STUDY OF ELECTRORHEOLOGICAL EFFECT

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The problem of the effect of an electric field on the shear flow of a suspension of finely dispersed quartz in naphthene with admixtures of a surface-active agent is discussed. The possibility of increasing the apparent viscosity of such rheological systems by four orders of magnitude is shown. Experimental results are given that show that a field creates, besides electroviscosity, viscoelasticity and antithixotropy.

1. Interest in processes of convective heat and mass transfer in external electric and magnetic fields has grown in recent years. A considerable number of theoretical and experimental papers have been written on this problem. Many of them have indicated that electric and magnetic fields exert a great influence on energy, momentum, and mass fluxes and on other important characteristics of transfer processes. The customary interpretations ignore electrorheological and magnetorheological effects, which can only partially be confirmed only for nonconducting gases. The behavior of dropping liquids—especially disperse flowing systems—is greatly affected by external electric and magnetic fields [1–5].

G. V. Vinogradov and his students [6–8] have studied the effect of an external electric field (constant) on the shear flow of a grease whose microstructure was a framework system (soap) filled with a dispersed moving phase (oil), and established the interesting and important fact that the disperse medium migrated toward the cathode while the framework was squeezed in the opposite direction. The experiments were performed in a rotary uniaxial cylindrical instrument. When the rotor served as the cathode, the resistance to its rotation gradually weakened. Clearly expressed thixotropy, which was caused by the field, was simultaneously observed.

An extensive study of electroviscosity was made recently by Klass and Martinek [9]. They studied the flow curves of suspensions in their one-dimensional shear motion in constant and variable electric fields. It was noted that the field strength (to frequencies on the order of 1000 Hz) had a strong influence on the apparent viscosity of the suspension. The interpretation of electrorheological effects that is generally accepted today is based on the electrokinetic conception of the double electrical layer.

In our opinion, this point of view acceptably explains many but not all of the known facts. Actually, nonconducting disperse systems manifest the electrorheological effect the more clearly, the higher the electrokinetic ζ-potential. At the same time, the classical double-layer theory is ineffective for homogeneous flowing systems, which also manifest, although to a lesser degree, a reversible change in apparent viscosity when an electric field is applied to them.

2. The principal mechanisms of electro- and magnetorheological effects can be explained only through complex experimental studies of all aspects of the physical process: the physical chemistry of the medium and its individual components, the electrical, thermophysical, and electrophysical characteristics, and the rheological and rheodynamic parameters.

The present paper is the first in a series of such studies conducted at the Institute of Heat and Mass Transfer, Academy of Sciences, Belorussian SSR.* We present the results of experiments in viscous resistance when a static field whose force lines are transverse to the cylindrical shear surfaces acts on a flowing system.

The working fluid was a suspension of fine SiO_2 particles (spheroids of 0.1–0.12 μ) in cyclohexane with an admixture of a surface-active agent.

The experimental apparatus (Fig. 1) consisted of a rotary synchronous electric unit with coaxial cylinders, an electrical measuring unit with amplifiers, and regulated high- and low-voltage ac and dc power supplies. The apparatus was also equipped with the corresponding control and measuring units.

The radial gap between the rotor (d = 65.2 mm, H = = 69 mm) and the stator was 1 mm; the speed remained 100 rpm in these experiments.

The rotor, which was a cylinder with conic ends, was set up vertically. Its top was connected to the drive through a chuck and its bottom projection turned on a sliding bearing. Specially shaped circular grooves were made at the top and bottom of the stator to prevent distortion of the electric field near the ends of the rotor.

