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INFLUENCE OF MAGNETIC FIELD ON VISCOSITY OF SUSPENSIONS BASED ON DUSTED IRON POWDER

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The influence of a magnetic field on the viscosity of magnetic suspensions has been studied experimentally and a model of this process based on the law of viscous fluid flow in a channel with lattice-type hydrodynamic drags is proposed.

Introduction. Magnetic fluids as promising technological media with an ever-expanding field of application have been the subject of much investigation. The physicochemical studies of these media have evolved into a separate direction of investigation of field-matter interactions. Along with magnetic fluids there also exist magnetic suspensions, where the concentrations and sizes of the magnetic impurity particles are much higher than in the fluids. The effect of change in the viscosity of the suspensions may be due to the orientation ordering of impurity particles and is more pronounced than in molecular liquids [1, 2]. Below we present the results of investigation of this process for the sedimentation-stable magnetic suspensions obtained by us on the basis of transformer oil (t.o.), dusted iron powder (d.i.p.), oleic acid, and a thickening agent (CIATIM-201).

Experimental. We have used the most popular method of capillary viscosimetry due to the simplicity of its realization and a fairly high accuracy of measurements. The outflow time t of some volume of substance V through a capillary of radius R and length l under the action of a constant pressure P is determined. The dynamic viscosity of the substance is estimated by the Poiseuille formula [3]

$$\eta = \frac{t}{8l} \pi R^4 \frac{P}{V} . \tag{1}$$

It should be noted that the Poiseuille formula holds for a steady flow of a Newtonian fluid in a capillary of unlimited length and is, strictly specking, inapplicable to suspensions. Here it is necessary to introduce a correction A reflecting the deviation of the flow velocity profile from the parabolic type and taking into account the specific features of the flow in a particular capillary of the experimental facility:

$$\eta = At \frac{P}{V} . \tag{2}$$

The required correction can be calculated from the results of [4, 5] or determined experimentally with the use of a standard viscosimeter (e.g., a rotational one). However, there is no need to do this if not the absolute value of the dynamic viscosity, but only its relative change under the action of the external field, is determined.

In the proposed experiment, the time t in which the suspension level in the burette is lowered from height h_1 to height h_2 is measured. In considering a differentially small displacement of the level h by the value dh, we have

$$\eta = Adt \frac{P}{dV} , \quad P = \rho gh , \quad dV = Sdh , \tag{3}$$

$$dt = \frac{S\eta dh}{A\rho gh} . \tag{4}$$

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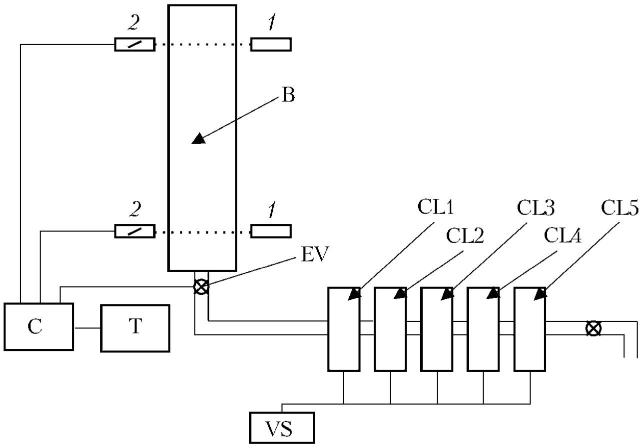

Fig. 1. Block diagram of the experimental facility for measuring the dynamic viscosity of magnetic suspensions upon application of an external magnetic field: 1) and 2), optoelectronic sensors; B, burette; C, commutator; T, timer; CL1–CL5, electromagnet coils; VS, low voltage source; EV, electromagnetic valve.

Integrating expression (4) within h_1, h_2, we obtain

$$t = \frac{S\eta}{A\rho g} \ln\left(\frac{h_1}{h_2}\right). \tag{5}$$

Upon application of a magnetic field under the same experimental conditions Eq. (5) takes on the form

$$t_{\mathrm{i}} = \frac{S\eta_{\mathrm{m}}}{A\rho g} \ln\left(\frac{h_1}{h_2}\right). \tag{6}$$

The relative change in the viscosity is determined by the proportion

$$\frac{\Delta\eta}{\eta} = \frac{\eta_{\mathrm{m}} - \eta}{\eta} = \frac{t_{\mathrm{m}} - t}{t}. \tag{7}$$

It is to be qualified that relation (7) holds only at low flow velocities of the suspension, when the viscosity is velocity-independent. In our experiment the flow velocity of the suspension does not exceed 10^{-2} m/sec and this condition is fulfilled. The block diagram of the experimental facility is given in Fig. 1.

A low-voltage source simultaneously feeds voltage and controls current through the electromagnet coils (all coils are identical). The portion of the capillary before the electromagnet coils was chosen so that along the full length of the tube the suspension flow had a laminar steady character. The suspension outflow time between control markers is measured by means of optoelectronic sensors operating in the infrared range. The sensors are linked through a commutator with an electronic frequency meter with a time interval measurement unit. The measurement accuracy of the outflow time is 0.001 sec. The specific feature of the experiment is the investigation of the influence on the suspension of a constant magnetic field of both one and several coils simultaneously at a longitudinal (with respect to the flow) direction of the field lines. Comparison of the results makes it possible to correct the model of the process being investigated.

