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Some features of the interaction of magnetic fluid drops with magnetized aggregates with a rotating magnetic field

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ABSTRACT

Peculiarities of the interaction of magnetic fluid drops with a rotating magnetic field caused by the micro-rotations of micro-aggregates of colloidal particles were investigated. Two frequency modes of drop rotations are considered which are characterized by the nature of rotation. A mathematical model of non-deformed drops has been developed which considers the micro-rotations of magnetized aggregates in the drop. Features of the falling magnetic fluid spherical drop with magnetized aggregates in a liquid medium exposed to a rotating magnetic field were studied as well as the rotation of a flat (disc-shaped) drop of such fluid floating on the water surface. The behavior of the disc-shaped drop was numerically modelled for the basic mode of rotation, which has revealed good qualitative agreement of numerical and experimental results.

1. Introduction

Magnetic fluids (MF) [1–3] are colloidal solutions of nano-sized ferromagnetic particles stabilized by a surface-active substance (SAS). The mean size of the particles is about 10 nm, which provides colloid sedimentation stability, single-domain particles and MF high magnetic susceptibility.

It is known that due to the disturbance of the balance of the forces of inter-particles attraction and repulsion under the influence of different factors, the single-domain particles in magnetic fluids stable to stratification could form aggregates. Many studies have concerned the above processes, the analysis of which could be found in some reviews [3,4]. In [5], a formation of two types of aggregates in a kerosene-based MF was observed, i.e. drop-shaped aggregates, the shape of which varies under the action of a magnetic field, and quasi-solid aggregates which, in some situations [6,7], could have a magnetic moment different from zero.

The presence of such aggregates in the magnetic fluid must apparently determine the features of the fluid interaction with the external magnetic field caused by the alignment of the aggregates' magnetic moments with the field. Actually, some phenomena found earlier in magnetic fluids are caused by the micro-rotations of dipole colloidal particles [8,9], that is why a model of inner rotations considering the non-balance processes of magnetic relaxation and the occurrence of a volumetric ponderomotive moment of forces has been developed to describe the magnetic fluids. Numerous studies concerned with the problems have been analyzed in [3]. It might be suggested that the possibility of inner rotations of not only individual colloidal particles but also of their magnetized aggregates must introduce essential correction into the characterization of the above-pointed phenomena.

With this in mind, the present study was focused on the investigation of the peculiarities of the interaction of MF drops containing a developed system of magnetized aggregates with a rotating magnetic field. In some cases, for comparison, similar experiments with drops of a microscopically homogeneous magnetic fluid of the same magnetization in the studied fields were carried out. Peculiarities of conduct of the fluids with magnetized aggregates should be considered while designing the devices where magnetic fluids with such aggregates are the working medium.

2. Methods and procedure of experiments

The MF drops with a well-developed system of magnetized aggregates subject to a uniform rotating magnetic field are investigated. The falling of a spherical MF drop in an aqueous medium exposed to a rotating in a vertical plane magnetic field was studied as well as the behavior of a flat (disc-shaped) MF drop floating of the water surface in a horizontally rotating magnetic field.

The falling of the MF drop was studied using a setup illustrated in Fig. 2. Under gravity, an MF drop (1) falls onto the bottom of a cell (2) filled with water. A vertically rotating magnetic field of intensity 0.9 kA/m was induced by two crossed pairs of Helmholtz

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Nomenclature

MF	magnetic fluid
SAS	surface-active substance
PC	personal computer
VO	vacuum oil
GPU	graphics processing unit

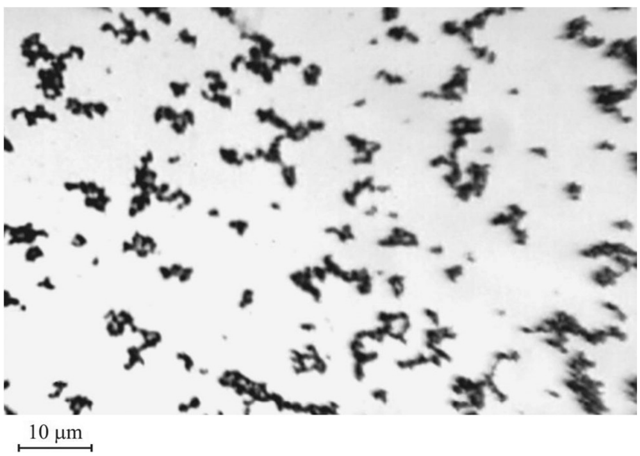

Fig. 1. Microphotography of magnetized aggregates typical of vacuum oil (VO-3)-based magnetic fluids.

