EXPERIMENTAL DETERMINATION OF THE COEFFICIENT OF DISCHARGE FROM A CHANNEL THROUGH PERFORATED WALLS

A. D. Rekin

UDC 532.5(083)

Values of discharge coefficient are found for the flow of air from one channel to another through a perforated wall with different dynamic pressures for the flows in both channels.

In modern practice, the surfaces of a body are commonly protected from the thermal action of a high-temperature gas flow by the use of porous materials. In several cases of practical importance, when gradual blockage of the pores leads to instability of the hydraulic characteristics of the porous materials, it is best to replace the latter with perforated plate materials with a large number of holes of a diameter equal to the order of thickness of the wall. Bernoulli's equation for gas or liquid streams flowing through holes in such a wall can be used to express the mean velocity of flow of the gas through the wall, analogous to the injection velocity in studying porous cooling, in the form

$$v_w = \mu c \sqrt{2\Delta p/\rho}, \tag{1}$$

where the discharge coefficient μ considers the compression of the cross section of the streams in the holes and the losses due to the viscosity of a real gas.

A theoretical solution, with determination of the discharge coefficient, has been obtained only for an ideal fluid flowing from a plane channel into a stationary medium through a slit in a channel wall of zero thickness [1]. Parameters were found characterizing the value of the discharge coefficient: $\Delta p/q_c$ and d/H. It was shown that at $\Delta p/q_c = 0$ the value of μ is equal to zero, while at $\Delta p/q_c \gg 1$ it asymptotically approaches the limiting value μ_∞.

Results of an experimental determination of μ in the discharge of air from a channel into a stationary medium through single slits or holes were presented in [1], while results for numerous holes (through a perforated wall) were presented in [2]. Both studies were done only for large values of $\Delta p/q_c$, when the value of μ turned out to be close to limiting. The same works presented results of tests in which μ was determined in the flow of air from a large cavity (i.e., in the absence of directed movement of the air in the cavity) into an infinite entraining flow. Similar values of μ were obtained for both a perforated wall and for single holes with $\Delta p/q_f \gg 1$. Meanwhile, for small $\Delta p/q_f$, the values of μ proved to be considerably greater for a perforated wall than for single holes (in view of the reduction in the effective value of q_f for subsequent series of holes in the perforated wall compared to the first row [2]).

In the present work, we determined μ in the flow of air from a single channel to another through a perforated wall with different dynamic pressures for the flows in both channels.

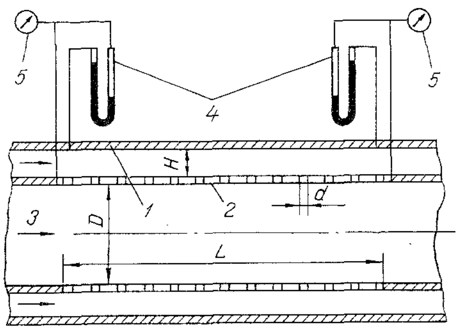

Fig. 1. Diagram of model: 1) outer tube; 2) inner tube with perforated section; 3) direction of air flow; 4) differential manometers; 5) manometers.

Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 43, No. 1, pp. 54-58, July, 1982. Original article submitted April 27, 1981.

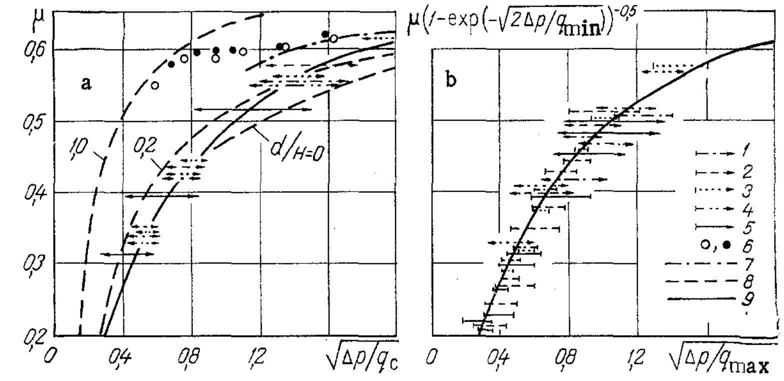

Fig. 2. Dependence of coefficient of discharge from a channel on the dimensionless pressure drop on a wall (a — in a stationary medium; b — in a moving medium) according to test results [1-5) for sections 1-5, respectively; 6) for single hole and slit, respectively [1]; 7) discharge through a perforated plate [2]] and calculations [8) according to the theoretical solution in [1]; 9) according to Eqs. (2) or (3)].