Measurement Data. As the measurements have shown, the change in the suspension viscosity depends on the applied magnetic field strength and the magnetic impurity concentration but is independent of the field direction (with the suspension flow or against it). The measurement data obtained under the action of a constant magnetic field of one and five coils are presented in Fig. 2. The concentration of impurity particles is given in volume fractions, and the particle sizes range from 0.005 to 0.016 mm.

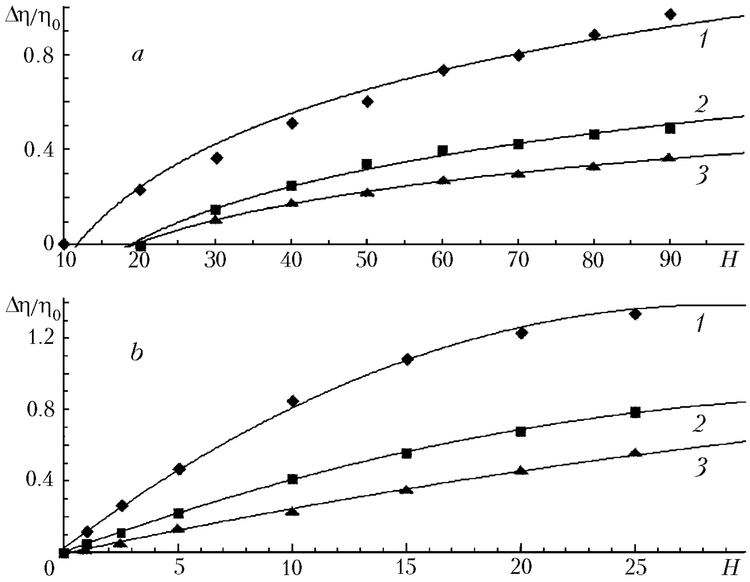

Fig. 2. Relative change in viscosity versus the magnetic field strength of one (a) and five (b) coils: 1) t.o. + 30% d.i.p., 2) t.o. + 10% d.i.p., 3) t.o. + 5% d.i.p.

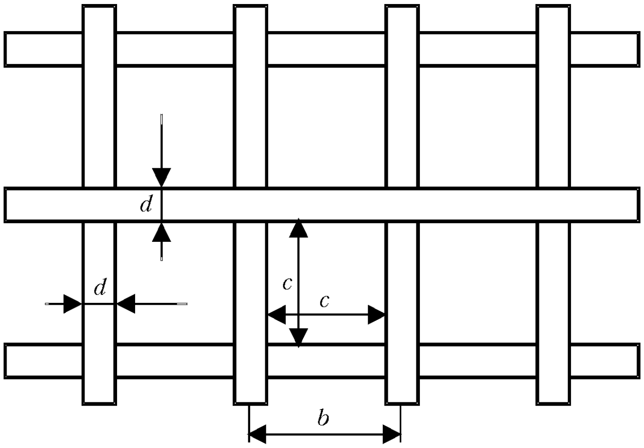

Fig. 3. Lattice-type drag.

The dependence of $\Delta\eta/\eta_0$ on the magnetic field strength of one coil reaches saturation in fields with a strength of the order of 100 kA/m. For five coils saturation begins already at 25 kA/m in a coil. The character of the dependences can be approximated by a logarithmic function with a correlation coefficient no less than 0.98 (at small impurity concentrations these same dependences can also be approximated by the Langevin function). The maximum value of the change in viscosity under the action of the field of one coil reaches 100% of the initial value, and under the action of five coils it reaches 250%. In each case this is much higher than in molecular magnetic fluids (20%). Moreover, at small impurity concentrations and a fixed value of the magnetic field strength in a coil a linear dependence between the relative change in the suspension viscosity and the number of coils is observed.

Proposed Model of the Process. The results obtained suggest that the possible cause of the change in the suspension viscosity is the structurization of impurity particles in the magnetic field. Magnetic impurity particles, lining up with the field lines to form bridge structures, create hydrodynamic drags impeding the suspension flow. The amount of drags is determined by the number of sites of the field action (number of coils), and the efficiency of drags (as to the change in viscosity) is determined by the suspension magnetization. Geometrically, these drags represent a lattice structure following the structure of the magnetic field lines (cones narrowing towards the central axis

