THE TEMPERATURE FLUCTUATIONS IN A TURBULENT FLOW OF WATER CONTAINING A POLYMER

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Results are given on the mean temperature distribution and on the autocorrelation and spectral functions for the temperature fluctuations in a turbulent flow of water or a weak solution of polyacrylamide.

The literature contains numerous papers on the causes of resistance reduction and lower heat transfer in the turbulent flow of water containing certain macromolecular substances. Various hypotheses have been made to explain these effects, which involve thickening of the viscous sublayer, extension of the transient flow state, suppression of high-frequency pulsations, and so on.

It has been shown [1, 2] that macromolecular compounds produce a considerable reduction in the extents of transverse velocity fluctuations and an increase in the anisotropy of the turbulent eddies, together with a substantial increase in the intermediate region for the turbulent flow.

Here we present measurements on the temperature distribution and the fluctuation characteristics for the turbulent flow of water and a 0.012% solution of polyacrylamide.

The autocorrelation and spectral functions for the latter solution were calculated for a Reynolds number of about $2 \cdot 10^4$; the reduction in the resistance was dependent on the degree of destruction of the solution and varied from 70 to 40%.

The tests were done with a tube of 10×10 mm^2 and length 100 cm; three walls of the tube were made of lucite, while the fourth was made of chromium-plated copper. Heat was supplied uniformly through the copper plate from an electrical heater. The channel had a hydrodynamic stabilization length of 110 times the diameter.

The temperature fluctuations and the mean temperature were measured by ten thermocouples extending along the flow at different distances from the wall; the diameters of the wires were 0.09 mm, or else 0.6 mm for the two thermocouples nearest to the wall. These couples were 0.1 and 0.3 mm from the wall

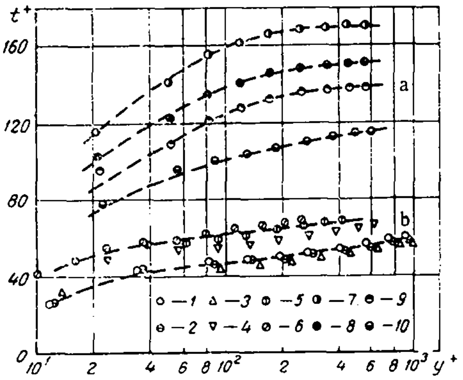

Fig. 1. Averaged temperature profiles in dimensionless coordinates: a, water; 1) Re = 21600; 2) 22200; 3) 24200; 4) 13500; 5) 8700; 6) 4880; b, 0.012% solution of polyacrylamide: 7) Re = 22200, $\zeta/\zeta_0 = 0.3$; 8) 21800 and 0.34; 9) 21600 and 0.38; 10) 20200 and 0.44. $t^+ = (t_{CT} - t)\rho c_p \bar{v}^*/q$.

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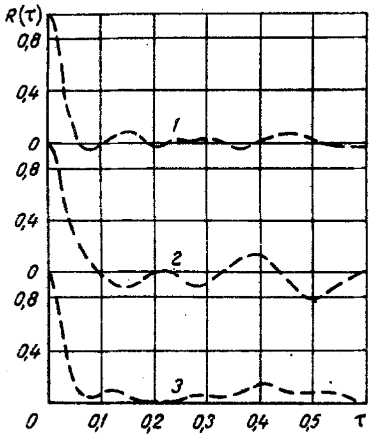

Fig. 2

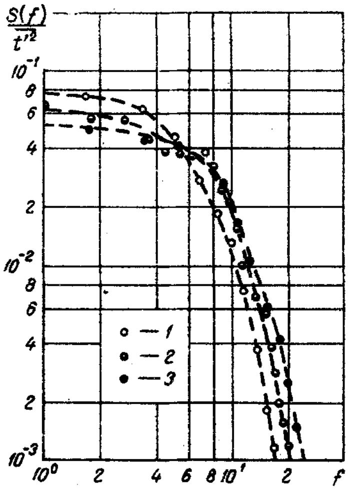

Fig. 3

Fig. 2. Autocorrelation function of temperature fluctuations: 1, water, Re = 22200; 2, 3, 0.012% polyacrylamide solution, Re = 22200, $\zeta/\zeta_0 = 0.3$ and Re = 20700, $\zeta/\zeta_0 = 0.54$. τ, sec.

Fig. 3. Normalized spectral density of temperature fluctuations. 1, 2, polyacrylamide solution, Re = 22200, $\zeta/\zeta_0 = 0.3$ and Re = 207000, $\zeta/\zeta_0 = 0.54$; 3) water, Re = 22200. f, Hz.

