INTENSIFICATION OF CONVECTIVE HEAT TRANSFER IN THE LOCAL SWIRLING OF A FLOW OF AN ANOMALOUSLY VISCOUS FLUID BY SCREW SWIRLERS

Yu. G. Nazmeev

UDC 536.242.001.5

It is known that the use of screw swirlers to intensify convective heat transfer in channels makes it possible to significantly boost heat output. It was shown in [1] that such swirlers installed at the inlet of long heat-exchanger tubes increases the heat transfer coefficient by a factor of 1.6-2.5. However, all of the studies of screw swirlers that we know of have dealt with intensifying heat transfer in viscous media.

Since local swirling of the flow with screw swirlers provides a substantial benefit in terms of heat transfer in the flow of viscous fluids, it is the goal of the present work to experimentally determine the possibility of intensifying heat transfer in long tubes in the case of flow of anomalously viscous media and to evaluate the thermohydrodynamic efficiency of using such a method with such fluids.

Tests were conducted on an experimental unit working with a closed loop. The main working section was a 1-m-long steel tube 0.019 m in diameter. The roughness of the inside surface of the tube corresponded to a class 8-9 finish. The single-thread screw swirlers installed at the inlet of the working tube had central rods 0.006 m in diameter and were made of 0.8-mm-thick sheet steel. The swirlers had two turns of sheet in order to provide fuller swirling of the flow and at the same time reduce metal consumption. The outside diameter of the swirlers corresponded to the inside diameter of the working channel (0.019 m). We investigated screw swirlers ranging in relative pitch S/D from 0.36 to 1.73. The tests were conducted under steady thermal and hydrodynamic conditions with heating.

The experimental unit included the tube heat exchangers for preliminary and final control of the fluid temperature installed in front of the working-channel inlet. The temperature of the fluid at the channel inlet and outlet was measured with standard thermometers with graduations of 0.1°C. The pressure gradient was determined with a system of differential manometers placed over the entire length of the tube, including the initial section with the screw swirler. The Reynolds number was varied by changing the flow rate with a cock installed at the working-section outlet. The working section was heated with sectional Nichrome electric heaters which made it possible to vary the thermal boundary conditions. Additional sectional heaters were installed above the main heaters to compensate for heat losses.

As models of anomalously viscous fluids, we used 0.65 and 1.0% aqueous solutions of sodium carboxymethylcellulose (Na-CMC). The results of viscosity measurements of the model fluids in the temperature range 20-80°C are shown in Fig. 1. The thermophysical characteristics, determined in accordance with [2], are shown in Table 1. The empirical values of mean heat transfer coefficient were determined through the mean logarithmic temperature head

$$\bar{\alpha} = \frac{Q}{F\Delta\bar{t}_{\log}}. \tag{1}$$

The temperature of the channel wall was calculated as the weighted mean temperature along the channel

$$\bar{t}_{\mathrm{wa}} = \frac{\sum_{i=1}^{k} l_i (t_i + t_{i+1})}{2\sum_{i=1}^{k} l_i}. \tag{2}$$

Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 41, No. 4, pp. 669-673, October, 1981. Original article submitted October 1, 1980.

0022-0841/81/4104-1117$07.50

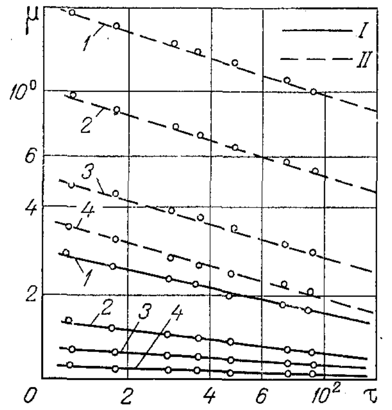

Fig. 1

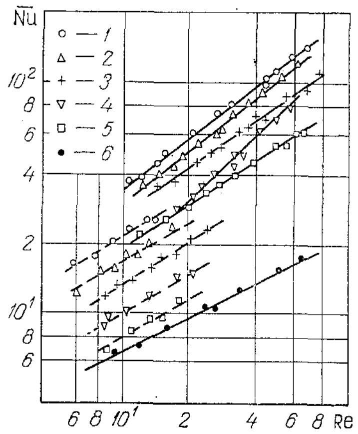

Fig. 2

Fig. 1. Results of viscosity measurements of the model fluids (1 — 20°C; 2 — 40; 3 — 60; 4 — 80): I) 0.65% Na-CMC; II) 1% Na-CMC. μ, Pa·sec; τ, Pa.

Fig. 2. The function $\overline{\mathrm{Nu}} = f(\mathrm{Re})$ for the investigated fluids ($l/D = 52.6$): 1) S/D = 0.36; 2) 0.73; 3) 0.95; 4) 1.26; 5) 1.73; 6) smooth channel (remaining notation the same as in Fig. 1).

