EFFECT OF AN ELECTRIC FIELD ON THE DISCHARGE OF POLYDISPERSIONS FROM A SLOTTED VERTICAL PLANE–PARALLEL CHANNEL

V. K. Gleb and S. A. Demchuk

UDC 532.135:537.212:541.182

Results are shown of an experimental study concerning electrorheological dielectric systems and the hydrodynamic characteristics of their discharge from a slotted plane–parallel channel in the presence of a constant electric field.

The aim of this study was to establish the mechanical behavior of thin dielectric suspensions during their isothermal gravity discharge from a slotted plane–parallel channel formed by two thermostatic hollow

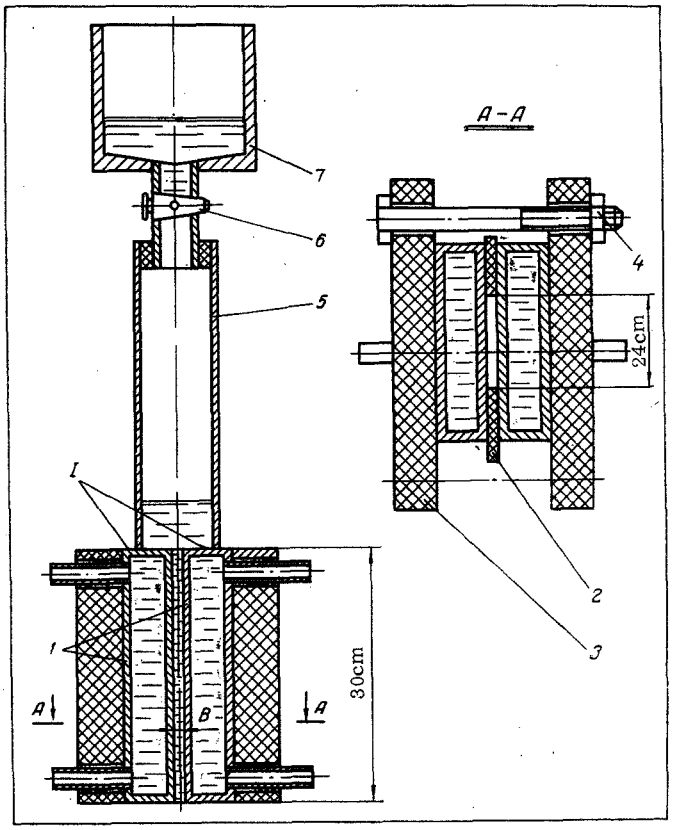

Fig. 1. Schematic diagram of the test apparatus: 1) copper electrodes; 2) acrylic glass insert; 3) Textolite plate; 4) fastener components; 5) vessel with graduation markers; 6) tap; 7) vessel with the test material; I) to the high-voltage source.

Institute of Heat and Mass Transfer, Academy of Sciences of the Belorussian SSR, Minsk. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 23, No. 4, pp. 681-685, October, 1972. Original article submitted October 8, 1971.

