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Short Communication

Influence of Brownian Diffusion on Levitation of Bodies in Magnetic Fluid

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The present work deals with experimental investigation of the levitation of magnetic and non-magnetic bodies in a magnetic fluid when essentially influenced by Brownian diffusion of magnetic particles in it. It is established that the point of levitation of bodies in a magnetic fluid varies with time.

Keywords: Magnetic fluid, Brownian diffusion, Levitation.

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1. INTRODUCTION

As theoretically shown [1, 2], the processes of magnetophoresis and Brownian diffusion in a magnetic fluid under inhomogeneous magnetic fields can essentially influence a static pressure distribution in it due to a redistribution of magnetic particle concentration. Accordingly, the statics of a magnetic fluid and, particularly, conditions for levitation of magnetic and non-magnetic bodies in it can, to a considerable extent, be specified by these processes.

This fact is of special importance for magnetic fluid devices based on the levitaton of permanent magnets in the magnetic fluid: suspensions in measuring devices [3], dynamic shock absorbers [4], etc. for which the stability of parameters, in particular suspension elasticity, is significant.

Among the fundamental parameters responsible for mass transfer processes in the magnetic fluid are:

– mobility of magnetic particles b that for spherical particles is determined through the viscosity of the carrier fluid η and through their radius R: $b = 1/6\pi\eta R$;

– diffusivity D that in Einstein's classical theory of Brownian diffusion of particles is related to the mobility by $D = kTb = kT/6\pi\eta R$;

– dimensionless criterion $U = \mu_0 m_m H_0/kT$ that is the ratio of the potential energy of a particle with a magnetic moment mm under a magnetic field H_0 to its thermal energy kT. Here μ_0 is the magnetic permeability of vacuum, k is the Boltzmann constant, T is the temperature.

– characteristic dimension of concentration inhomogeneity l, at which the particle concentration changes e times. It is determined by the value $U = 1$. In this case, as a characteristic value of a magnetic field one should choose a product of a characteristic value of its *gradient* $G = |gradH|$ and a characteristic dimension: $H_0 = Gl$. Then $l = kT/\mu_0 m_m G$.

– characteristic diffusion time, τ, of particles in the magnetic fluid. It is determined as follows: $\tau = l^2/D = \pi\eta RkT/(\mu_0 m_m G)^2$.

2. EXPERIMENT

Experiment is carried out with magnetic fluids based on transformer oil and kerosene with magnetite particles. Their properties are presented in a table below.

Table 1 – Physical properties of used magnetic fluids

Carrier fluid	Transformer oil	Kerosene	
Magnetic fluid name	MOT-31	MK-28	MK-44
Magnetisation of saturation M_S, kA/m	31,2	28,3	43,8
Density ρ, kg/m^3	1270	1158	1305
Magnetic fluid viscosity η, Pa·s	0,0356	0,0025	0,0066
Carrier fluid viscosity η, Pa·s	0,02	0,0008	
Magnetic particles volume concentration, %	6,6	5,9	9,1
Magnetic particle diameter, d_m	7,6-12	8-12	8,4-12

The mean magnetic moment of magnetite particles is $m_m = 2.5 \cdot 10^{-19}$ J/T.

2.1 Levitation of a Permanent Magnet in Magnetic Fluid

The influence of mass transfer processes in the magnetic fluid on the levitation of a permanent magnet in it is studied by the example of an object typical for the above-mentioned magnetic fluid devices. It represented a magnet inside a large magnetic fluid drop held on a horizontal solid base, as shown in Fig. 1.

Rectangular ferrite-barium magnets with magnetization along the shortest side are used. Their size is 10 × 20 × 5 mm, and mass is 4,7 g.

At the initial time moment, the permanent magnet placed into a homogeneous magnetic fluid occupies some equilibrium position at a distance h_0 from the

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base. With time, because of the processes of magnetophoresis and Brownian diffusion, the concentration of magnetic particles in the vicinity of the magnet increases and near the base decreases. As a result, the magnet when acted upon by the gravity moves closer to the base and finally occupies a new equilibrium position. In experiment, this movement Δh is fixed by means of a cathetometer with an accuracy of 0.01 mm.

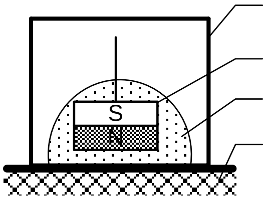

Fig. 1 – Scheme of experimental cell on permanent magnet levitation. 1 – solid base, 2 – magnetic fluid, 3 – permanent magnet, 4 – transparent cover

It should be noted that such variations also result in enhancing the stiffness of the system.

Data for the one magnet will be presented below. Maximum magnetic field intensity at the surface of it is 65 kA/m, and the corresponding gradient of the field intensity at this point is equal to 15000 kA/m^2.

The values of the criterion U corresponding to this magnetic field is 5,1.

The magnetic fluid volume V is varied from 3000 to 5000 mm^3.

Time variations of the positions of levitation of the magnet in the magnetic fluid are shown in Figs. 2 and 3.