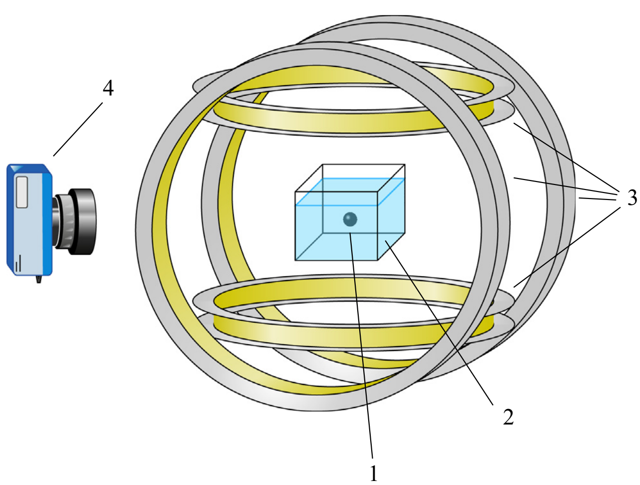

Fig. 2. Schematic of the experimental setup used to investigate the falling of an MF drop: 1 – MF drop, 2 – water-filled cell, 3 – two crossed pairs of Helmholtz coils; 4 – video camera.

coils. The height of the drop fall was 60 mm. The drop falling process was video recorded by a video camera (4); the video records were analyzed by a PC.

The disc-shaped drop behavior on the water surface was studied using a setup displayed in Fig. 3. A cell (2) filled with water with a drop (1) of the investigated magnetic fluid was placed into the zone exposed to a uniform rotating magnetic field of intensity 1.5 kA/m induced by two crossed pairs of Helmholtz coils (3); the intensity vector of the field was aligned in the horizontal plane. The MF drop was placed on the water surface; the drop became disc-shaped, its parameters were varied by liquid soap preliminary added into the water. In order to alleviate the probability of drop deformation in the investigated range of field intensities, drops

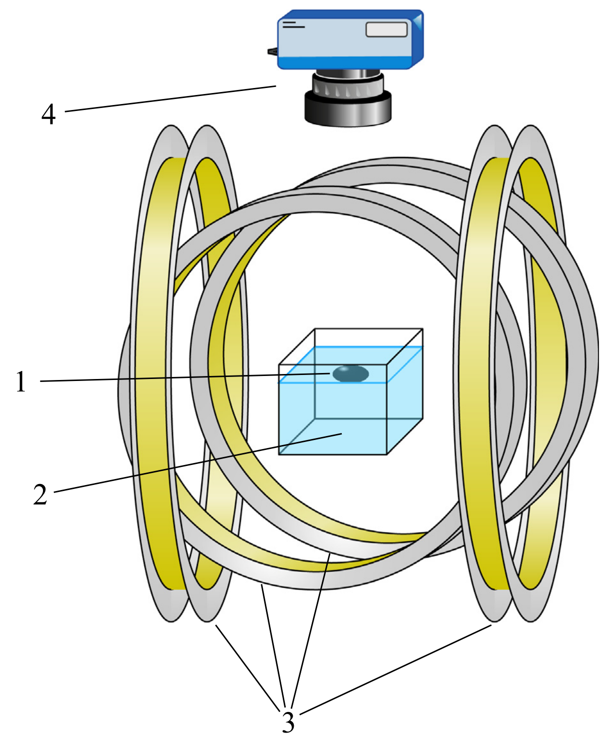

Fig. 3. Schematic of the experimental setup used to investigate the behavior of the drop on the water surface: 1 – MF drop, 2 – water-filled cell, 3 – two crossed pairs of Helmholtz coils; 4 – video camera.

with a relatively small concentration of the disperse phase ($\varphi \simeq 1\%$) were investigated. A small amount of aluminium powder which reflected well the light from the lamp was spread over the water surface and the drop to study the fluid flow velocities and to define the drop angular velocity. The drop motion was recorded by a video camera (4), with the further analysis of the drop behavior by a PC. Additional experiments were performed with a drop of a homogeneous (non-aggregated) magnetic fluid on the same base which had the same magnetization in the investigated field range ($H \sim 1.5$ kA/m) to reveal the role of the aggregates in the mechanism of the disc-shaped drop rotation.

Magnetic fluids with a well-developed system of μ-sized magnetized aggregates were used to produce drops. The conditions of such aggregates' formation and the features of their behavior in steady and alternating magnetic fields were studied by authors earlier in [6,7,10,11]. It was shown that under certain conditions aggregates with a magnetic moment could form in the colloids containing rather big magnetically rigid particles. As a rule, such aggregates exhibit a well-pronounced shape anisotropy, they react quickly enough to the external magnetic field switch on; when the field changes its direction to the opposite, the aggregates turn by 180°, which confirms the presence of the aggregates' self magnetic moment. The formation of magnetized aggregates is possible at a long-term (up to tens of years) storage of magnetic colloids with