The experiments were performed in the following order.

a) The electrical conductivity of the pure working fluid was checked up to the breakdown voltage (ΔU = = 85 kV/cm). The experiments were begun only when

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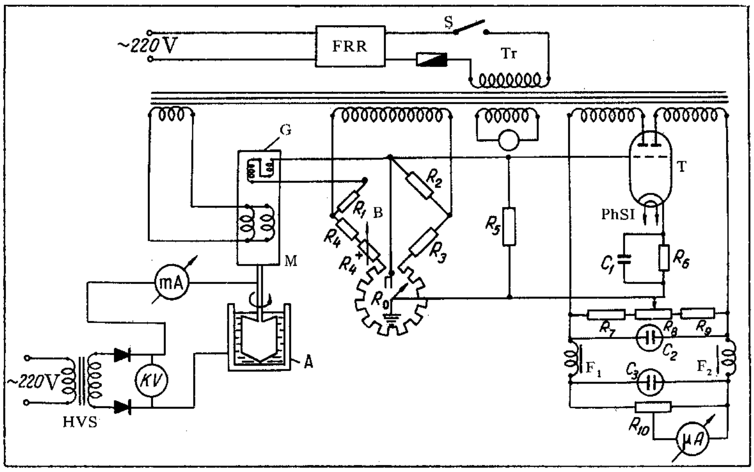

Fig. 1. Schematic of electrorheological apparatus: A—rotary unit; M—synchronous micromotor; G—synchronous microgenerator; FRR—ferroresonant regulator; B—semibalanced bridge; PhSI—phase-sensitive indicator; F_1, F_2—filters; HVS—high-voltage supply.

the conduction current of the pure liquid phase was negligible (10–15 μA).

b) A surface-active agent and the disperse phase were added to the liquid phase, and the suspension was carefully stirred until it was homogeneous.

c) The conductivity of the suspension was checked; it had to be negligible.

d) The viscosity of the suspension in the absence of an external electric field was measured.

e) The field was applied; its strength U was increased in equal steps. Two readings were taken for each fixed U: one immediately after U was changed and the other somewhat later, when the needle had finally come to rest. Since this suspension displayed lags and aftereffects in its mechanical behavior in an external electric field, the first readings allowed the instantaneous-reversible part of the change in apparent electroviscosity η_{rev} to be recorded, while the total change in η could be determined from the equilibrium readings of the instrument.

Figure 2 shows the typical results in terms of $\eta_{rel} = \eta/\eta_0$ (ratio of viscosity to viscosity without field) and ΔU, which is the field-strength gradient in the gap of the instrument.

The following points are noteworthy.

a) The relation $\eta_{rel} = f(\Delta U)$ is very nonlinear (parabolic); its equilibrium branch is particularly steep.

b) At ΔU values that are approximately 40% of the breakdown limit, the apparent viscosity is increased by two orders of magnitude. Therefore, the maximum expected increase in η_{rel} must be on the order of 10^4.

c) As η_{rel} increases, the rotor slows down until the drive power (20 VA) is insufficient and the electric motor stops. This limit is indicated on the equilibrium curve and has stable multiple reproducibility.

As observations showed, the flowing system had distinct antithixotropy. That is, when the field is gradually removed, the return branch of the curve $\eta_{rel} = f(\Delta U)$ is situated above the original branch. When the field is completely removed, $\eta_{rel.0}$ for a time retains a value that is several times greater than unity. When the liquid has stood for a short time, however, the residual electroviscosity relaxes and completely disappears after 30–40 min.

CONCLUSIONS

Results of measurements of the electrorheological effect in suspensions are presented and discussed. It is found that when an electric field is applied, viscoelasticity is observed, in addition to electroviscosity.

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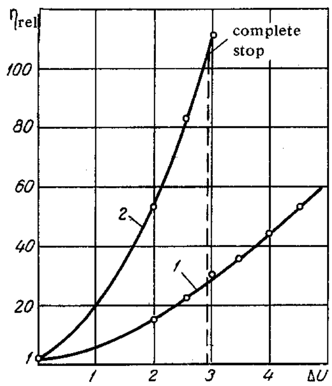

Fig. 2. Relative viscosity versus electric-field strength (kV/cm) (liquid phase—naphthene; solid phase—SiO_2; $\gamma = 350\ sec^{-1}$): 1) instantaneous changes in apparent viscosity; 2) equilibrium state.

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