STUDY OF ELECTRORHEOLOGICAL EFFECT DURING FLOW OF DIELECTRIC SUSPENSIONS IN A HORIZONTAL COAXIALLY CYLINDRICAL CAPACITOR

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UDC 532.135

Results are presented for an experimental study of the electrorheological effect during the forced flow of dielectric suspensions in a horizontal coaxially cylindrical channel under the effect of a constant electric field. The hydrodynamic pressure head, the concentration of the solid phase, and the channel geometry were varied in the experiments. The dependences of the relative volumetric flow rate of the suspension Q_{el}/Q_0 on the voltage of the constant electric field obtained are discussed.

The electrorheological effect, i.e., the effect of a reversible change in the rheological characteristics of a number of nonaqueous suspensions in strong electric fields, is of considerable interest in theoretical and applied plans [1].

Until recently the attention of investigators has mainly been concentrated on the physicochemical and physicomechanical aspects of the ERE, since the principal mechanisms of the phenomenon can be clarified on this basis. For applied problems, however, it is important to study the hydrodynamics of the isothermal and nonisothermal flow of nonaqueous suspensions in tubes and channels under the effect of an external electric field.

The literature data available on this question are sparse. Only the report of V. K. Gleb and S. A. Demchuk [2] is known, which presents the results of an experimental study of the effect of constant electric fields on the gravitational flow from the plane-parallel slot of a capacitor of suspensions of diatomite in AMG-10 aviation hydraulic oil, transformer oil, and kerosene containing additions of polyisobutylene. The plane-parallel slot channel was formed by two hollow brass electrodes and two insulating gaskets. The electric field applied to the suspension flowing in the channel decreased its flow velocity. The effect of the field was the greater, the smaller the gap between the electrodes, the smaller the velocity of the suspension at the entrance to the channel, and the greater the concentration of the solid phase.

We continued the experiments on the study of the flow of dilute dielectric suspensions in an electric field which were begun in [2] but on another channel model — in a horizontal coaxially cylindrical capacitor. The channel geometry selected differs from the flat model in that one can neglect the end effects and create an undistorted electric field in the channel. In addition it is more appropriate for modern heat exchangers.

A diagram of the experimental working section is presented in Fig. 1. The coaxial slot channel is formed by the interchangeable inner tube 1 and the body 2. The inner tube is strictly centered relative to the body by a system of insulating and metallic bushings and by the ebonite supporting rings 3. The surfaces of the channel were carefully polished. A quasi-uniform electric field is formed in the gap by applying a high voltage to the body from a VS-23 stabilized source. A thermostatic medium is pumped through the tube and the casing and assures the constant temperature of the walls of the coaxial channel. The electrorheological suspension is fed to the flow section from a constant-level tank under a hydrostatic pressure head. The hydrodynamic resistance of the working section of the channel was determined from the difference in static pressures at the entrance and exit of the channel. The flow rate of the suspension at the channel exit was determined by volumetric means.

Institute of Heat and Mass Exchange, Academy of Sciences of the Belorussian SSR, Minsk. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 26, No. 5, pp. 820-824, May, 1974. Original article submitted November 27, 1973.

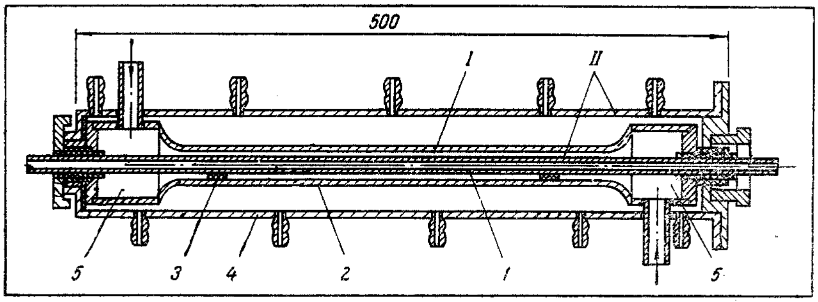

Fig. 1. Diagram of experimental working section: 1) inner tube-electrode; 2) body; 3) supporting ring; 4) casing; 5) damping chambers with smooth entrance; I) to high-voltage source; II) to ground.

