4. V. I. Myshenkov, in: Proceedings of the Mathematical Methods in Gasdynamics Section, Second International Colloquium on Gasdynamics of Explosions and Reaction Systems [in Russian], Vychisl. Tsentr. Akad. Nauk SSSR, Moscow (1971).
5. V. I. Kravchenko, Yu. D. Shevelev, and V. V. Shennikov, Numerical Study of the Flow of a Viscous Incompressible Liquid around a Cylinder Set into Motion Instantaneously [in Russian], Preprint No. 37, Inst. Problem. Mekh. Akad. Nauk SSSR, Moscow (1974).
6. S. Taneda, J. Phys. Soc. Japan, 11, 302 (1956); Rep. Res. Inst. Appl. Mech., Kyushu Univ., 4, 99 (1956).
7. L. A. Vulis and V. P. Kashkarov, Theory of the Viscous Liquid Jet [in Russian], Nauka, Moscow (1965).
8. R. I. Ayukaev, E. V. Badatov, A. A. Volkov, and M. É. Aérov, in: Reports to the Fifth All-Union Conference on Heat and Mass Transfer [in Russian], Vol. 6, ITMO, Akad. Nauk BelorusSSR, Minsk (1976).
9. N. A. Slezkin, Dynamics of a Viscous Incompressible Liquid [in Russian], GITTL, Moscow (1955).
10. M. Van Dyke, Perturbation Methods in Fluid Mechanics, Academic Press (1964).
11. G. A. Korn and T. M. Korn, Manual of Mathematics, McGraw-Hill (1967).
12. I. S. Gradshtein and I. M. Ryzhik, Tables of Integrals, Sums, Series, and Products, Academic Press (1966).
13. H. Bateman and A. Erdelyi, Higher Transcendental Functions, Vol. 2, McGraw-Hill (1953).
14. E. Janke, F. Emde, and F. Lösch, Special Functions, Functions, Graphs, and Tables [Russian translation], Nauka, Moscow (1968).
15. P. K. Chang, Separation of Flow, Pergamon (1970).
16. G. K. Batchelor, Introduction to Fluid Dynamics, Cambridge University Press (1967).
17. M. A. Lavrent'ev and B. V. Shabat, Problems in Hydrodynamics and Their Mathematical Modeling [in Russian], Nauka, Moscow (1973).

INFLUENCE OF THE CONCENTRATION INITIAL SECTION ON THE MAGNITUDE OF DIFFUSION FLUXES IN TURBULENT FLUID FLOW

Yu. E. Guber

UDC 532.517.4:536.2.242+629.7.063

Results of an experimental investigation of the influence of initial sections of a mass delivery surface on values of the Stanton number are presented.

A stabilized temperature (concentration) profile is achieved in very rare cases in turbulent fluid flows with Prandtl (Schmidt) numbers significantly greater than one (oil heat exchangers, electrochemical treatment in viscous electrolytes, etc.) and a length of the initial section of the transfer surface sufficiently large. Hence, the design dependences of the heat and mass transfer, obtained for a developed temperature (concentration) profile, are barely suitable under these conditions. The methods used at this time to take account of the influence of the initial thermal (diffusion) section on the average values of the Nusselt (Stanton) numbers [1, 2] are empirical in nature.

An experimental investigation was conducted in the range of Reynolds numbers between $1\cdot10^4$ and $1.3\cdot10^6$ and of Schmidt numbers, $1.5\cdot10^3$–$5.2\cdot10^4$, on two experimental setups. The change in the limit diffusion currents in an oxidation—reduction reaction on potassium ferroferricyanide which proceeds on solid electrodes is studied in the research as a function of the extent of the electrode along the flow. The method of conducting the tests and the experimental setups are described in detail in [3, 4]. The electrodes were glued flush with the side surface of a rotating cylinder. The rotating cylinder has definite advantages over other

S. Lazo Kishinev Polytechnic Institute. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 32, No. 5, pp. 856-859, May, 1977. Original article submitted May 31, 1976.

objects because of the absence of an undeveloped hydrodynamic boundary layer on its side surface. When the whole cylinder side surface is the working surface, the diffusion problem is simplified, since the need to take account of the influence of the initial section on the mass delivery drops out. At the same time, the possibility of studying the mass transfer under conditions of an undeveloped concentration boundary layer with a completely developed hydrodynamic boundary layer appears on rotating cylinders for which the extent of the working surface along the circumference is limited.

Nickel electrodes 20 mm high along the cylinder generator were located at an equal distance from the end faces of a 70-mm-high and 100-mm-diameter cylinder. The influence of the initial section of the transfer surface on the mass delivery was studied on electrodes of 2, 5, 10, 20, and 85 mm extent along the circumference of the cylinder. The diffusion fluxes under conditions of a fully developed concentration profile were measured on working cylinders on which the electrode was located along the whole circumference of the cylinder (314 mm long).