TABLE 1. Thermophysical Characteristics of the Polymer Solutions

Aqueous soln. of Na-CMC, %	Meas. temp., °C	ρ, kg/m³	$c_p \cdot 10^3$, J/kg·deg	λ, W/m·deg
0,65	20	1014	3591	0,5618
	40	1011	3580	0,5615
	60	1009	3572	0,5614
	80	1006	3560	0,5611
1,0	20	1022	3572	0,5612
	40	1017	3510	0,5610
	60	1012	3530	0,5608
	80	1008	3540	0 5606

The working tube had a system of Chromel—Copel thermocouples sealed in the inside and outside surfaces of the wall which were used to monitor the wall temperature and maintain the thermal boundary conditions.

The magnitude of the effect realized by increasing the heat transfer coefficient in the tube with local swirling of the flow using screw swirlers was evaluated and the Reynolds number region of the maximum effect determined by analyzing the test results in the form of the function $\overline{\mathrm{Nu}} = f(\mathrm{Re})$ (Fig. 2). In the analysis, the inside diameter of the tube was taken as the characteristic geometric dimension, while the effective viscosity of the fluid was determined from the measured viscosities for the mean temperature and shear stresses along and across the flow. Tests were also conducted in a smooth channel without swirlers for the sake of comparison.

It is evident from a comparison of the test results with the data in [1] that the effect achieved in increasing the heat transfer coefficient in the case of local swirling of a flow with screw swirlers is much greater for the anomalously viscous fluid than for viscous fluids. There was as much as a sevenfold increase in the heat transfer rate compared to the smooth tube (0.65% Na-CMC).

Analysis shows that the heat-transfer rate decreases with an increase in the pitch of the screw swirler (Fig. 3). This tendency is most clearly manifest in the pattern of change in heat transfer relative to the pitch with an increase in the Reynolds number.

In evaluating the effect of the screw pitch on the relative change in the resistance coefficients ξ/ξ_0, where ξ was determined with allowance for losses in imparting rotation to the flow, it was established that the fluid resistance coefficient increases sharply with a

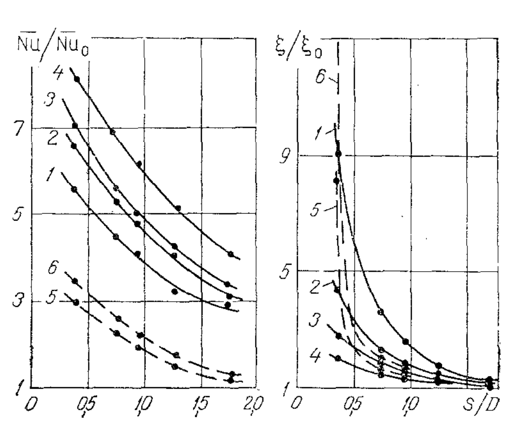

Fig. 3

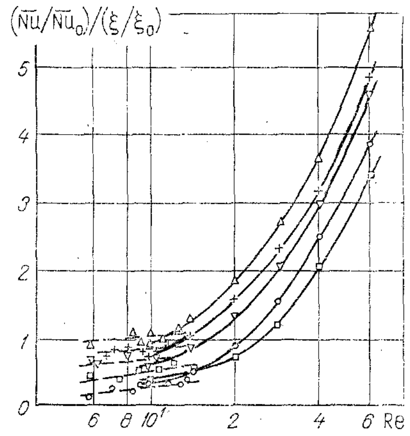

Fig. 4

Fig. 3. Effect of pitch of short (2 turns) single-thread screw swirler on the relative change in the heat transfer and fluid resistance coefficients: 1) Re = 15; 2) 30; 3) 40; 4) 60; 5) 7; 6) 20 (remaining notation the same as in Figs. 1 and 2).

Fig. 4. Thermohydrodynamic efficiency of using a short screw swirler to intensify convective heat transfer in anomalously viscous media (same notation as in Figs. 1 and 2).

decrease in pitch. The coefficient also increases with a reduction in the Reynolds number. With an increase in Re, the increase in heat transfer exceeds the increase in hydraulic losses (0.65% Na-CMC).

Since the use of heat-transfer intensifiers (such as the swirlers) is accompanied by an increase in hydraulic losses, according to [3, 4] the relationship between $\overline{Nu}/\overline{Nu}_0$ and ξ/ξ_0 may be considered one of the criteria of the efficiency of the chosen method of intensifying heat transfer. The overall thermohydrodynamic efficiency of the given heat-transfer intensifier in the form of the relation

$$(\overline{Nu}/\overline{Nu}_0)/(\xi/\xi_0) = t\,(\mathrm{Re}), \tag{3}$$

applicable for comparing objects with the same determining dimensions, was evaluated under the condition of reduction of the values of $\overline{Nu}$ and Re to the same values of Re for the smooth tube. The test results shown in Figs. 2 and 3 were analyzed in this manner.

Analysis of the relations (Fig. 4) shows that, with an increase in the effective viscosity of the fluid, the thermohydrodynamic efficiency of using short screw swirlers in long tubes to intensify convective heat transfer in anomalously viscous media decreases in connection with abrupt damping of the flow swirl beyond the intensifier.

