q_V, volume density of energy release; P, pressure; κ, relative coefficient of diffusion; Fo_m, modified Fourier criterion; ξ, coefficient of hydraulic resistance; and m, porosity of bundle of tubes with respect to the heat-transfer agent.

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FLOW IN A ROTATING SLOT CHANNEL WITH INJECTION THROUGH ONE WALL AND COMPENSATING SUCTION THROUGH THE OTHER

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UDC 532.516

The results of calculating the velocity field and integral characteristics for laminar conditions are presented and analyzed.

The use of porous materials is regarded as a promising trend in the improvement of convective cooling systems, including rotary components of power machinery. As a consequence, it is necessary to investigate the flow of coolant media in rotating channels with walls through which there is injection or suction. In a general formulation, this problem is extremely complex, since the field of hydrodynamic characteristics is significantly three-dimensional. However, as in the case of motionless channels with permeable walls [1, 2], a series of simple model problems may be formulated and solved, thereby elucidating the basic specific effects and obtaining the corresponding quantitative estimates. One such problem forms the subject of the present work.

Suppose that a prismatic slot channel of constant height 2h, in which a viscous liquid moves isothermally, is uniformly rotated at angular velocity ω relative to an axis perpendicular to the wide wall forming the slot. A Cartesian coordinate system 0, x, y, z is introduced; this system is rigidly connected to the channel, and is oriented so that the y axis is directed along the axis of rotation, the z axis is parallel to the lateral boundary wall of the channel in the direction of flow, and the coordinate origin is in the median plane of the channel.

Assume that the wide walls are of uniform porosity over the surface. At the wall $y = h_0$, $v_0 = \text{const} < 0$, which corresponds to injection. At the wall $y = -h$, the normal velocity is also v_0, i.e., there is suction equal in intensity to the injection. The side walls are impermeable. In these conditions, the liquid flow rate along the axis 0z is constant and the problem may be formulated for calculating developed flow, in which the relative-velocity field does not depend on the coordinate z. Limiting consideration to flow in the region far from the side walls, the equations of relative motion may be written in the form

$$\nu \frac{d^2u}{dy^2} = \frac{\partial p^*}{\partial x} + 2\omega w + v_0 \frac{du}{dy}, \tag{1}$$

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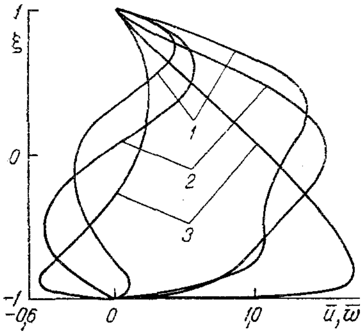

Fig. 1

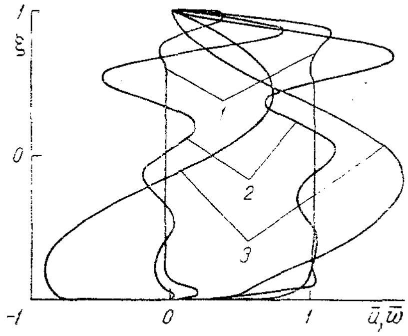

Fig. 2

Fig. 1. Velocity profiles for $\gamma = 4$: 1) $\varepsilon = 5$; 2) 10; 3) 30.
Fig. 2. Velocity profiles for $\gamma = 16$: 1) $\varepsilon = 10$; 2) 50; 3) 200.

$$0 = \frac{\partial p^*}{\partial y}, \tag{2}$$

$$\nu \frac{d^2 w}{dy^2} = \frac{\partial p^*}{\partial z} - 2\omega u + v_0 \frac{dw}{dy}. \tag{3}$$

The boundary conditions for the system in Eqs. (1)-(3) are

$$u = w = 0 \text{ when } y = \pm h. \tag{4}$$

It follows from Eqs. (1)-(3) that p^* is a linear function of the coordinates x, z

$$p^* = Ax + Bz + \text{const}.$$

To determine the constants A, B, there are two integral relations

$$\int_{-h}^{h} w dy = 2hw_m, \quad \int_{-h}^{h} u dy = 0, \tag{5}$$

the first of which is the condition for the specified flow rate to be present, while the second is a consequence of the impermeability of the channel side walls. The problem in Eqs. (1)-(5) was considered in [3] for the case when $v_0 = 0$.