The model used in the experiment was two coaxial tubes (Fig. 1). The internal diameter of the outer perforated tube was 32 mm, while that of the replaceable inner tubes with perforated sections D = 20 mm. The walls of the tubes were 1 mm thick. The diameters of the holes and the frequency of their placement on the investigated sections Nos. 1-5 are shown in Table 1. The length L for sections Nos. 1, 2, 4, and 5 was 70 mm, while L = 140 mm for section No. 3 (with low permeability).

The flow of air through the wall in the perforated section was directed both from the inner tube into the outer annular channel and in the opposite direction. In the tests, we measured the air flow rate in the inner tube and in the annular channel (using specially graduated measuring rings), the difference in static pressures in the channels (using differential water-column manometers), and the absolute pressures. All measurements were made at the beginning and end of the perforated section. Air was supplied to the model at an ambient temperature of 290-293°K.

The value of μ was calculated, in accordance with Eq. (1), from the change in the air flow rate in the inner tube on the perforated section and the mean value of $\sqrt{\Delta p}$ on this section. The Reynolds number Re_D, determined from the mean mass velocity of the air flow in the tube at the beginning of the perforated section and the tube diameter, varied during the tests from $3 \cdot 10^4$ to 10^5. The number Re_H for the annular channel was $(3-7) \cdot 10^4$, while the number Re_d for the holes was $(1-6) \cdot 10^3$. The dynamic pressure of the flow in both channels was calculated on the assumption that the air flow was unidimensional, i.e., that $q = G^2/(2\rho \cdot F^2)$, where F is the cross-sectional area of the channel and G is the air flow rate at the investigated cross section. The maximum possible error of the discharge coefficient (at low values of the latter) was about 20%.

We first conducted tests with the air flowing from the inner tube, with no outer tube ($q_f = 0$). The results of calculation of μ for different perforated sections are shown in Fig. 2a in relation to the parameters $\sqrt{\Delta p/q_c}$ (in the present case, $\Delta p = p_c - p_0$, where p_0 is the external pressure). Since the static pressure and the dynamic pressure at the ends of the perforated section turn out to be equal, the range of variation of the parameter $\sqrt{\Delta p/q_c}$ within which one mean value of μ is found is indicated in Fig. 2a by segments with arrows. Assuming that the dependence of μ on $\sqrt{\Delta p/q_c}$ is the same for all of the sections investigated (in view of $d/D \ll 1$), we will draw one approximating curve. This curve is described by the formula

$$\mu = \mu_\infty [1 - \exp(-\sqrt{2\Delta p/q_c})]. \qquad (2)$$

The curve intersects all of the straight-line segments in Fig. 2a. We took the empirically determined discharge coefficient of a fluid through a single hole in a thin wall (dividing

TABLE 1. Characteristics of the Perforated Sections

Section No.	d, mm	Frequency of holes per cm²	c
1	0,8	4,52	0,0227
2	2,0	0,74	0,0233
3	0,8	2,26	0,0113
4	1,2	2,26	0,0255
5	1,7	2,26	0,0510

two stationary media) as the limiting value of μ_∞ here. In the range of Reynolds numbers $Re_d = 100$-10,000, μ is nearly constant and is equal to 0.65 [3].

Figure 2a shows theoretical values of μ (dashed lines) in the flow of an ideal fluid from a plane channel of height H through a single slit of width $d/H = 0$, 0.2, and 1.0 [1]. The quantity d/D had values within the range 0.04-0.1 in the tests. It can be seen that the theoretical values of μ for the slit proved to be close to the empirical values found for holes in a perforated wall. This agreement was favored by the fact that the reduction in μ due to friction losses in the holes are negligible with a thin wall compared to the constriction of the jet cross section in the holes (at $Re_d > 1000$). Also, additional tests were conducted with section No. 5 with the installation of a packet of grids in the tube 100 mm in front of the perforated section, to even out the velocity profile. A developed "tube" velocity profile was realized in the above-described tests in the air flow. Measurements of longitudinal velocity were made at the beginning and end of the perforated section by means of L-shaped full- and static-pressure tubes 1 mm in diameter. The measurements showed that there is a slight change in the velocity profile along the 70-mm perforated section both in the case of an equalizing grid and without the grid. The values of μ found in the additional tests were nearly the same (within the limits of accuracy of the experiment) as without the grids in the tube. Thus, in a first approximation, we may ignore the effect of the longitudinal velocity profile (within the limits of its change from uniform to developed-tube) on the discharge coefficient.

Figure 2a also show experimentally determined values of μ for the discharge of air from the channel through a single slit with $d/H = 1$ [1], through a single hole with $d/H = 2$ [1], and through a plane perforated wall with $d/H = 0.07$-0.18 [2]. It can be seen that the values of μ for single holes and slits are higher than for the perforated tube due to the higher value of d/H, which also follows from the analytical solution in [1].

