MAGNETIC FLUID NANOPARTICLE FRACTIONATION: EXPERIMENTS AND SAMPLE ANALYSIS

MAIOROV M., MEZULIS A.
Institute of Physics, University of Latvia, 32 Miera, Salaspils LV-2169, Latvia
E-mail address of corresponding author: maiorov@tesla.sal.lv

Abstract:
In the present work, fractionation is achieved by two different experiments: centrifugation and gravity sedimentation column. Three samples are obtained and compared by their particle size distribution: the fractions from the bottom and from the top of the gravity sedimentation column after 30 days of exposition, and the light fraction after centrifugation for 8 hours at acceleration 7000 g.

1. Introduction

The ferrofluid is a colloidal solution of stabilized magnetic nanoparticles in a liquid carrier. Usually it is a polydisperse system with a rather wide size distribution. Under some conditions, such as gravitation, acceleration, gradient magnetic field and temperature, redistribution of the magnetic nanoparticles occurs in the volume [1]. As a result, not only the particle concentration but also the mean particle size of the colloidal solution varies with taken part of the solution volume i.e. the fractionation takes place.

2. Experiment

The setup for gravity sedimentation is shown in fig 1. The concentration of magnetic nanoparticles at the top and at the bottom of the test-tube was obtained by measuring the inductance of the coils by a high precision LC meter Quad-Tech 7600. The sample exposition lasted for 30 days.

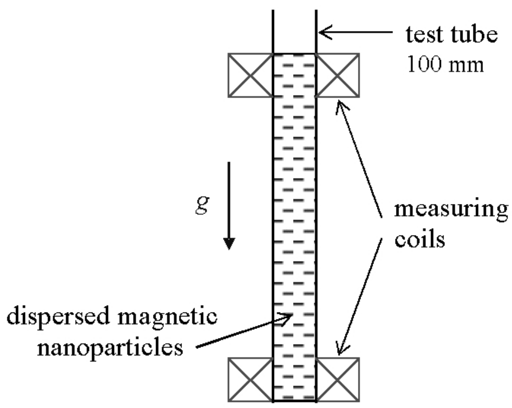

Figure 1: Setup for the gravity sedimentation.

A sketch of the centrifugation is shown in fig 2. The centrifugation time was 8 hours. After centrifugation, the upper layer of the sample was collected by a syringe.

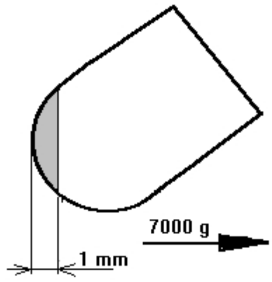

Figure 2: Centrifugation of a sample.

Three samples were obtained: S1 and S2 are fractions from the bottom and top of the gravity sedimentation column, and S3 is the light fraction after centrifugation. These samples were examined by the relaxation of the optical anisotropy setup [2, 3]. The relaxation of the optical anisotropy is studied according to the method in Ref. [2] with turnoff time for the magnetic field < 300 ns, and by a digital oscilloscope and a PC for performing measurements illustrated in fig. 3.

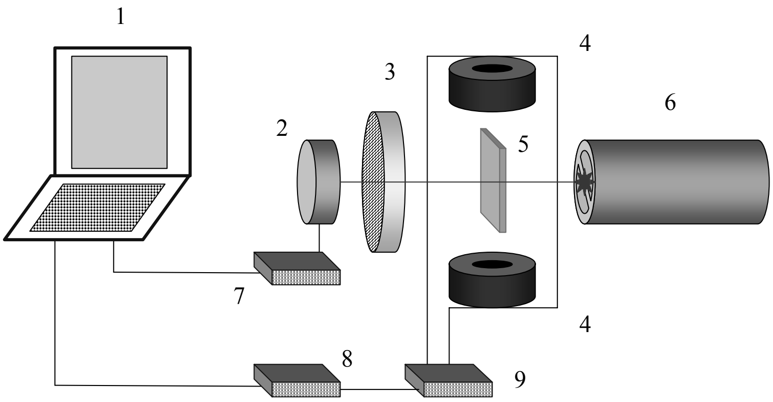

Figure 3: The experimental setup: 1 – PC, 2 – photo-detector, 3 – optical analyzer, 5 - experimental cell, 4 – pulse electromagnet, 6 – laser, 7 – digital oscilloscope, 8 – pulse generator, 9 – powerful pulse amplifier.

Polarized light beam from the laser 6 passes through the sample cell 5, which is submitted to the pulse magnetic field of the magnet 4. The polarization plane of the light makes a 45° angle with the direction of the magnetic field. Afterwards the beam passes through the optical analyzer 3, which polarization plane is normal to that of the laser beam. The setup is adjusted so that no light passes to the photo-detector 2 when the sample is isotropic. Main information was obtained by recording the relaxation process of optical anisotropy after switching off the external magnetic field. The relaxation curves of tested samples are displayed in fig 4.

