2. V. G. Levich, Physicochemical Hydrodynamics, Prentice-Hall, Englewood Cliffs (1962).
3. B. N. Yudaev, O. V. Tsirlin, and A. A. Yushkin, "Steady motion of a gas bubble," Inzh.-Fiz. Zh., No. 4, 25 (1973).

MAGNETORHEOLOGICAL EFFECT NEAR THE CURIE POINT

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Results of an experimental study are presented which pertain to the magnetorheological effect in a ferrofluid at temperatures near the Curie point of the dispersed phase.

An external magnetic field, while structurizing a ferrofluid suspension, radically alters its rheological properties (magnetorheological effect). This effect was experimentally studied under conditions where the magnetic properties of the dispersed ferromagnetic phase could be assumed to be independent of the temperature [1-3]. As is well known, ferromagnetic materials have the fundamental property that the long-range magnetic order breaks down due to heating until it completely vanishes (at the Curie point). This limits utilization of the magnetorheological effect at temperatures near the Curie point. On the other hand, simultaneous action of a magnetic fluid during heating of a magnetorheological fluid to temperatures near the Curie point can be useful for several practical applications.

These authors studied the magnetorheological characteristics of a system with a dispersed phase having its Curie point within the test range of temperatures. Other components of the active medium were selected on the basis of a low-temperature sensitivity of their physicochemical properties over the test range of temperatures, so as to ensure stability of the system during the entire period of time needed for performing the experiment.

The saturation magnetization of our ferrofluid suspension during changes of the temperature was measured by the Faraday method. From the thus obtained curves depicting the temperature dependence was found the critical point corresponding to the loss of magnetic properties by the substance. This critical point was 145°C. The critical temperature in a weak magnetic field (H = 2 Oe) was somewhat higher and equal to 158°C.

Rheological measurements were made with a rotary viscometer "Rheostat-2", its nonmagnetic working part placed in a magnetic field normal to the shear plane. The test cell was thermostated over the test range of temperatures, this range extending from room temperature to beyond the critical point established on the basis of magnetization measurements.

The resulting flow curves are rheograms characteristic of magnetorheological systems with a nonlinear dependence of the shearing stress on the strain rate [2].

Heating of this ferrofluid suspension during deformation at a given strain rate lowers its effective viscosity until the magnetorheological effect has been completely compensated. At a temperature near the critical point for this system (t = 145°C) the effective viscosity of the magnetorheological composite material asymptotically approaches some value within the corresponding critical range, while the effect of the magnetic field gradually weakens (Fig. 1).

The temperature dependence of the viscosity component due to interaction between particles of the system upon application of a magnetic field can be examined through the expression

$$\Delta\eta = \frac{\eta_{Ht} - \eta_t}{\eta_{H0} - \eta_0}, \tag{1}$$

where γ_{Ht} denotes the effective viscosity of the ferrofluid suspension in a magnetic field at a given temperature; η_t, viscosity without a magnetic field at that temperature; and $\eta_{H,0}$, η_0, respectively, the effective viscosity in a magnetic field and the viscosity without a magnetic field at the initial temperature of the system.

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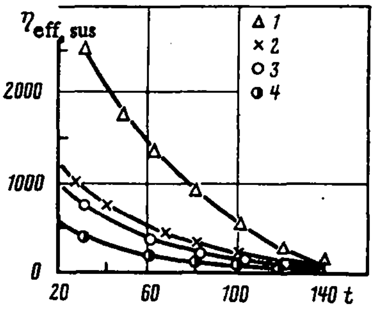

Fig. 1

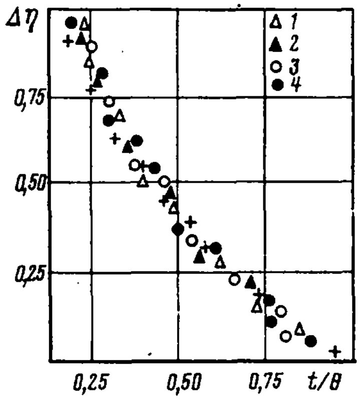

Fig. 2

Fig. 1. Dependence of the effective viscosity $\eta_{eff,sus}$ of the ferrofluid suspension on the temperature (t, °C) and the magnetic field intensity (H, Oe): 1) $\gamma = 27\ sec^{-1}$ and H = 600 Oe, 2) $\gamma = 27\ sec^{-1}$ and H = 0, 3) $\gamma = 145.8\ sec^{-1}$ and H = 600 Oe, 4) $\gamma = 145.8\ sec^{-1}$ and H = 0.

Fig. 2. Relative increment of viscosity of the magnetorheological system as a function of the relative temperature: 1) $\gamma = 27\ sec^{-1}$; 2) $\gamma = 48.6\ sec^{-1}$, 3) $81\ sec^{-1}$, 4) $145.8\ sec^{-1}$.

The thus evaluated data for various strain rates, with $\Delta\eta$ as a function of the relative temperature t/θ (θ denoting the critical point), are shown in Fig. 2.

Other authors [2-4] have proposed a correlation between the increment of viscosity of a ferrofluid suspension in a magnetic field and the energy of magnetic-dipole interaction u between particles, viz.,

$$u = 6\mu_0 m^2/\pi d^3, \tag{2}$$

where u is the energy of the dipole–dipole interaction between particles; μ_0, magnetic permeability; d, diameter of particles; and

$$m = \frac{\pi d^3}{6} I_s \tag{3}$$

is the magnetic moment of particles.

In our case the relative increment of viscosity due to change in temperature should be proportional to the quantity $(I_s/I_0)^2$, where I_s and I_0 are the magnetizations of the ferrofluid suspension at the given temperature and at the initial temperature, respectively. If that is indeed so, then the dimensionless quantity $(I_s/I_0)^2$ as a function of the relative temperature t/θ should follow the trend of the $\Delta\eta = f(t/\theta)$ curve. The points on the $(I_s/I_0) = f(t/\theta)$ curve, indicated by "+" marks in Fig. 2, do lie closely enough to the viscosity curve.

On the basis of these results, therefore, it is possible to predict the mechanical behavior of magnetorheological systems near the Curie point.

LITERATURE CITED

1. V. I. Kordonskii, Z. P. Shul'man, and T. V. Kunevich, "A study of the magnetorheological effect," in: Rheology of Polymer and Dispersion Systems and Rheophysics [in Russian], Part 2, Minsk (1975), pp. 79-82.
2. S. A. Demchuk, V. I. Kordonskii, and Z. P. Shul'man, "Magnetorheological characteristics of ferrofluid suspensions," Magn. Gidrodin., No. 2, 35-37 (1977).
3. Spasojevic, T. F. Irvine, and N. Argon, "Effect of a magnetic field on the rheodynamic behavior of ferromagnetic suspensions," Int. J. Multiphase Flow, 1, 607-622 (1974).
4. E. E. Bibik, "Certain effects of interaction between particles during flow of ferrofluids in magnetic fields," Magn. Gidrodin., No. 3, 25-32 (1973).