THE CHAIN STRUCTURE CONTRIBUTION TO THE MAGNETOVISCOSITY OF A KEROSENE BASED FERROFLUID [1]

ЦЕПНАЯ СТРУКТУРА ВКЛАДОВ В МАГНИТНУЮ ВЯЗКОСТЬ ФЕРРОЖИДКОСТИ, ОСНОВАННОЙ НА КЕРОСИНЕ

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Ferrofluids consist of single domain particles (≈ 10 nm in diameter) dispersed in a liquid carrier like water, kerosene, petroleum and so on. These fluids exhibit a superparamagnetic behaviour. The colloidal stability is achieved in two ways. Firstly, the particles are coated with long-chain surfactant molecules which reduces the short range Van der Waals interaction. Secondly, the particles are made as small as possible in order to reduce the effect of the long-range magnetic dipolar interaction. But as a consequence of the dipole-dipole interaction between particles the particle tends to attract the neighbouring particles in the direction of its magnetic moment. It is expected, therefore, that the particles form clusters. From observation of various physical properties, it is concluded that not only individual particles but also the clusters of these particles play an important role in physical phenomena [1].

The viscosity of magnetic fluids is generally increased by the application of the magnetic field. The first suggested mechanism [2] of the viscosity increase was interpreted in terms of the hindrance of rotation particles by the magnetic field. The maximum value of this magnetoviscosity effect is $\Delta\eta/\eta_0]_{max} = 3\varphi/2$, where φ is the volume concentration of magnetic particles. This mechanism cannot explain the anomalous behaviour of viscosity in some ferrofluids [3]. Therefore it seems that the magnetoviscosity can hardly be interpreted in terms of the rotation of individual particles. Another possibility is that the magnetoviscosity is caused by the cluster formation of the particles rather than by the hindrance of rotation of the individual particles. The last mentioned contribution to viscosity was calculated by Bibik [4]. This magnetoviscosity contribution is given by the dissipation process on the chain structures of the magnetic particles. But Bibik did not consider the dependence on the applied magnetic field. The final result in situations when the magnetic field is perpendicular to the flow of the ferrofluid is given in paper [5] by the formula

$$\Delta\eta(H) = \Delta\eta H/(H^2 + H_B^2)^{1/2}. \tag{1}$$

where $\Delta\eta_B = \mu^2 n/2\pi\mu_0\gamma R_2^3$ is Bibik's result and $H_B = \mu/\pi\mu_0 R_2^3$. μ is the magnetic moment of a particle, n is the concentration of the magnetic particles in unit volume. R_2 is the distance between particles in a chain system and γ is the velocity gradient. Using eq. (1) we obtain in the limits of small and large fields the following equations:

$$\Delta\eta(H \to 0) = \Delta\eta_B H/H_B \tag{2}$$

and

$$\Delta\eta(H > H_B) = \Delta\eta_B(1 - H_B^2/2H^2) \tag{3}$$

respectively.

From the slopes of the magnetoviscosity vs magnetic field for $H \to 0$ ($\mathrm{tg}\,\alpha_0$) and vs $1/H^2$ for $H > H_B$ ($\mathrm{tg}\,\alpha_\infty$) we can easy obtain using eqs. (2) and (3) the following relation

$$\mathrm{tg}\,\alpha_\infty/\mathrm{tg}\,\alpha_0 = H_B^3/2. \tag{4}$$

which makes it possible to determine H_B and the R_2 distance between particles in the chain system respectively.

For the experimental measurement we have used a kerosene based ferrofluid with Fe_3O_4 particles, stabilized with an oleic acid sheath. The values of the viscosity were measured from the flow times of the ferrofluid with the magnetic field perpendicular to the flow direction. The experimental points of the viscosity are shown in Fig. 1. The viscosity increase is about twice that of the viscosity in the zero field. It is evident that this increase cannot be explained as a consequence of the rotation of individual particles, because the volume concentration is about $\varphi = 0.03$.

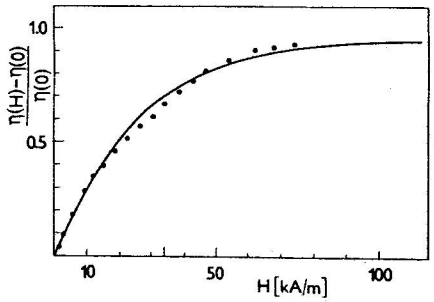

Fig. 1. Magnetoviscosity of a kerosene based ferrofluid as a function of the magnetic field. The full line is the theoretical fit given by eq. (1). $H_B = 34$ kA/m.

The theoretical fitting line is given by the full line in Fig. 1. The agreement between theory and experiment is good. The value $H_B = 34$ kA/m has been determined from eq. (4). The discrepancy between theory and experiment can be explained in terms of the particle size distribution, because the theory was proposed for particles of the same size. The particle size distribution has been calculated from room temperature magnetization measurements. The magnetization curve as a function of the magnetic field is given in Fig. 2. Using the Chantrell technique [6] for the calculation of the parameters of the log-normal distribution we have determined these values: the median diameter of particles is $D_v = 12$ nm and the standard deviation $\sigma = 0.336$. The saturation magnetization of the ferrofluid is $I_s = 6.51$ mT and the concentration of magnetic particles in unit volume is $n = 1.89 \times 10^{22}$ particles/m^3. If we consider particles with the same size $D = D_v$, we can obtain from value H_B for the distance between particles in the chain system the value $R_2 = 16$ nm. This means that the value of the stabilizing sheath of oleic acid on the magnetic particle is about 2 nm when the particles are in contact.

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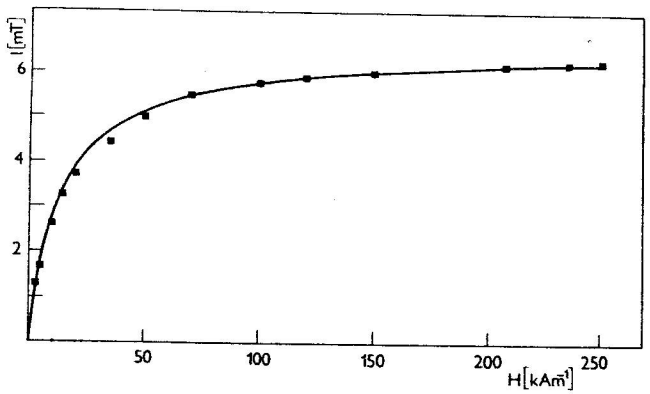

Fig. 2. Room temperature magnetization curve of a kerosene based ferrofluid. The full line is the theoretical fit obtained by the log-normal particle size distribution function and the superparamagnetism theory.

REFERENCES

[1] Chikazumi, S., Taketomi, S., Ukita, M., Mizukami, M., Miyajama, H., Setogawa, M., Kurimara, Y.: J. Magn. Magn. Mater. *6* (1987), 245.
[2] Shliomis, M. I.: Zh. Eksp. Theor. Fiz *61* (1971), 133.
[3] Popplewell, J., Charles, S. W.: IEEE Trans. on Magnetics *17* (1981), 2923.
[4] Bibik, E. E.: Magn. Gydrodyn. (1973), 25.
[5] Kopčanský, P., Horvath, D., Zentko, A.: Czech. J. Phys. *B38* (1988), 1181.
[6] Chantrell, R. W., Popplewell, J., Charles, S. W.: IEEE Trans. on Magnetics *14* (1978), 975.

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