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PARTICLE VELOCITY DISTRIBUTION IN THE FLOW OF AQUEOUS POLYETHYLENE SOLUTIONS IN A CIRCULAR PIPE

A. I. Zhernovoi, Yu. F. Ivanyuta, and I. I. Takhistova

UDC 532.529.5

A distribution of longitudinal velocity, averaged over the cross section in the turbulent flow of water and aqueous solutions of polyethylene in thin pipes, is obtained on a nuclear magnetic resonance unit.

A distribution function for longitudinal velocity pulsations was obtained in [1] in the turbulent flow of water and aqueous solutions of polyethylene in a pipe. Unfortunately, the experiment was not sensitive to the sign of the pulsations, and the function obtained was averaged relative to positive and negative pulsations.

For a new experiment, we used the same nuclear magnetic resonance (NMR) unit as in [1], with slight differences (Fig. 1). The liquid flowing through the pipe, 700 mm long with a 6.0 mm inside diameter (1), was magnetized positively by polarizer 2. By means of the IMI-2 magnetic induction meter, we used detector 3 to record an NMR signal of an intensity proportional to the magnetization M of a unit volume of the flowing liquid. The change in the NMR signal over time was photographed from the screen of an S8-7A memorizing oscillograph. The nutation coil 5 was powered by a G4-26 generator. The liquid was pumped from a 50-liter container by pump 6. The pump was located outside of the pipe to avoid degradation of the polyethylene solution.

Particles of the liquid were marked by the nutation coil, which created a weak variable magnetic field directed perpendicular to the vector of the external magnetic field in the coil. The G4-26 generator created a variable electrical field with a frequency of 100 kHz — equal to the nucleus precession frequency — and a power corresponding to a 180° rotation of

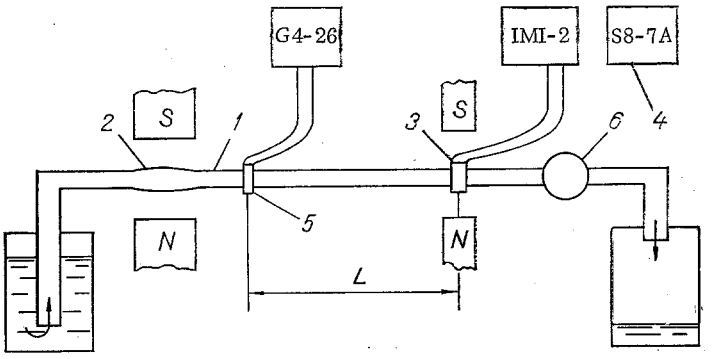

Fig. 1. Block diagram of experimental unit for obtaining a particle velocity distribution function in liquid flow in a pipe.

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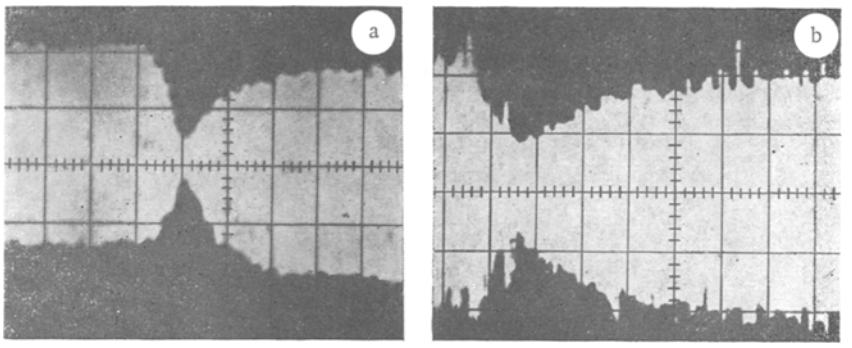

Fig. 2. Photographs taken from the oscillograph screen, reflecting the time dependence of NMR signal intensity for water (a) and an aqueous polyethylene solution (b).

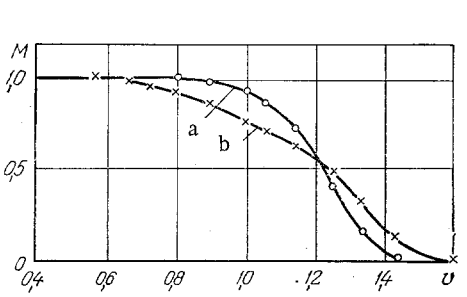

Fig. 3

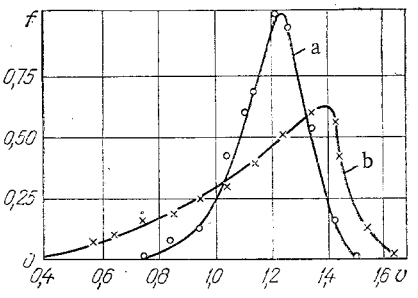

Fig. 4

Fig. 3. Dependence of magnetization M (rel. units) on particle velocity v (m/sec) for water (a) and polyethylene solution (b).