The studies were conducted on suspensions of diatomite in transformer oil. The content of the solid phase by weight varied from 0 to 5% while the concentration of the activator was 6-7%. The activator is a necessary component part of electrorheological suspensions. Its absence leads to the disappearance of the electrorheological effect in the experimental suspensions [3]. Through the addition to the SAS suspension of oleic acid the sedimentation rate in the course of the experiment was reduced to a value much lower than the flow velocity of the suspension.

The effect of an electric field on the flow of the pure carrier medium, transformer oil, was studied first. As it turned out, the electric field alters the relationship of the flow rate to the pressure head insignificantly. The relative volumetric flow rate differed by only 6-7% (Fig. 2b, curve 5). Apparently, the change in the relative flow rate under the effect of an electric field would be even less in carefully purified and dehydrated transformer oil.

The introduction of a disperse phase into the transformer oil radically affects the hydrodynamic characteristics of the flow (Fig. 2b).

The suspension moving in the horizontal coaxially cylindrical capacitor is acted on by:

1. The mechanical force produced by the pressure drop. It orients the moving particles of the solid phase and the dispersing medium along the walls of the channel.

2. The electrical force produced by the external transverse electric field. It leads to the interaction of the rigid and induced dipoles of the medium with the external field, orients the particles across the channel, and creates fibrillar structures which span the interelectrode gap. The apparent viscosity of the suspension increases due to the additional dissipation of energy connected with the destruction of these structures by the hydrodynamic pressure head. The dependence of the relative volumetric flow rate Q_{el}/Q_0 on the voltage of the electric field for different hydrostatic pressure heads is presented in Fig. 2a. Each curve has an activation section AB within which the purely mechanical factors predominated over the electrical forces. In the "activation" section the flow rate of the suspension is constant in time. The extent of this section, i.e., the width of the plateau AB, is determined by the hydrostatic pressure head H, and is the greater the higher the pressure head. Then follows a section of nonlinear decrease in the relative flow rate of the suspension because of the increase in effective viscosity. The curves in this section have the form of descending parabolas whose steepness is determined by the magnitude of H. The very lowest section of the curve is characterized by the unstable flow of the working medium caused by the prevailing of the factor of structure formation over the mechanical forces. As a result the aggregation of the solid phase occurs in the channel up to its complete closing at certain electric field voltages E^*. The value of E^* is determined by the competition of the hydrostatic pressure head and the structure formation in the electric field. Blocking of the channel also occurs with a further increase in the voltage, i.e., for $E > E^*$. Here the time from the moment of application of the voltage until the complete blocking of the channel decreases with an increase in the applied voltage up to the value $E = E_{max}$ at which the closing of the channel cross section by the solid phase occurs almost instantly.

In the third section the strong structure formation leads to a change in the concentration and to the clearing of the suspension which flows out, up to the point where it is completely cleared of the disperse phase.