In view of the linearity of the problem, it is expedient to formulate it using complex quantities. Introducing dimensionless variables here, Eqs. (1)-(5) are rewritten in the form

$$\frac{d^2\zeta}{d\xi^2} - \varepsilon \frac{d\zeta}{d\xi} - 2i\gamma^2\zeta = \gamma^2, \tag{6}$$

$$\zeta = 0 \text{ for } \xi = \pm 1, \tag{7}$$

$$w/w_m = \operatorname{Re}(c\zeta), \quad u/w_m = \operatorname{Im}(c\zeta), \tag{8}$$

$$c = 2 \Big/ \int_{-1}^{1} \zeta d\xi. \tag{9}$$

Solving Eq. (6) with the conditions in Eq. (7), it is found that

$$\zeta = \frac{i}{2}\left\{\frac{\exp(\lambda_1\xi)\operatorname{sh}\lambda_2 - \exp(\lambda_2\xi)\operatorname{sh}\lambda_1}{\operatorname{sh}(\lambda_1 - \lambda_2)} + 1\right\}, \tag{10}$$

$$\lambda_{1,2} = \frac{\varepsilon}{2} \pm \sqrt{\left(\frac{\varepsilon}{2}\right)^2 + 2i\gamma^2}. \tag{11}$$

The set of Eqs. (8)-(11) forms an explicit expression for calculating the velocity field in the channel. Note that the problem of flow between porous plates was considered earlier in [4]. However, the initial formulation of the problem there was somewhat different from that adopted here, the solution was determined by a cumbersome expression, and the calculations were restricted to parameter values $\gamma \leq 2$, $\varepsilon \leq 5$.

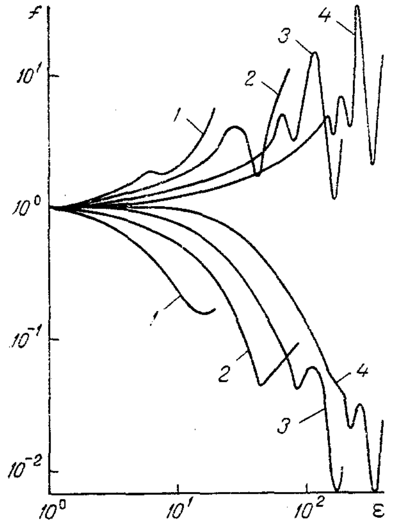

Fig. 3

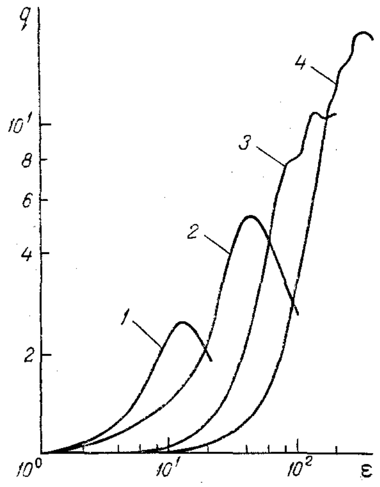

Fig. 4

Fig. 3. Dependence of the longitudinal component of friction at the wall on ε (the upper family corresponds to the wall with suction and the lower family to the wall with injection): 1) $\gamma = 4$; 2) 8; 3) 16; 4) 32.

Fig. 4. Dependence of the flow rate circulating in the transversal direction on the parameter ε: 1) $\gamma = 4$; 2) 8; 3) 16; 4) 32.

Profiles of the velocity components with various injection–suction intensities are shown in Figs. 1 and 2. For relatively low γ (Fig. 1), the rearrangement in the profile of the longitudinal velocity component with increase in ε consists in disappearance of the M-shaped form characteristic of flow with impermeable walls [3] and shift of the velocity maximum toward the wall with suction. When $\varepsilon \gg \gamma$, the profile $w(\xi)$ is close to the dependence

$$w = \frac{\varepsilon(\exp(\varepsilon\xi) - \operatorname{ch}\varepsilon - \xi \operatorname{sh}\varepsilon)}{\operatorname{sh}\varepsilon - \varepsilon \operatorname{ch}\varepsilon},$$

obtained in [2] for a nonrotating channel.