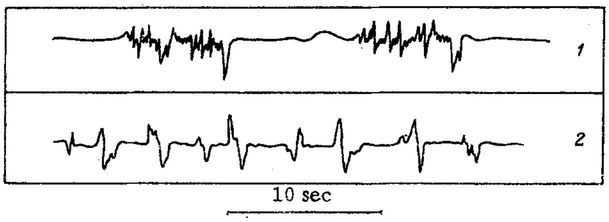

Fig. 4. Oscillograms of temperature fluctuations in the range of transitional Reynolds numbers (Re = 3500) for water (1) and polyacrylamide solution (2).

respectively. The time-constants of the thermocouples did not exceed 0.006 sec under the working conditions.

It is possible for a film of deposit to form when one uses thermocouples in solutions of polymers, which can alter the time-constants of the thermocouples, but estimates showed that this effect was small. This was confirmed also by the identity in the spectral densities obtained by means of two adjacent thermocouples differing in diameter.

The mean emfs were measured by means of a low-resistance R-306 potentiometer and a M-195/1 reflecting galvanometer. The fluctuating signals from the thermocouples and potentiometer were passed to a dc amplifier and then to an M-102 loop oscillograph via a circuit similar to that used in [3]. The passband for the signal was 0 to 30 Hz. The autocorrelation and spectral functions for the temperature fluctuations were calculated by digitizing the graphical information from the oscillograms by means of a PUOS-1 semiautomatic device.

The results (Fig. 1) show that the temperature distribution shows the same trend as the average velocity. When polymers are used, the temperature shifts upwards in dimensionless coordinates of t^+ against Y^+, while the intermediate region increases in scale. The upward shift in the temperature distribution is greater the larger the resistance reduction effect.

The autocorrelation and spectral functions were calculated by means of the scheme used in [4]; the Nyquist frequency used in processing the oscillograms was 42.8 Hz, while the equivalent number of degrees of freedom was 79.

The autocorrelation function fell rapidly from unity to zero, and then oscillated around zero (Fig. 2). The autocorrelation curves enable one to evaluate the integral time scale and the microscale of the turbulent fluctuations in the temperature.

The integral scale was found to vary little with distance from the wall, but the value for a fresh polyacrylamide solution was about twice that for water at the same Reynolds numbers. The autocorrelation curves also showed that the integral scale decreased as the Reynolds number increased. The microscales were found respectively as 0.026 and 0.039 sec for water and fresh polyacrylamide solution at identical Reynolds numbers.

A fuller idea on the time scales is given by the spectral density for the temperature fluctuations derived by Fourier transformation from the autocorrelation function. Figure 3 shows the distribution of the relative spectral density for the temperature fluctuations for water and two modes of flow of the polyacrylamide solution. It follows directly from the data that water gives higher frequencies than do the solutions at the same Reynolds numbers, so the results confirm that the resistance reduction in the solutions occurs by suppression of the high-frequency pulsations.

The recordings of the temperature fluctuations served also to observe the onset of turbulence. The curves showed that the temperature fluctuations in a nonisothermal flow are of turbulent origin and are due to transfer of heat by the velocity fluctuations. The water in the solution had no temperature fluctuations in the flow when this was laminar, and the turbulence arose at Reynolds numbers about 2200. An intermediate character of flow occurred up to Reynolds numbers of $4\text{-}4.5 \cdot 10^3$. Therefore, in this case the resistance reduction mechanism cannot be ascribed to extension of the transient state from laminar to turbulent flow.

Figure 4 also shows that the frequencies of the temperature fluctuations at the onset of turbulence in the solution was less than that for water, but that the frequency of occurrence of turbulent motions in the solution was higher, while the duration of the bursts was less.

NOTATION

$Y^+ = yv^*/\nu$	is the dimensionless coordinate;
t^+	is the dimensionless temperature;
v^*	is the dynamic velocity;
q	is the heat flux density;
R	is the autocorrelation coefficient;
τ	is the time shift;
S	is the spectral density;
t^{-12}	is the rms temperature fluctuation;
ξ	is the hydraulic resistance coefficient;
ξ_0	is the hydraulic resistance coefficient for Newtonian fluids.

LITERATURE CITED

1. E. M. Khabakhpasheva and B. A. Perepelitsa, Inzh.-Fiz. Zh., 14, No. 4 (1968).
2. E. M. Khabakhpasheva and B. V. Perepelitsa, Inzh.-Fiz. Zh., 18, No. 6 (1970).
3. M. Kh. Ibrazimov, V. I. Merkulov, and V. I Subbotin, Liquid Metals [in Russian], Atomizdat, Moscow (1967).
4. N. K. Vinnichenko, N. Z. Pinus, et al. Turbulence in the Free Atmosphere [in Russian], Gidrometizdat, Leningrad (1968).