$  is the value of  $c_e$  at  $t \rightarrow \infty$ ;

$t_s = \frac{m_n}{k_s} \times \frac{p_V}{(p_V - c_{e\infty})^2}$  is the time constant of the transient process ( $c_e = f(t)$ ).

The dependence of the effective concentration of the gaseous component upon time does not have any explicit expression. Changing the transient function to its normalized form  $h(t)$  allows us to examine and compare the different experimental data in the general form:

$$\ln \left( \frac{1 - k_p h(t)_0}{1 - k_p h(t)} \times \frac{h(t) - h(t)_\infty}{h(t)_0 - h(t)_\infty} \right) - \frac{k_p h(t)_0 - k_p h(t)}{1 - k_p h(t)} \times \frac{1 - k_p h(t)_\infty}{1 - k_p h(t)_0} = -\frac{(t - t_0)}{t_s}, \quad (11)$$

where  $k_p = c_{e0}/p_V$  is the coefficient which is connected with the initial content of the gaseous component in the volume  $V$ ;  $h(t) = c_e/c_{e0}$  is the transient function;  $h(t)_\infty = c_{e\infty}/c_{e0}$  is the value of  $h(t)$  at  $t \rightarrow \infty$ .

The time constant  $t_s$  may be determined by the experimental data of the transient process and can be expressed as:

$$t_s = \frac{V_0}{RT} \times \frac{1 - k_p}{k_s} \left( 1 - \frac{c_{es}}{p_V} \right)^{-2}. \quad (12)$$

The coefficient of the diffusional conductivity of the liquid-gas surface layer can be expressed from Eq. (12) as:

$$k_s = \frac{V_0}{RT} \times \frac{1 - k_p}{t_s} \left( 1 - \frac{c_{es}}{p_V} \right)^{-2}. \quad (13)$$

As the area of the interfacial surface  $S$  is fixed, the coefficient  $k_s$  can be expressed in the following form:

$$k_s^0 = \frac{k_s}{S}. \quad (14)$$

Because of the difficulties of the determination of the exact thickness of the surface layer the coefficient  $k_s^0$  can be used to estimate the state of the gas-liquid interface. If we know the thickness of the surface layer  $l_s$ , we can determine its permeability  $P_s$ :

$$P_s = \frac{l_s}{S} k_s^0. \quad (15)$$

The given description of the transient process determines the main relationships between the parameters of the gaseous component in the gas volume  $V$  (at a constant pressure of the gaseous phase) and the parameters of the consumption of the gaseous component by the liquid. The given method can be used for the determination of the flow of the consumption of the gas by the examined system in the liquid phase and for the

estimation of the influence of the surfactants on the gas exchange between the gas and liquid phases, taking into account the state of the surface layer.

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## SÜSTEEMI GAAS-VEDELIK GAASILISE KOMPONENDI MASSIÜLEKANDE UURIMINE

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On uuritud gaasilise komponendi ülekannet süsteemis gaas-vedelik. Gaasifaasi parameetrite muutuse kaudu on kirjeldatud gaasi voogu läbi gaasi-vedeliku piirpinna. On kasutatud gaasi efektiivse kontsentratsiooni mõistet.

On toodud gaasilise komponendi ülekandeprotsessi iseloomustavad võrrandid konstantse rõhu ja gaasi muutuva ruumala korral. Need võrrandid võimaldavad eksperimentaalandmete alusel määrata heterogeense süsteemi faasidevahelist piirpinda iseloomustavaid difusioonilisi parameetreid ja pindaktiivsete ainete mõju gaasi-vedeliku piirpinnal toimuva gaasi ülekandeprotsessi seaduspärasustele.

## ПЕРЕХОДНЫЙ ПРОЦЕСС МАССОПЕРЕДАЧИ ГАЗОВОГО КОМПОНЕНТА В СИСТЕМЕ ГАЗ-ЖИДКОСТЬ

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Получены уравнения переходного процесса гетерогенной системы: переменный объем газовой смеси постоянного давления – поверхностный слой жидкости, потребляющей газовый компонент. При выводе уравнений использовано понятие т.н. эффективной концентрации газового компонента. Полученные уравнения предлагаются для определения как потребления газа исследуемой жидкостью, так и диффузионной проводимости и проницаемости ее поверхностного слоя. По значениям этих диффузионных параметров может оцениваться влияние поверхностно-активных веществ на газообменные процессы в природных водоемах и очистных сооружениях.