EXPERIMENTAL STUDY OF TURBULENT FRICTION IN A FLAT DIFFUSOR BY THE ELECTROCHEMICAL METHOD

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The results are presented for an experimental study by the electrodiffusion method of the surface friction during turbulent movement of an incompressible liquid in a flat diffusor with an expansion angle of 2°. A comparison of the experimental data with the values of the surface friction obtained by Clauser's method gives satisfactory correspondence.

The use of the characteristics of turbulent flows in the presence of a pressure gradient represents an important scientific and technical problem. Knowledge of the shear stress at the wall has great importance for the calculation of such flows and the understanding of their structure. Measurements of the coefficient of surface friction have been made, in particular, using a thermal pickup [1], using Clauser's method [2, 3], and using surface tubes [4, 5]. However, none of these methods is versatile enough in a broad range of variation in the conditions. The most serious drawback of these methods is the basic necessity of calibration which can be conducted only in a stream without a gradient, which differs greatly in its characteristics from a stream with a significant pressure gradient.

In the present work the electrodiffusion method [6, 7] was chosen for the measurement of surface friction. An electrochemical exchange reaction between potassium ferri- and ferrocyanide takes place at the electrode which is embedded flush with the surface. The Schmidt number is 2400 so that with small enough pickup sizes the diffusion boundary layer lies deep within the viscous sublayer. The high rate of the electrochemical reaction makes it possible to measure the pulsation characteristics of the flow.

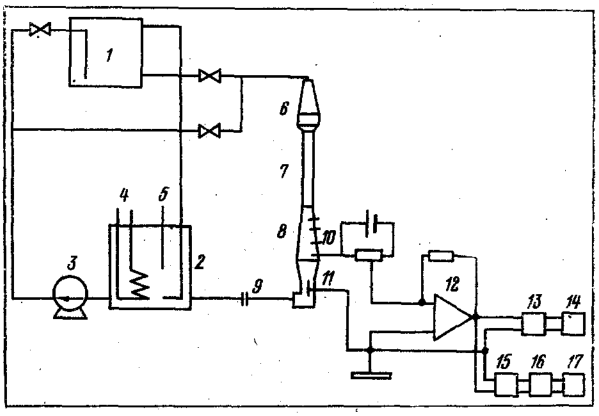

Fig. 1

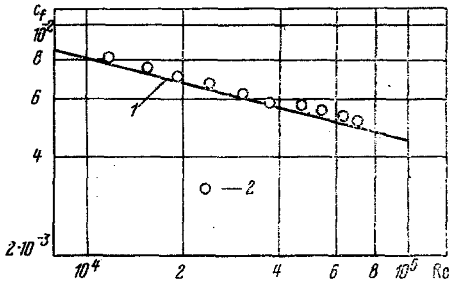

Fig. 2

Fig. 1. Diagram of measurements of surface friction: 1) constant level tank; 2) lower tank; 3) pump; 4) supply of cooling water; 5) nitrogen line; 6) entry diffusor, forechamber, convergent channel; 7) flat channel; 8) test section; 9) flow meter; 10) electrodiffusion pickups (cathode); 11) anode; 12) direct current amplifier; 13) RC filter; 14) recording potentiometer; 15) squarer; 16) RC filter; 17) recording potentiometer.

Fig. 2. Comparison of experimental data with empirical equation: 1) $\xi = 0.079/\mathrm{Re}^{0.25}$; 2) experimental data obtained by pickup 0.5 mm in diameter.

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TABLE 1. Values of Shear Stress at Wall

$Re \cdot 10^{-3}$	τ, N/m²				
	x=0,058m	x=0,089m	x=0,110 m	x=0,141 m	x=0,172 m
1,17	0,825	0,755	0,566	0,471	0,385
1,53	1,41	1,16	0,867	0,714	0,600
1,93	2,18	1,72	1,26	1,04	0,844
2,41	3,32	2,44	1,74	1,45	1,19
3,08	5,21	3,64	2,64	2,13	1,78
3,71	7,30	4,94	3,62	2,95	2,46
4,66	11,0	7,42	5,60	4,50	3,88
5,41	14,3	9,68	7,26	5,81	5,01
6,30	18,3	12,4	9,25	7,47	6,30
7,05	22,4	15,0	11,1	9,00	7,64

Despite the fact that some of the limitations of the thermoanemometer are inherent to the electrochemical method, this method is one of the most suitable for measuring the characteristics of turbulent flows with pressure gradients.