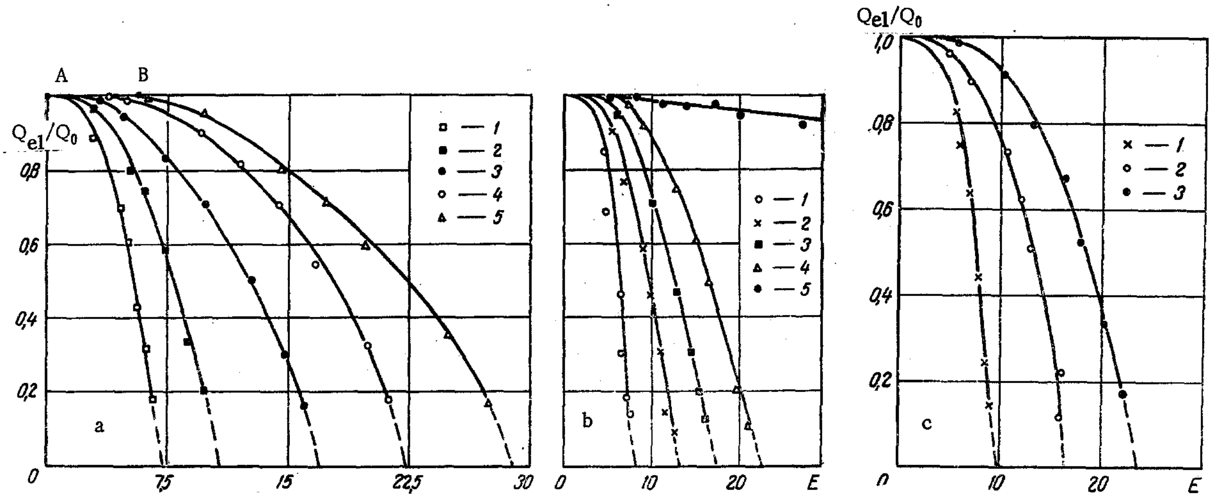

Fig. 2. Dependence of relative volumetric flow rate Q_{el}/Q_0 of suspension of diatomite in transformer oil on voltage of external constant electric field E(kV/cm) during flow from horizontal coaxially cylindrical capacitor: solid lines indicate steady flow; dashed lines indicate unsteady flow: a) C = 2%; $\Delta r = 2.7 \cdot 10^{-3}$ m; T = 293°K; 1) H = 2006; 2) 2878; 3) 5931; 4) 7675; 5) 9420 N/m^2; b) 1) C = 1; 2) 2; 3) 3; 4) 5; 5) 0%; T = 293°K; $\Delta r = 2.7 \cdot 10^{-3}$ m; H = 5931 N/m^2; c) C = 2%; T = 293°K; 1) Δr = 1; 2) 2; 3) $2.7 \cdot 10^{-3}$ m; H = 7675 N/m^2.

For all the curves presented in Fig. 2 the region of time variation in the flow rate begins upon reaching a certain relative flow rate, namely $Q_{el}/Q_0 = 0.2$.

As seen from Fig. 2a, an increase in the hydrostatic pressure head shifts the flow curves toward higher voltages and leads to degradation of the effect.

Figure 2b illustrates the effect of the electric field on the relative volumetric flow rate of the suspension of diatomite in transformer oil with variation in the concentration of the solid phase.

For the suspension of diatomite in transformer oil the electrorheological effect increases with an increase in the concentration of the disperse phase: the curves of the dependence $Q_{el}/Q_0(E)$ are shifted toward lower electric field voltages and this shift depends on the relationship between the pressure head, the concentration of the solid phase, and the electric field voltage. If the concentrations are low the forming structures are easily destroyed by the mechanical forces at low field voltages and the particles of the disperse phase are not retained in the channel. With an increase in the concentration of diatomite in the suspensions the electrorheological effect is more strongly expressed for a fixed hydrostatic pressure head: the activation section and E* are reduced and the rate of increase in the effective viscosity of the suspension increases, i.e., the curvature of the parabolic section increases.

The intensity of the electrorheological effect in the combined electric and shear fields is determined by the size of the gap between the capacitor plates. The results of tests of the flow of a suspension of diatomite in transformer oil are presented in Fig. 2c for the following ratios of the radii of the constituent cylinders: R_1/R_2 = 8/5.3, 8/6, and 8/7, where R_1 and R_2 are the radii of the outer and inner cylinders.

A change in the gap leads to a change in the area of the electrodes and consequently affects the hydraulic resistance, but as the curves in Fig. 2c indicate, the electrical forces play the decisive role in the separation of the curves with respect to the gaps. The effect of the electric field on the relative flow rate is stronger in narrow slots: the same value of Q_{el}/Q_0 is reached with smaller electric field voltages for a gap of 10^{-3} m.

The activation section is reduced with a decrease in the gap. The zone of unstable flow starts at smaller values of E due to the development of the additional hydraulic resistance connected with the formation of a layer of particles near the electrode, and the steepness of the parabolic section of the curves increases. This is because the electric field has a stronger effect on the behavior of the suspensions in the narrower slots.

NOTATION

E	is the voltage of electric field;
H	is the hydrostatic pressure head;
E^*	is the electric field voltage at which blockage of channel occurs;
Q_{el}	is the volumetric flow rate of liquid in electric field;
Q_0	is the volumetric flow rate of liquid at $E = 0$;
Q_{el}/Q_0	is the relative volumetric flow rate;
R_1	is the radius of outer cylinder-electrode;
R_2	is the radius of inner cylinder-electrode;
C	is the concentration of disperse phase;
Δr	is the distance between electrodes;
T	is the temperature of suspension.

LITERATURE CITED

1. Z. P. Shul'man et al., The Electrorheological Effect [in Russian], Nauka i Tekhnika, Minsk (1972).
2. V. K. Gleb and S. A. Demchuk, Inzh.-Fiz. Zh., 10, No. 4, 681 (1972).
3. U. S. Patent No. 3250726, Class 252-317.