Regarding the effect of the pitch of the screw on the overall thermohydrodynamic efficiency of its use with anomalously viscous media, it is apparent that the efficiency decreases sharply at a relative pitch S/D lower than 0.70 in connection with a predominant increase in fluid resistance. According to the test results, the optimum range of S/D is 0.7-1.2. Here, efficiency increases with an increase in the Reynolds number.

The rate of heat transfer exceeds the hydraulic losses by the greatest amount — fivefold — at effective viscosities below 0.18-0.25 Pa·sec. At higher values of effective viscosity, the use of a short screw intensifier yields almost no benefit in terms of increased heat transfer in long tubes, with hydraulic losses being substantial in this case.

The completed study has demonstrated the obvious promise of local screw swirlers for intensifying convective heat transfer in anomalously viscous media within a certain range of effective viscosity. In connection with this, it would definitely be interesting to obtain test data on the length of the swirled portion of a flow of an anomalously viscous medium and on the change in heat transfer along the tube. Such information will be forthcoming in later works.

NOTATION

S, pitch of screw swirler with 360° rotation; D, inside diameter of tube or outside diameter of swirler; $\bar{\alpha}$, mean heat transfer coefficient; F, area of heat-transfer surface; $\Delta\bar{t}_{log}$, mean logarithmic temperature head; Q, heat flux; $\bar{t}_{wa}$, mean wall temperature; t_i, t_{i+1}, thermocouple readings; l_i, distance between thermocouples; K, number of thermocouples; $\overline{Nu}$, ξ, mean Nusselt number and fluid resistance coefficient of tube with swirler; $\overline{Nu}_0$, ξ_0, same, for smooth tube; Re, Reynolds number; Pr, Prandtl number; μ, effective viscosity of fluid; τ, shear stress; ρ, density of fluid; C_p, specific heat; λ, thermal conductivity of fluid.

LITERATURE CITED

1. V. K. Shchukin, Heat Transfer and Hydrodynamics of Internal Flows in Body Force Fields [in Russian], Mashinostroenie, Moscow (1970).
2. G. M. Kondrat'ev, Thermal Measurements [in Russian], Mashgiz, Moscow—Leningrad (1957).
3. Yu. G. Nazmeev and N. A. Nikolaev, "Evaluating the efficiency of flow swirlers intensifying the process of heat transfer," Inzh.-Fiz. Zh., 36, No. 4, 653-657 (1979).
4. É. K. Kalinin, G. A. Dreitser, and S. A. Yarkho, Intensification of Heat Transfer in Channels [in Russian], Mashinostroenie, Moscow (1972).

NUMERICAL INVESTIGATION OF THE INTERACTION OF ISOTHERMAL, OPPOSITELY SWIRLING FLOWS IN AN ANNULAR CHANNEL

A. L. Dorfman and V. A. Maev

UDC 532.516

The influence of swirling of the flow in the recirculation zone behind the end surface separating oppositely swirling flows, in an annular channel in conditions of isothermal flow, is subjected to theoretical analysis.

A diagram of the investigated flow is shown in Fig. 1. At the inlet to an annular channel 1, formed by two coaxial cylinders 2, 3, swirling units 4, 5 are set up, separated by an annular divider 6, and creating swirling of the isothermal flow passing through them. The case where the swirling produced by the units 4 and 5 is oppositely directed is considered. The region investigated begins at cross section ad, and extends downstream a distance 4H (to cross section ef).

The system of equations of mean turbulent flow [1], considered in a cylindrical coordinated system under the assumption of axial symmetry, is closed by means of the introduction of the scalar turbulent viscosity, relating the components of the turbulent-stress tensor with the components of strain-rate tensor of the mean flow. To determine the turbulent viscosity, the mixing-path formula is used

$$\varepsilon = L^2 \sqrt{2\left(\frac{\partial u}{\partial x}\right)^2 + 2\left(\frac{\partial v}{\partial y}\right)^2 + 2\left(\frac{v}{y}\right)^2 + \left(\frac{\partial w}{\partial x}\right)^2 + \left(y\frac{\partial}{\partial y}\left(\frac{w}{y}\right)\right)^2 + \left(\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x}\right)^2}.$$

The distribution of the mixing path is described, in turn, by the relations

$$L = 0.4(y - R) \text{ when } y \leqslant R + 0.0225x, \quad L = 0.4(R + H - y)$$
$$\text{when } y \geqslant R + H - 0.0225x,$$
$$L = 0.06\sqrt{x(y - R)} \quad \text{when } R + 0.0225x \leqslant y \leqslant H/2 + R,$$
$$L = 0.06\sqrt{x(R + H - y)} \quad \text{when } R + H/2 \leqslant R + H - 0.0225x.$$

These relations imply, in particular, the proportionality of the mixing path to the square root of the distance from the cross section bc to the axis of the wake, which is found

V. I. Lenin "Nevskii Zavod" PO, Leningrad. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 41, No. 4, pp. 674-677, October, 1981. Original article submitted June 3, 1980.

0022-0841/81/1404-1120$07.50