The value of μ was determined for sections Nos. 1, 2, 3, and 5 in the presence of gas flows from both sides of the perforated wall. The initial longitudinal-velocity profile, determined in the outer annular channel ahead of the test section (using the above-described tubes), was developed. There was a marked change in this channel, however, along the 70-mm perforated section: the velocity maximum was shifted toward the outer, nonperforated wall when air was injected into the channel and was shifted toward the inner, perforated wall when air was withdrawn. However, even with high injection rates, there was not such an appreciable change in the velocity profile around the permeable wall (up to "separation") as there was with injection into an open flow. It was evidently as a result of this that we were unable (within the experimental error) to find a difference in values of μ with a change in the air flow direction from the tube into the annular channel in the reverse direction. All of the values of μ found can be approximately correlated by means of the relation

$$\mu\,[1-\exp(-\sqrt{2\Delta p/q_{min}})]^{-0.5} = \mu_\infty\,[1-\exp(-\sqrt{2\Delta p/q_{max}})]. \tag{3}$$

In accordance with Eq. (3), Fig. 2b shows all of the test results, except for those already shown in Fig. 2a. Plotted off the x axis is the value of the parameter $\sqrt{\Delta p/q}$, with selection of the maximum value of q from q_c or q_f (here, as in Fig. 2a, the range of variation in this parameter on the test section is plotted). The presence of the arrows to distinguish line segments denotes flow of air from the tube into the annular channel, while the vertical lines denote flow in the opposite direction. The values of μ off the y axis were corrected with respect to the mean (along the perforated section) value of q_{min} (q_f or q_c). It can be seen from Fig. 2b that Eq. (3) (solid line) satisfactorily describes the experimental data. The correlation of the test results shown in Fig. 2a with Eq. (3), which converts to Eq. (2) with $q_{min} = 0$ and $q_{max} = q_c$, was noted earlier.

NOTATION

μ, discharge coefficient; Δp, static pressure gradient on the permeable wall; q_c, dynamic pressure in the channel from which the discharge occurs; q_f, dynamic pressure of entraining flow; ρ, density; c, permeability of wall; d, diameter of holes or width of slit; D, diameter of tube; H, height of channel; Re, Reynolds number.

LITERATURE CITED

1. G. S. Shandorov, "Flow from a channel into stationary and moving media," Zh. Tekh. Fiz., 27, No. 1, 156-179 (1957).
2. V. V. Glazkov, M. D. Guseva, and B. A. Zhestkov, "Flow characteristics in a boundary layer on perforated plates," Izv. Akad. Nauk SSSR, Mekh. Zhidk. Gaza, No. 2, 182-187 (1977).
3. A. D. Al'tshul', Fluid Resistance [in Russian], Nedra, Moscow (1970).

ANALYSIS OF THE FLOW OF A NONLINEAR VISCOUS FLUID FOR CYCLIC DEFORMATION

N. G. Bekin, A. A. Lomov, and G. M. Goncharov

UDC 532.135

A hydrodynamic analysis was carried out for the propagation of shear vibrations in a layer of a nonlinear viscous "power-law" fluid.

Theoretical description and development of the methods of calculating and treating the cyclic deformation of polymeric materials are associated with great difficulties. They are caused not only by the necessity of solving nonlinear differential equations, but also of finding the acoustical characteristics of the substance being treated and their connections with its rheological properties. The following scheme of cyclic deformation is considered to be the most general one. A material is considered to be enclosed between two parallel plates, one of which executes harmonic vibrations in its plane (Fig. 1). In this case, from the vibrating plate there propagate shear waves perpendicular to the direction of motion of the plate. If the other plate is fixed, the waves are partly reflected from it, and partly damped. In the general case for a thin layer of fluid, the propagation of the waves can be described by the equation [1]

$$v = C_1 \exp i(-ky + \omega t) + C_2 \exp i(ky + \omega t). \tag{1}$$

In this case it is assumed that the waves excited by the vibrating plate are not distorted in form. This assumption is correct for the low-frequency range of cyclic deformation of highly viscous polymers and can be confirmed by using harmonic analysis of experimentally recorded low-frequency vibrations in a channel filled with a "power-law" material [2].

The boundary conditions in the present case have the form

$$v = v_0 \exp i\omega t \ \text{ for } \ y = 0, \ v = 0 \ \text{ for } \ y = h. \tag{2}$$

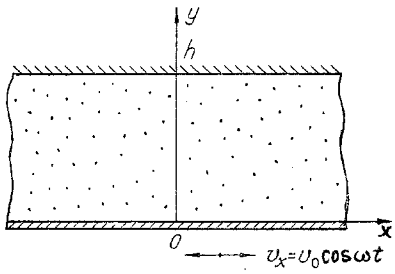

Fig. 1. Diagram of the deformation process.

Yaroslavl Polytechnic Institute. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 43, No. 1, pp. 58-62, July, 1982. Original article submitted May 14, 1981.

0022-0841/82/4301-0746$07.50