The most interesting features of the rearrangement of the profile of the transverse velocity component is degeneracy of the region with $u > 0$ at the wall with suction and the approach of the dependence $u(\xi)$ to antisymmetric form. Turning to the discussion of the results for large γ, it must be emphasized that, even when $\gamma \gtrsim 8$, the core with $w = \text{const}$ and $u = \text{const}$ is retained when $\varepsilon \lesssim 2\gamma$ (Fig. 2). At large ε in the central part of the channel, w and u oscillate around constant values; conditions with oscillatory $w(\xi)$, $u(\xi)$ are retained up to $\varepsilon \simeq 4.7\gamma - 20$, and then the velocity field is qualitatively restructured: in the dependence $w(\xi)$ there appears a single maximum shifted to the wall with suction, and the dependence $u(\xi)$ approaches antisymmetric form.

The results of calculating the ratio of the longitudinal component of the friction to the corresponding quantity obtained with $\varepsilon = 0$ and the same value of γ for both channel walls are shown in Fig. 3. It is evident that the variation in friction with increase in ε is very strong, and that $f < 1$ at the wall with injection, while $f > 1$ at the opposite wall. The oscillatory behavior of the dependence $f(\varepsilon)$ at large ε is also noteworthy.

The flow rate circulating in the transversal direction is of special interest. The dependence of ε on q determined as a ratio of the integral quantity

$$I = \int_{-1}^{1} \varphi d\xi, \quad \varphi = \begin{cases} u \text{ when } u > 0, \\ 0 \text{ when } u < 0 \end{cases} \tag{12}$$

to the corresponding quantity calculated for the same γ with $\varepsilon = 0$ (data from [3]) is shown in Fig. 4 for four values of γ.

The results of the calculations show that, with definite combinations of γ and ε, around 25% of the flow rate along the channel may circulate in the transversal direction. In real situations, such intensive circulation may have a decisive influence on the heat-transfer characteristics in the rotating channel with permeable walls.

NOTATION

x, y, z, Cartesian coordinates; u, v, w, components of the velocity of relative motion; p^*, modified pressure; h, channel halfheight; ω, angular velocity of rotation of the channel; ν, kinematic viscosity; w_m, mean velocity over the flow rate in the direction of the z axis; v_0, injection rate; $\varepsilon = v_0 h/\nu$, Reynolds number based on the injection rate; $\gamma = h(\omega/\nu)^{1/2}$, rotational parameter; $\xi = y/h$, dimensionless coordinate; $\bar{u} = u/\omega_m$, $\bar{w} = w/w_m$, dimensionless velocity components; c, ζ, complex quantities; f, ratio of the longitudinal component of friction to the corresponding quantity obtained with $\varepsilon = 0$ and the same γ; q, ratio of the flow rate circulating in the transverse transversal direction – Eq. (12) – to the corresponding quantity calculated for the same γ with $\varepsilon = 0$.

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NONSTEADY NONISOTHERMAL FLOW OF COMPRESSIBLE GAS IN A CHANNEL WITH TRACK SAMPLING

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A method is proposed for forming a linear mathematical model of a pulsating gas flow with entropy waves, in the case of gas sampling distributed along a channel, and the sampling are compared with experimental data.

Linearized equations of hydromechanics, heat transfer, and chemical kinetics are used for dynamic analysis, the determination of the acoustic and vibrational loads, and calculation of the stability of processes in power, transport, chemical-engineering, and other equipment [1, 2]. A method of constructing linear mathematical models of nonsteady isothermal gas flow in a cylindrical channel with distributed sampling is considered. Examples of such a channel may be a gas pipeline with take-off to the customer, a gas-distribution system in motors, the collector of a turbine nozzle apparatus with gas supply through a single tube and take-off over a ring at the nozzle, etc. Nonisothermal nonsteady gas flow in a cylindrical channel is described by the following system of linearized equations for dimensionless deviations (variations) of the parameters, neglecting viscosity, heat conduction, and diffusion and assuming that $D \ll L$ and the one-dimensional approximation may be used.

$$\frac{\partial \delta u}{\partial t} + u\frac{\partial \delta u}{\partial x} + \frac{p}{\rho u}\frac{\partial \delta p}{\partial x} = 0;$$
$$\frac{\partial \delta p}{\partial t} + u\frac{\partial \delta p}{\partial x} + \frac{\rho u c^2}{p}\frac{\partial \delta u}{\partial x} = 0; \qquad (1)$$
$$\frac{\partial \delta s}{\partial t} + u\frac{\partial \delta s}{\partial x} = 0.$$

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