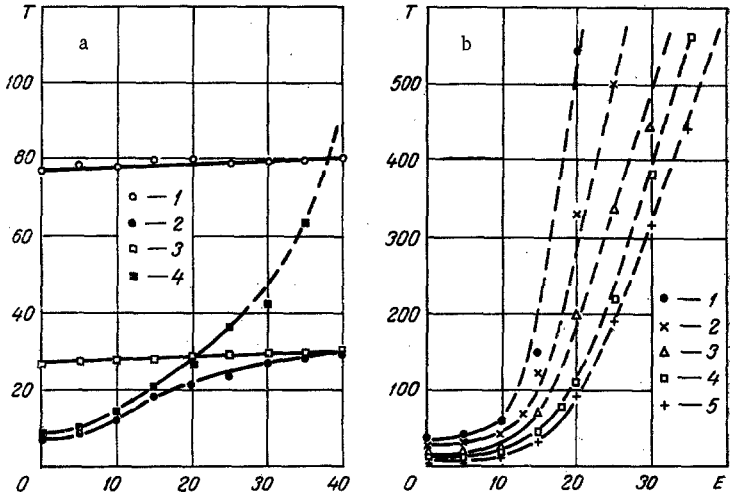

Fig. 2. Discharge time T (sec) of dielectric fluids from a slotted plane–parallel channel, as a function of the intensity of an externally applied electric field E (kV/cm), in steady flow (solid lines) and unsteady flow (dashed lines): (a): 1) transformer oil through B = 0.2 cm; 2) 1% (weight) suspension of diatomite in transformer oil through B = 0.2 cm; 3) 0.5% polyisobutylene solution in lamp kerosene through B = 0.1 cm; 4) 3% (weight) suspension of diatomite in transformer oil through B = 0.2 cm. Volume V = 100 cm^3. (b) 1) F = $2.6 \cdot 10^{-3}$ N; 2) $6.7 \cdot 10^{-3}$ N; 3) $12.7 \cdot 10^{-3}$ N; 4) $16.5 \cdot 10^{-3}$ N; 5) $21.7 \cdot 10^{-3}$ N. Volume V = 200 cm^3; channel width B = 0.2 cm.

copper-plate electrodes (Fig. 1). For the experiment we used suspensions of diatomite earth in oil, transformer grade and AMG-10 hydraulic grade, and in lamp kerosene with the addition of polyisobutylene as an electrically neutral thickener. The suspensions used in our tests represented anhydrous dielectric polydispersions with particle sizes ranging from a fraction of a micron to 50 μ.

The diatomite was first washed in water, then dried down to a 7-8% moisture level. Diatomite particles are very porous and highly heterogeneous in shape and size. The surface asperity and the serrated form of individual particles eases their coagulation and the subsequent structurization.

First we studied the mechanical behavior of the carrier fluids, transformer oil and AMG-10 oil, as well as of the polyisobutylene solution in lamp kerosene in a static electric field. A typical relation between the discharge time of a 100 ml volume unit (reciprocal of the volume flow rate) of suspension and the intensity of an externally applied constant electric field is shown in Fig. 2a (curves 1-3). The strongest effect of the electric field on the discharge time of these carrier fluids does not exceed 10%. The addition of a solid phase to the disperse medium causes a sharp increase in the electrorheological effect. According to Fig. 2b, the curve of discharge time vs field intensity has three distinct ranges: a) the "activation" range, within which the discharge time almost does not change with increasing field intensity but depends only on the hydrostatic force; b) the nonlinear range, where the discharge time rapidly becomes longer; and c) the linear range, where the discharge time becomes very long and the motion of the fluid is almost completely stopped by the action of a transverse field. The graph indicates also that the "activation" range becomes wider as the hydrostatic force F increases. It was found that the discharge process remained steady up to certain values of F and E, and that the rate of flow through a channel across section did not depend on the length of testing time. It was noted that increasing the field intensity E at a fixed hydrostatic force or decreasing the hydrostatic force F at a fixed field intensity would cause the discharge to become unsteady, i.e., the flow rate in the channel to gradually decrease. This phenomenon is explained as follows. The primary effect of an external electric field is a change in the suspension structure. Particles of the solid phase combine and orient themselves along the lines of force in the field so as to form fibrillar structures covering a channel section either partly or entirely. The stream of fluid tries to contort and disrupt these continuously regenerated fibrillar structures. At some instant of time the rates of structure formation and breakdown become equal, resulting in a dynamic equilibrium. This equilibrium

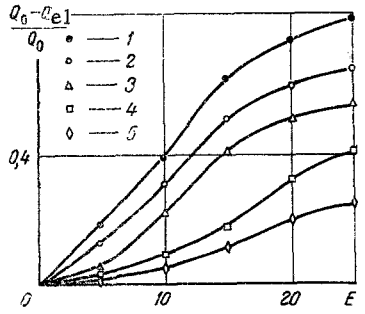

Fig. 3. Relative decrease in the flow rate as a function of the electric field intensity E (kV/cm), for a 1% diatomite suspension in a 1% keroseneous polyisobutylene solution discharging from a slotted plane–parallel channel in an externally applied electric field: 1) t = 289.15°K; 2) 293.15; 3) 303.15; 4) 313.15; 5) 323.15.

state depends on the magnitudes of E and F, shifting toward a higher breakdown rate at lower field intensities and larger hydrostatic forces.