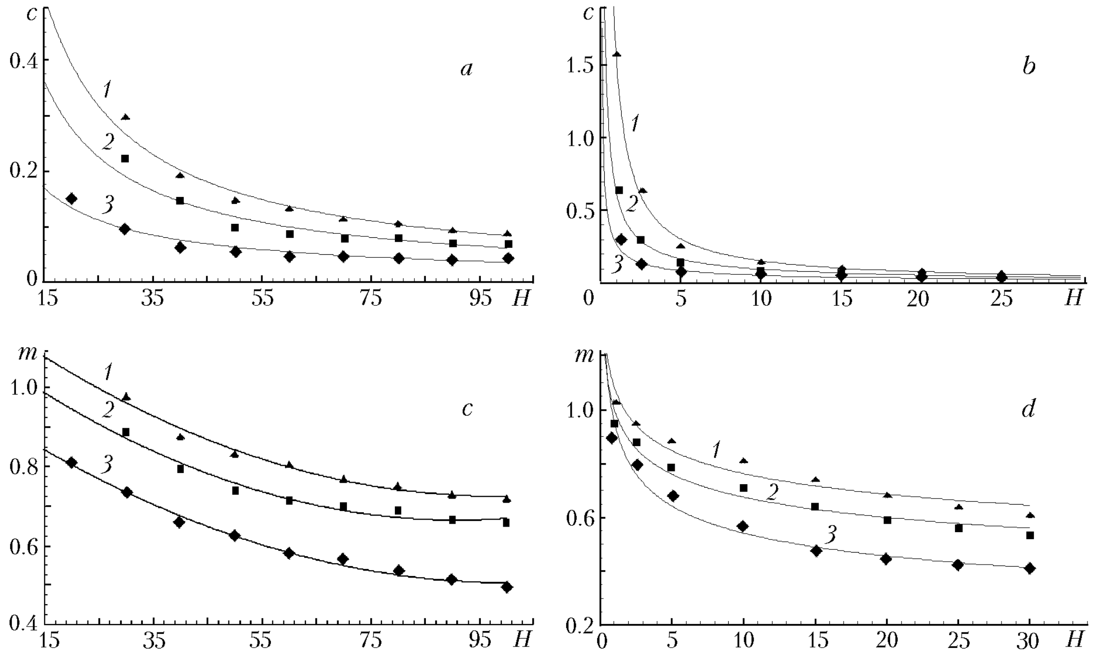

Fig. 4. Values of the parameters c (a, b) and m (c, d) versus the magnetic field strength of one (a, c) and five (b, d) coils. Designations 1–3 are same as in Fig. 2.

of the coil). The greatest resistance to the fluid flow arises near the capillary wall. The latter is confirmed by the fact that in the capillary an increase in the particle concentration near its walls at the exit from the coil is visually (at quantitative level) observed. Naturally, the supposed structures are not rigidly bound to the capillary walls and are moving inside it following the main fluid. Nevertheless, equivalently they can be considered as hydrodynamical drags partly overlapping the cross-section of the channel and changing the flow rate of the fluid. The most important thing here is the efficiency of overlapping the cross-section of the channel rather than the drag geometry. Of all kinds of local drags described in hydraulics [6, 7] lattice-type drags proved to be the most reasonable (Fig. 3).

The relative change in viscosity $\Delta\eta/\eta_0$ of the model medium is related to the geometric characteristics of the lattice by the following relations:

$$\frac{\Delta\eta}{\eta_0} = \frac{1}{m} - 1\,, \quad m = \frac{c^2}{b^2} = \frac{c^2}{(c+d)^2}\,.$$

The parameter m shows the relative area of the free cross-section of the channel; c is the size of the bridge structure segment. Assuming that the numerical value of d corresponds to the maximum size of magnetic impurity particles (0.016 mm), we have calculated the numerical values of the geometric characteristics of the lattice (parameters c and m). The results are presented in Fig. 4.

The calculations performed show that in the proposed model the influence of the magnetic field is reduced to a change in the dimensions of the lattice elements. This is equivalent to changes in the free area of the channel cross-section and fluid viscosity. An increase in the number of sites of action of the field is equivalent to an increase in the number of lattices and model medium viscosity. The numerical values of the model parameters satisfactorily describe the experimental data, which is evidence in its favor.

Conclusions. The action of a constant magnetic field on a magnetic suspension based on a liquid organic dielectric and metal powders permits doubling its viscosity. The model of the process can be based on fluid head losses on local hydrodynamical drags of the lattice type formed from field-oriented magnetic impurity particles.

NOTATION

A, facility constant; *b*, distance between the centers of lattice elements, m; *c*, distance between the inner surfaces of lattice elements, m; *d*, lattice element diameter, m; *g*, acceleration of gravity, m/sec^2; *H*, magnetic field strength, kA/m; h_1 and h_2, height of the initial and final levels of suspension in the burette, m; *dh*, change in the suspension level in the burette, m; *l*, capillary length, m; *m*, lattice spacing; *P*, pressure, N/m^2; *R*, capillary radius, m; *S*, area, m^2; *t*, time of suspension outflow through the capillary, sec; $t_{\rm m}$, time of suspension outflow through the capillary upon application of external magnetic field, sec; *V*, volume, m^3; *dV*, volume change, m^3; η, dynamic viscosity, N·sec/m^2; $\Delta\eta$, change in dynamic viscosity, N·sec/m^2; $\eta_{\rm m}$, dynamic viscosity upon application of magnetic field, N·sec/m^2; η_0, initial (without application of magnetic field) dynamic viscosity of the model medium, N·sec/m^2; ρ, suspension density, kg/m^3. Subscripts: m, magnetic.

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