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Abstract

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CONVECTIVE DIFFUSION IN LIQUID SOLUTIONS UNDER TURBULENT CONDITIONS

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V. G. Levich (^1) derived an equation for convective diffusion in liquid solutions to the surface of a rotating disk for the turbulent regime:

$$I \approx \frac{0.01\, c_0 s}{\alpha \mathrm{Pr}^{3/4}} (a\omega) \left(\frac{\nu}{a^2 \omega} \right)^{1/5}, \tag{1}$$

where I is the diffusion flux, s is the area of the disk, a is the radius of the disk, c_0 is the concentration of the substance in the bulk of the solution, ω is the angular velocity of rotation of the disk, ν is the kinematic viscosity of the solution, and α is a universal constant.

Equation (1) was derived in accordance with the ideas of L. D. Landau (^2) and V. G. Levich (^3) on the nature of turbulent motion in liquids near a solid surface, and in contradiction to the ideas of L. Prandtl (^4) and T. Karman (^5).

As far as the authors know, the only experimental verification of equation (1) is the work of I. A. Bagotskaya (^6), which showed that the diffusion flux is proportional to the diffusion coefficient to the power 3/4, and not to the first power, as follows from the theory of L. Prandtl and T. Karman.

The authors decided to confirm experimentally the validity of equation (1), showing the constancy of the universal constant α entering into this equation. A second aim of the work was to determine the numerical value of α, which was of interest in itself.

For the experimental verification of equation (1), the authors measured the rate of dissolution of terephthalic acid, practically insoluble in water (^7), in dilute aqueous solutions of water–triethylamine, water–hexamethylenimine, and water–ammonia by the rotating-disk method under turbulent conditions. The apparatus for measuring the rate of dissolution and the method of carrying out the experiment are described in (^8).

The results of measurements of the diffusion fluxes, together with all the data necessary for calculating the value of α, are given in Table 1. The error in determining the diffusion fluxes under turbulent conditions was 3-6%.

The values of the diffusion coefficients of ammonia and hexamethylenimine at various temperatures were calculated by the authors from data on the rate of dissolution of terephthalic acid in dilute aqueous solutions of ammonia and hexamethylenimine under laminar conditions, using V. G. Levich' s equation (⌒2):

$$I = 0.62 D^{2/3} \nu^{-1/6} \omega^{1/2} c_0. \tag{2}$$

The value of the diffusion coefficient of triethylamine at 17° was taken as $0.43 \cdot 10^{-5}$ $\mathrm{cm}^2 \cdot \mathrm{sec}^{-1}$ (⌒8). The kinematic viscosity of dilute aqueous solutions of ammonia was taken equal to the kinematic viscosity

Table 1

Value of the universal constant α, entering the equation of V. G. Levich for convective diffusion under turbulent conditions

Solution	C_0, mmol of cell × cm^{-3}	I, mmol of cell × cm^{-2} sec^{-1}	t, °C	$\nu \cdot 10^2$, cm^2 sec^{-1}	$D \cdot 10^5$, cm^2 sec^{-1}	$\mathrm{Re} = \frac{a^2\omega}{\nu}$	α
Water—ammonia	0.5	0.040	67.5	0.45	6.0	119000	0.16
Water—ammonia	0.5	0.052	67.5	0.45	6.0	179000	0.16
Water—ammonia	0.5	0.023	40.0	0.65	3.5	82500	0.15
Water—ammonia	0.5	0.032	40.0	0.65	3.5	124000	0.14
Water—ammonia	0.5	0.016	30.0	0.80	2.6	67000	0.14

Solution	C_0, mmol of cell $\times$ cm^{-3}	I, mmol of cell $\times$ cm^{-2} sec^{-1}	t, °C	$\nu \cdot 10^2$, cm^2 sec^{-1}	$D \cdot 10^5$, cm^2 sec^{-1}	$\mathrm{Re} = \frac{a^2\omega}{\nu}$	α
Water—ammonia	0.5	0.018	30.0	0.80	2.6	100000	0.14
Water—hexamethylenimine	0.2	0.0035	40.0	0.75	1.0	71500	0.14
Water—hexamethylenimine	0.2	0.0055	40.0	0.75	1.0	107000	0.13
Water—hexamethylenimine	0.2	0.0055	40.0	0.75	1.0	251000	0.13
Water—hexamethylenimine	0.2	0.0030	30.0	0.9	0.72	59600	0.12
Water—hexamethylenimine	0.2	0.0045	30.0	0.9	0.72	89300	0.11
Water—hexamethylenimine	0.2	0.0045	30.0	0.9	0.72	209000	0.11
Water—triethylamine	0.2	0.0020	17.0	1.06	0.43	50600	0.14

Solution	C_0, mmol of cell × cm^{-3}	I, mmol of cell × cm^{-2} sec^{-1}	t, °C	$\nu \cdot 10^2$, cm^2 sec^{-1}	$D \cdot 10^5$, cm^2 sec^{-1}	Re = $\frac{a^2\omega}{\nu}$	α
Water—triethylamine	0.2	0.0027	17.0	1.06	0.43	75800	0.11

water(9), for triethylamine solutions—according to the data of(10), and the kinematic viscosity of hexamethylenimine—water solutions was determined with a Heppler viscometer. Thus, the mean value of α is equal to 0.13. The probable error of an individual measurement of α was ± 0.01, and the probable error of the mean value of α was ± 0.003. Thus, α retains its value as a constant, independently of the nature of the diffusing substance, when the diffusion coefficients vary fifteenfold (from $6.0 \cdot 10^{-5}$ to $0.43 \cdot 10^{-5}$ cm^2 sec.$^{-1}$) and the Reynolds numbers vary from $\sim 5 \cdot 10^4$ to $\sim 2.5 \cdot 10^5$.

The constancy of the value of the universal constant α, entering equation (1), is a confirmation of the correctness of the views of L. D. Landau and V. G. Levich on the nature of turbulent motion in liquids near a solid surface.

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