A diagram of the experimental apparatus is presented in Fig. 1.

The test section was made in such a way that a plate having sockets in it for the electrochemical pickups fitted into it on one side. Plugs containing openings for taking the static pressure were inserted in the same sockets (there were five sockets in all). Openings with a diameter of 0.4 mm were drilled in the plugs. A Pitot tube, whose tip was positioned in the same cross sections in which the electrochemical pickups were located, was introduced into the test section from the other side.

Two kinds of electrochemical pickups were used to measure the surface friction: one made of platinum wire 0.5 mm in diameter for measurements of the average current and one with dimensions 0.020 × 0.200 mm for measurements of the root-mean-square values of the current in the cell. This was connected with the fact that the effect of impurities showed up less on pickups of larger sizes but they were unsuitable for measurements of the root-mean-square values of the current pulsations since their transmission function drops sharply at relatively low frequencies [6]. Pickups of small sizes, while they had less stability, made it possible to measure an additional component of the surface friction.

As is known, in a quasi-stationary approximation one can write

$$\bar{\tau} \sim \overline{I^3} = \bar{I}^3\left[1+3\left(\frac{\sqrt{\overline{I'^2}}}{\bar{I}}\right)^2\right].$$

Hence it is seen that for the measurement of the average values of the surface friction it is sufficient to measure the average current and the root-mean-square value of the current pulsations in the electrochemical cell.

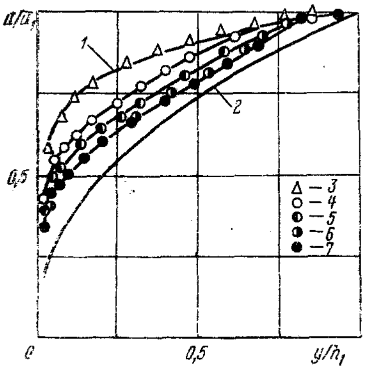

Fig. 3

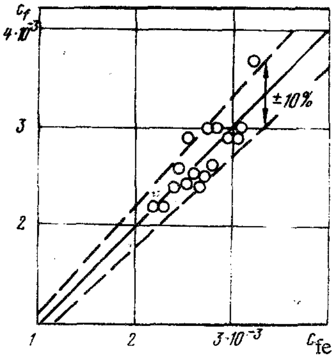

Fig. 4

Fig. 3. Velocity profiles: 1) $u/u_1 = (y/h_1)^{1/7}$; 2) $u/u_1 = (y/h_1)^{0.43}$ (see [2]); 3) flat channel; 4) x = 0.089 m; 5) 0.110; 6) 0.141; 7) 0.172 m.

Fig. 4. Comparison of coefficients of surface friction obtained by the following methods: c_{fe}, using the electrochemical method; c_f, using Clauser's method.

A diagram of the surface friction measurements is presented in Fig. 1. The signal from the electrochemical cell enters the direct current amplifier 12, and two lines operate in parallel after the amplifier: the first is for measurements of the average current in the cell and the second is for measurements of the root-mean-square value of the current pulsations. In the first line the signal from the amplifier enters an RC filter with a time constant of 15 sec and then goes to the KSP-4 recording potentiometer 14. In the second line the pulsation component of the signal is first isolated and then sent to the squarer 15 and then, as in the first line, to the filter 16 and recording potentiometer 17. The high frequencies of the current oscillations and the square of the current pulsations are averaged by the filters 13 and 16, and the average of the low-frequency oscillations of these values is derived from the records of the recording potentiometers. The frequency characteristic of the squarer was uniform in the frequency band from 0.1 to 3 kHz.