In the absence of influence of the initial section of the mass delivery surface, the experimental results correspond, with 7% accuracy, to the solution of the convective mass-transfer differential equation

$$\frac{\partial}{\partial y_+}\left[\left(\frac{1}{\mathrm{Sc}}+by_+^n\right)\frac{\partial \bar{c}_+}{\partial y_+}\right]=0 \tag{1}$$

with the boundary conditions

$$\bar{c}_+(0)=0,\quad \bar{c}_+(\infty)=1 \tag{2}$$

obtained in [5]. For a damping law of the turbulent transfer coefficient in a viscous sublayer, which follows from tests on rotating cylinders, on which the concentration boundary layer was fully developed [3]:

$$\frac{\varepsilon}{\nu}=2.7\cdot 10^{-4}y_+^4, \tag{3}$$

this solution results in the dependence

$$\mathrm{St}_\infty=0.115\mathrm{Sc}^{-3/4}\sqrt{\frac{c_f}{2}}. \tag{4}$$

The hydrodynamic drag coefficient of a cylinder rotating in the cylindrical vessel of the first setup was computed by means of the formula

$$\frac{1}{\sqrt{c_f}}=-0.6+4.07\lg \mathrm{Re}\sqrt{c_f}, \tag{5}$$

which correlates the test data of direct measurements [6]. Values of the hydrodynamic drag coefficients of a cylinder rotating in the hexagonal working vessel of the second apparatus were determined from test results on mass delivery, obtained on electrodes with a fully developed concentration boundary layer and on electrodes from which the turbulent transfer could be neglected [3].

The set of values of the Stanton number obtained in tests and averaged along the electrode length

$$\overline{\mathrm{St}}=\frac{\overline{\mathrm{Nu}}}{\mathrm{Re}\cdot\mathrm{Sc}}\sqrt{\frac{c_f}{2}} \tag{6}$$

as a function of the dimensionless extent of the electrode along the flow

$$\xi_L=2.1\cdot 10^{-3}\,\frac{\mathrm{Re}\sqrt{\frac{c_f}{2}}}{\mathrm{Sc}^{1/4}}\cdot\frac{L}{r} \tag{7}$$

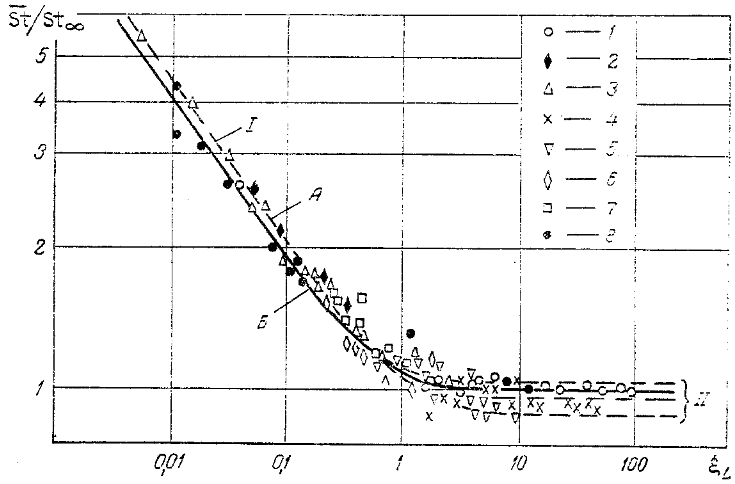

Fig. 1. Influence of the extent of the transfer surface on the diffusion fluxes to turbulent flows. A) Experimental results: 1-3) cylinder, electrochemical method, setup No. 1 [1) L = 314 mm; 2) 10; 3) 2]; 4-7) cylinder, electrochemical method, setup No. 2 [4) L = 85 mm; 5) 20; 6) 10; 7) 5]; 8) tube, dissolution method, results [8]; B) theoretical curve according to [7]: $I — \frac{\overline{St}}{St_\infty} = 0.92\xi_L^{-\frac{1}{3}}$; $II — \frac{\overline{St}}{St_\infty} = 1 + \frac{1}{100\,\xi_L}\left(1.33 - e^{-10\xi_L}\right)\left[8 + \left(\frac{L}{r}\right)^{0.5}\right]$

is described well by two interpolation relationships (Fig. 1):

$$\text{for } \xi_L \leqslant 0.1 \quad \frac{\overline{St}}{St_\infty} = 0.92\xi_L^{-1/3}, \tag{8}$$

$$\text{for } \xi_L > 0.1, \quad \frac{\overline{St}}{St_\infty} = 1 + \frac{1}{100\,\xi_L}\,[1.33 - \exp(-10\xi_L)]\left[8 + \left(\frac{L}{r}\right)^{0.5}\right]. \tag{9}$$

This result agrees with the solution of the differential equation of convective diffusion to a surface of any extent along the flow, executed in [7].

Since the wall curvature exerts no essential influence on the magnitude of the thermal (diffusion) fluxes for Pr(Sc) >> 1, it can be assumed that the relationships $\overline{St}/St_\infty = \psi(\xi_L)$ are also valid for plates, tubes, and other objects. This is indeed indicated by the test results [8] presented in the figure, which were obtained by dissolution of different sections of the inner surface of a cylindrical tube along the length.