Fig. 4. Curve of particle velocity distribution function f relative to v (m/sec) for water (a) and polyethylene solution (b).

the magnetization vector. Connection of the generator to the flow section where the coil field frequency was at that moment equal to the precession frequency gave rise to a sharp boundary between the regions of positive and negative magnetizations of the liquid. Passing at a mean velocity v_{av} over the distance L between the nutation coil and the coil of the detector, the boundary eroded as a result of longitudinal velocity pulsations.

Figure 2 shows photographs taken from the oscillograph screen for water (a) and a solution of polyethylene WSR-301 of a concentration $1 \cdot 10^{-1}$ kg/cm^3 (b) at a constant flow rate of $34.5 \cdot 10^{-3}$ liter/sec. The investigated flow regime corresponded to turbulent flow with a Reynolds number Re = 7300. The envelope of the photographic image represents the dependence of the intensity of the detector signal I on time t. In connection with the proportionality of I and M, the resulting relation I(t), allowing for background, is similar to the relation M(t). Thus, excluding the photographic background of the relation I(t), we obtained the curves of the relation M(t). We then replotted the latter in the coordinates M and v (Fig. 3), since v = L/t for water (a) and the polyethylene solution (b).

It is apparent from these relations that there are more particles traveling both faster and slower than the mean flow velocity in the polyethylene solution than in water.

The derivative of the relation M(v) (Fig. 4) is the function of particle distribution according to longitudinal velocity f(v), with $\int f(v)dv$ being the same for both curves. It is apparent in comparing the distribution curves for water (a) and the polyethylene solution (b) that the particle velocity distribution is Gaussian in character for water, the particles having velocities from $0.6v_{av}$ to $1.2v_{av}$ and the most probable velocity coinciding in all but 3% of the cases with the mean velocity. The distribution function in the case of the solution flow is non-Gaussian and the curve spreads out in both directions — higher and lower velocities. The range of velocities here is $0.32\text{-}1.32v_{av}$, and the most probable velocity is 20% higher than the mean.

NOTATION

L, length of investigated section of pipe; t, time of passage of liquid over section; v_{av}, mean flow velocity; v, particle velocity; M, magnetization per unit volume of the liquid; I, intensity of NMR signal; f(v), particle velocity distribution function.

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TURBULENT PIPE FLOW OF CONCENTRATED EMULSIONS WITH A NONEQUILIBRIUM DISPERSE PHASE

A. K. Rozentsvaig

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Quantitative data are obtained in velocity pulsation damping and the amount by which particle coalescence exceeds the turbulence microscale is calculated for the pipe flow of concentrated emulsions.

The motion of two-phase systems is generally described with the assumption that the laws of conservation of mass, momentum, and energy are satisfied. Meanwhile, the complete system of Navier—Stokes equations should consider the effect of disperse-phase particles on the motion of the dispersion medium, while the equation of motion of the particles should reflect, along with external body forces and forces of interaction between the particles, the effect of the motion of the dispersion medium. As a result, to obtain a closed system of equations, it is necessary to have a kinetic equation describing the dynamic state of the disperse phase, together with the corresponding boundary conditions [1, 2]. Such a system of equations is particularly valuable is analyzing similitude among two-phase flows [3], although it is difficult to obtain final theoretical relations, such as for turbulent flow.

However, the large amount of empirical data available on turbulent flows of unstable emulsions, connected with study of the mixing of mutually insoluble liquids and the rate of phase separation in various commercial processes, can be used to construct a partial semiphenomenological model of a two-phase system. This will provide us a sufficiently simple basis on which to perform engineering calculations connected with the movement of unstable emulsions. At the same time, the model, being in good agreement with the empirical data, will serve as a reliable basis for semiempirically analyzing the assumptions necessary to analytically study the complete system of equations for a two-phase system.

The goal of the present work is to study anomalous effects and is a consequence of the inadequacy of the homogeneous model of a two-phase system in the case of coarse-dispersed emulsions with a nonequilibrium disperse phase. We also hope to obtain quantitative estimates of the above effects using experimental data.

Inverse Effect of Disperse-Phase Concentration on Turbulent Flow of an Emulsion in a Pipe

It has been shown for emulsions of immiscible liquids of similar densities that the motion of disperse-phase drops in the inertial range of uniform turbulent flow nearly coincides with the motion of the dispersion medium [4]. Also, it is known that an emulsion with a low-viscosity dispersion medium is capable of retaining Newtonian rheological properties up to W = 0.5 in the turbulent regime [5]. In determining effective viscosity in accordance with the Darcy—Weisbach equation for a homogeneous liquid, the Newtonian behavior of the emulsion was controlled by comparing measured and theoretical velocity profiles.

We will show that the turbulence damping in mixers noted in [6] is consisted with the available empirical data for pipes through which unstable emulsions are being pumped in a

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