The motion of every particle in a shear flow is not only translatory but also rotational. The application of a transverse electric field results in its interaction with rigid and induced dipoles, causes the particles to orient themselves in the field, and, in the final analysis, brings about an increase in the apparent viscosity [1, 2].

The discharge characteristics of electrorheological suspensions in an electric field are basically affected by the two opposing forces: 1) the hydrodynamic force which moves the particles along the electrode walls, and 2) the electric force which orients the particles normally to the velocity vector.

As long as the hydrodynamic force predominates, the process remains steady. The shear strength of the structure is low here, and additional energy dissipation due to the presence of an electric field affects only the apparent viscosity of the fluid without producing any aftereffects. A further increase of the field intensity causes particles of the dispersed phase to form bridges across the interelectrode gap, the number and the dimensions of these bridges depending on the electric field intensity and on the hydrostatic force. At some field intensity level the hydrodynamic and the electric forces become balanced. Discharge of the fluid ceases then. Under large pressure differences the discharge velocity remains high without decreasing, on the other hand, because no structurization takes place under high shear rates.

The shear rate in a flat channel is generally nonuniform across the section and varies from a maximum at the channel wall to zero at the channel axis. When the electric field intensity is increased, the flow velocity will decrease until, at certain limiting E and F levels the channel is shut down.

The structurizing process in a stream occurs at a fast rate and throughout the volume. After the external electric field has been removed, however, there remains, according to our observations, a stationary layer of dispersed-phase particles adhering to the electrically conductive channel walls. This causes a gradual blocking of the passage section. In designing and testing electrorheological devices, therefore, one must also account for the wall effect which contributes to process instability.

Blocking of passage sections is accompanied by a change in the solid-phase concentration in the system. The filtering, which occurs here during specific discharge modes, may result in a complete purification of the carrier fluid.

We note that a sudden application of a sufficiently strong electric field will cause a momentary clearing of the suspension, which can be explained by polarization effects. An active system is very sensitive to temperature variations and changes in the solid-phase concentration.

According to the graph in Fig. 2a (curves 2 and 3), a 1% (weight) suspension of diatomite in transformer oil goes into saturation, i.e., into a range where the apparent viscosity reaches a constant value and does not increase further. In a 3% (weight) suspension of the same combination of materials this effect is noted much more distinctly.

The cause of this "saturation" effect is probably the scarcity of solid material for the formation of sufficiently stable structures in a 1% suspension.

Of interest is the temperature characteristic of the electrorheological effect (Fig. 3). The strength of this effect decreases markedly with rising temperature. A heating of the suspension results in an increasing interphase surface, which should weaken the electrorheological effect, but also in an increasing ion mobility, which should strengthen this effect. The effective viscosity of such a suspension will depend on which of these two factors is dominant.

Studies have shown that, during a simultaneous action of shear fields and electric fields, the strength of the electrorheological effect depends not only on the factors mentioned earlier but also appreciably on the dispersivity of the solid phase, on the moisture content in the dispersion, on the channel geometry, etc.

On the basis of additional composite electrophysical and thermophysical measurements, it will be possible to predict the electrorheological effect rather accurately.

NOTATION

E	is the electric field intensity;
F	is the hydrostatic force of fluid column;
T	is the discharge time;
t	is the temperature;
V	is the volume;
B	is the channel width;
Q_0	is the fluid flow rate at $E = 0$;
Q_{el}	is the fluid flow rate in an electric field;
$(Q_0-Q_{el})/Q_0$	is the relative decrease in the flow rate.

LITERATURE CITED

1. A. V. Lykov, R. G. Gorodkin, and Z. P. Shul'man, Inzh.-Fiz. Zh., 15, No. 4 (1968).
2. A. V. Lykov, Yu. F. Deinega, R. G. Gorodkin, and A. D. Matsepuro, Rheophysics and Rheodynamics of Fluid Systems [in Russian], Nauka i Tekhnika, Minsk (1970).