NOTATION

b, constant in the law for damping of the turbulent transfer coefficient; n, exponent in the damping law; c, concentration; c_∞, concentration in the volume; c_+, dimensionless concentration; $\sqrt{c_f/2}$, hydrodynamic drag coefficient; L, extent of the electrode along the flow; r, cylinder radius (characteristic dimension); W_*, dynamic viscosity; $y_+ = yW_*/\nu$, dimensionless coordinate in a direction perpendicular to the wall; ε, turbulent transfer coefficient; ν, coefficient of kinematic viscosity; ξ_L, dimensionless extent of the electrode along the flow; Pr, Prandtl number; Sc, Schmidt number; St, Stanton number ($\overline{St}$ averaged along the length of the electrode; St_∞ under conditions of a fully developed concentration boundary layer); Nu, Nusselt number; Re, Reynolds number.

LITERATURE CITED

1. M. A. Mikheev and I. M. Mikheeva, Principles of Heat Transfer [in Russian], Énergiya, Moscow (1973).

2. W. M. Kays, Convective Heat and Mass Transfer, McGraw-Hill (1966).
3. Yu. E. Guber, T. S. Kornienko, and M. Kh. Kishinevskii, in: Papers of the Technology Faculty of Kishinev Polytechnic Institute [in Russian], No. 24, Kishinev (1971).
4. M. Kh. Kishinevskii, T. S. Kornienko, and Yu. E. Guber, Élektrokhimiya, 8, No. 4 (1972).
5. J. G. Son and T. G. Hanratty, Amer. Inst. Chem. Eng. J., 13, No. 4 (1967).
6. T. Theodorsen and A. Regier, NACA Rept., No. 793 (1944).
7. M. Kh. Kishinevskii and T. S. Kornienko, Teor. Osn. Khim. Tekhnol., 5, No. 4 (1974).
8. T. S. Kornienko, V. V. Kyaburu, and M. Kh. Kishinevskii, Teor. Osn. Khim. Tekhnol., 6, No. 5 (1972).

WALL—PARTICLE INTERACTION IN A VERTICAL GAS SUSPENSION FLOW

N. I. Gel'perin, L. I. Krupnik,
Z. N. Memedlyaev, and V. G. Ainshtein

UDC 621.547

The results of an experimental investigation of the carrier velocity fields in a vertical gas suspension flow are presented, and the development of the shear stress due to interaction between the particles and the channel walls is analyzed.

A quantitative evaluation of the relation between the velocity distribution in a developed turbulent continuum flow and the tangential wall stress (τ_g), based on the Prandtl mixing length hypothesis, leads to the logarithmic law:

$$\frac{w}{w_*^g} = A_0 \lg \frac{w_*^g y}{\nu} + B_0. \tag{1}$$

With respect to gas suspension flows, on the interval $30 \leq w_*^g y/\nu \leq 700$ this law quite satisfactorily describes [1-3] the velocity field of the carrier medium [at various mean velocities w_m = 8-30 m/sec and solids flow concentrations μ_f = 0.1-16 $(kg \cdot h^{-1})/(kg \cdot h^{-1})$] as deformed by the presence of the solid particles.

Investigations were carried out [2, 3] by means of a Pitot tube in channel sections of diameter D = 2R = 50 mm with various degrees of hydrodynamic flow stabilization L/D = 11-111. In the experiments we used narrow fractions of quartz sand of diameter d = 0.17 mm, AV-17 anion-exchange resin d = 0.52 mm, glass pellets d = 1.3 mm, corundum pellets d = 1.05 mm, and wheat d = 3.9 mm. Values of $\tau_g(w_*^g)$ were obtained from the data of measurements of the local carrier velocities w(y), using Clauser's method of nets [1] and Preston's equation [2]. In Fig. 1 we present the results of an investigation of the carrier velocity fields on the stabilized section (L/D = 100) of a vertical gas suspension flow. Clearly, in the inner region of the turbulent flow core all the experimental data (Fig. 1a) are grouped about dependence (1) with constants A_0 and B_0 equal to 5.5 and 5.8, respectively. It is noteworthy that, according to Nikuradze's data [4], the values A_0 = 5.5 and B_0 = 5.8 most accurately describe the experimental points in the turbulent wall region (y/R ≈ 0.2) of continuum flows.

Attempts have been made to use an equation of type (1) to calculate the total resistance of a gas suspension flow (τ_t, ΔP_t) including, in addition to the carrier friction losses (τ_g, ΔP_g), the energy expended on keeping the particles in the suspended state (τ_s, ΔP_s) and the losses (τ_w, ΔP_w) due to interaction between the particles and the channel walls (friction, collision).† For this purpose the gas suspension is treated [5, 6] as a quasihomogeneous

†The introduction of the "tangential" stresses τ_s, τ_w and the corresponding dynamic flow velocities is justified only phenomenologically and constitutes a convenient mathematical technique.

Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 32, No. 5, pp. 860-864, May, 1977. Original article submitted May 20, 1976.