The surface of the pickups more than 0.2 mm in size was determined in a UIM-1 microscope and the pickups of smaller sizes were photographed in an MBI-6 microscope. In this case the surface of the pickup was determined from the photograph.

To test the method of measuring the surface friction the first experiments were conducted in a flat channel with different Reynolds numbers. In this case the flat section was mounted at the site of the test diffusor after a preconnected flat channel which produced completely stabilized liquid flow.

In a flat channel $\bar{I}^3$ and $\overline{I^3}$ differ by no more than 3%, since under these conditions the relative value of the friction pulsation does not exceed 30%.

The results of a comparison of the coefficients of surface friction obtained (on pickups 0.5 mm in diameter) with the empirical equation

$$\xi = \frac{0.079}{\mathrm{Re}^{0.25}}$$

are shown in Fig. 2.

Good correspondence of the data is observed. The results of the measurement of shear stress by the electrochemical method differ from the values calculated from the equation by no more than 5-7%.

The main experiments were conducted in a flat diffusor with an expansion half-angle of 2° and an entrance cross section of 10 × 120 mm. The electrochemical pickups were located at distances of 58, 89, 110, 141, and 172 mm from the entrance to the diffusor (distance reckoned along the wall). All the sockets were adjusted to one size so that all the measurements were made by one pickup which was successively moved from one cross section to the next. The surface friction was measured in five cross sections and velocity profiles were measured in the last four cross sections.

The velocity profiles in the four cross sections are presented in Fig. 3 for $\mathrm{Re} = 7.05 \cdot 10^4$:

$$\mathrm{Re} = \frac{\bar{u}2h}{\nu}.$$

Also shown here is an experimental velocity profile in the flat channel, which agrees well with the law $u/u_1 = (y/h_1)^{1/7}$. The velocity profiles were analyzed in the coordinates

$$\varphi = \frac{u}{u_\tau}, \quad \eta = \frac{yu_\tau}{\nu}.$$

The analysis of the velocity profiles in these coordinates showed that they all have a general logarithmic section. This circumstance allowed us to use Clauser's method to calculate the surface friction from the experimental velocity profiles [8].

The following equation [8] was used to calculate c_f:

$$\frac{u}{u_\tau} = \frac{1}{\varkappa} \ln\left(\frac{yu_\tau}{\nu}\right) + c; \; \varkappa = 0.4; \; c = 5.0; \; \frac{u}{u_1}\sqrt{\frac{2}{c_f}} = \frac{1}{\varkappa} \ln\left(\frac{yu_1}{\nu}\sqrt{\frac{c_f}{2}}\right) + c.$$

The value of c_f was calculated by the method of successive approximations for all the points of the profile lying within the region $50 < \eta < 200$ (for the first approximation it was assumed that $(\sqrt{c_f/2})_0 = 0.1$). Then the average value of the surface friction corresponding to the given cross section was calculated.

It is shown in Fig. 4 that the surface friction determined by the two methods, the electrochemical method and Clauser's method, differs by no more than 10% (with a few exceptions). Such a comparison shows that it is possible to determine the surface friction in gradient flows of fluids in channels by using measurements of velocity profiles.

Values of the shear stress at the wall obtained by the electrochemical method in five cross sections of the diffusor at several Reynolds numbers are shown in Table 1.

NOTATION

c_f	is the coefficient of surface friction;
τ	is the shear stress at wall;
I	is the pickup current;
I'	is the pulsation component of current;
Re	is the Reynolds number;
u	is the flow velocity;
u_1	is the flow velocity at axis of channel;
y	is the transverse coordinate;
ξ	is the coefficient of friction;
x	is the longitudinal coordinate (along wall);
h	is the half of channel height at entrance;
h_1	is the half of channel height at given cross section;
U_τ	is the rate of friction;
$\bar{u}$	is the average velocity in given cross section.

Subscripts

The bar $-$ pertains to average values.

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