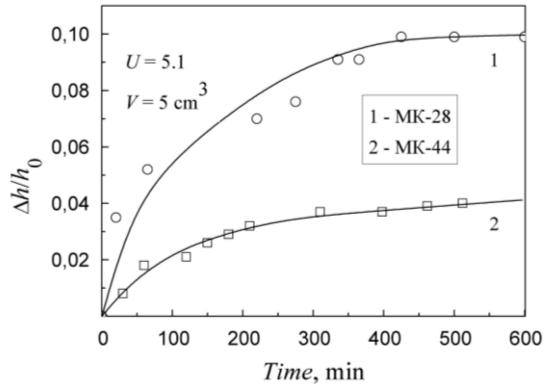

Fig. 2 – A relative displacement $\Delta h/h_0$ of the levitation point of the magnet in the kerosene based magnetic fluid in time

The comparison of the data in Figs. 2 and 3 first of all attracts attention to an essentially different time of attaining a new equilibrium position by the magnet for different fluids.

As seen from the presented in Introduction expression for the characteristic diffusion time, τ, of magnetic particles in the magnetic fluid, it is directly proportional to the viscosity of the carrier fluid. For the conditions of the experiment described it is 220 min for kerosene based magnetic fluids and 5500 min for transformer oil based fluids. This is consistent with the order of magnitudes for the results plotted in Figs. 2 and 3.

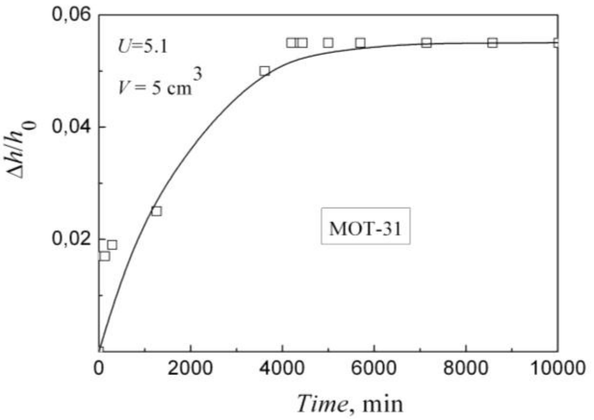

Fig. 3 – A relative displacement $\Delta h/h_0$ of the levitation point of the magnet in the transformer oil based magnetic fluid in time

2.2 Levitation of a Non-magnetic Body in Magnetic Fluid

A plexiglas disc 7 mm in height and 23 mm in diameter is used as a non-magnetic body. A coaxially magnetized circular ferrite-barium magnet 20 mm in height, with inner and outer diameters equal to 84 and 40 mm, respectively, is used as a source of an inhomogeneous magnetic field. Maximum values of the magnetic field intensity and its vertical gradient on the magnet axis are equal to 22 kA/m and 3000 kA/m^2. Because of its small density, the disc was floating over the magnetic fluid surface. The fluid filled a cylindrical vessel located inside the magnet ring, as presented in Fig. 4.

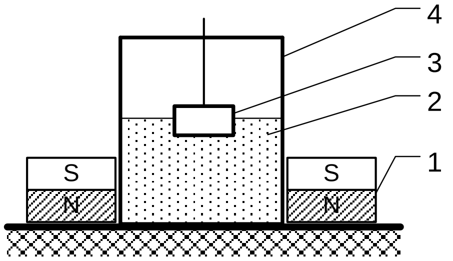

Fig. 4 – Scheme of experimental cell on levitation of nonmagnetic disk. 1 – circular permanent magnet, 2 – magnetic fluid, 3 – non magnetic disc, 4 – transparent vessel

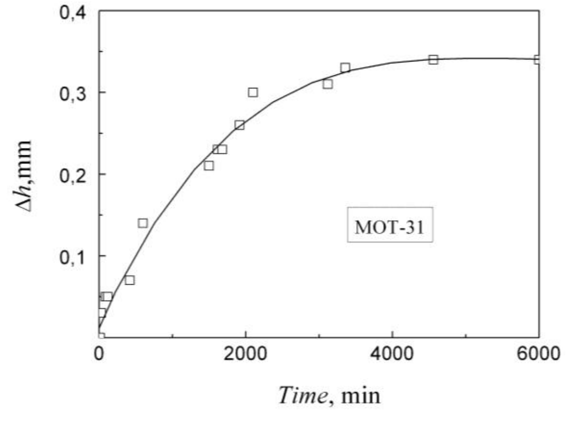

Fig. 5 – Absolute displacement Δh of the levitation point of a nonmagnetic disc in the transformer oil based magnetic fluid in time

In this case, the buoyancy force acting upon the disc decreases with time and it more submerged into the fluid [2]. In experiment, this movement Δh was also fixed by means of the cathetometer. The results are presented in Fig. 5.

As seen from Fig. 5, the characteristic diffusion time is of the order of 4000 min and corresponds to the identical experimental data on the floating of the magnet in the transformer oil based magnetic fluid, Fig. 3.

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