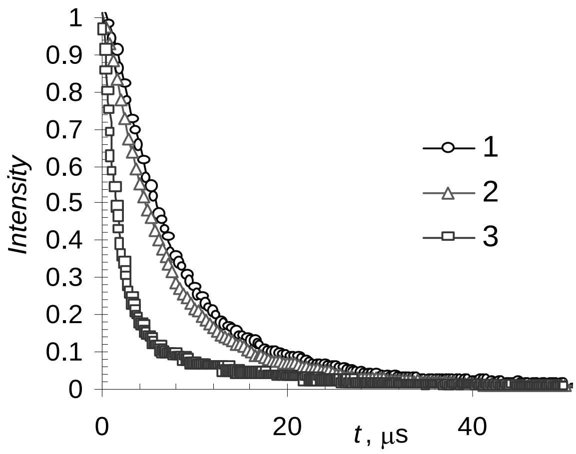

Figure 4: The relaxation of ferrofluid optical anisotropy after fractionation: 1, 2 - bottom and top of the gravity sedimentation column, 3 - top of the centrifuge cell.

As the next step, the obtained optical signal relaxation curves were analyzed by decomposition on the sum of exponents by the regularization method [4]:

$$I(t) = \sum_{i}^{N} I_i \exp(-12 D_{ri}\, t), \tag{1}$$

where N is the number of the particle fractions, D_{ri} is the rotational diffusion coefficient of a particle from the corresponding fraction, I_i is the light intensity induced by the corresponding fraction. In this case, results were obtained by minimization of the next functional:

$$S_c = \frac{1}{t_{\max}} \int_0^{t_{\max}} \left(I(t) - \sum_{i=1}^{N} I_i \cdot e^{-12 D_{ri} t} \right)^2 dt + \alpha \cdot \Omega \tag{2}$$

where $\Omega = \sum_{i=1}^{N} I_i^2$ is the Tikhonov stabilizer of the first type, $0 < \alpha \ll 1$ is a regularization parameter.

The rotational diffusion coefficient D_r depends on the viscosity of the carrier, particle size and temperature. For a spherical particle it is:

$$D_r = \frac{kT}{6\eta V}, \tag{3}$$

where k is the Boltzmann constant, T is the temperature, η is the viscosity of the carrier fluid, V is the volume of a particle. The set of D_{ri} was converted to the set of diameters d_i.

3. Results

The comparison of the size distribution obtained from the optical relaxation analysis confirms the particle fractionation during sedimentation (fig 3).

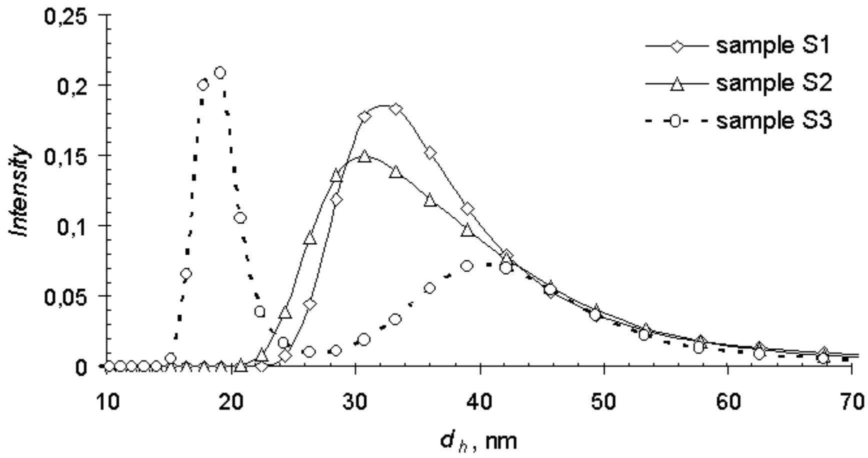

Figure 5: Particle size distribution after gravity sedimentation (S1, S2) and centrifugation (S3).

The bimodal distribution obtained with the centrifuged sample S3 may be explained by a phenomenon that particle sedimentation is dependent not only on the particle size, but also on the particle form. With this in mind, after centrifugation the sample may contain round particles of small size and some quantity of big elongated particles. The elongated particles have highly exposed optical anisotropy and thus give a significant contribution to the analysed optical signal.

So the relaxation of optical anisotropy has high sensitivity, and its analysis may be useful for the magnetic colloid fractionation monitoring under the condition of gravity.

4. References

[1] Blums E., Cebers A., Maiorov M. M., Magnetic Fluids. Berlin, New York, Walter de Gruyter & Co 1997.

[2] Maiorov M. M., Zablotsky D. Y., Measurements of rotary and translation diffusion of magnetite nanoparticles in hydrocarbon based magnetic fluid. Magnetohydrodynamics, vol. 41 (2005), no. 4, pp. 353–359.

[3] Maiorov M. M., Experimental investigation of the kinetics of magnetic birefringence and dichroism in a dilute magnetic fluid. Magnetohydrodynamics, vol. 13 (1977), no. 3, pp. 281-285.

[4] Maiorov M. M., Blums E., Raj K. Inverse task for evaluation of particle size distribution of polydisperse magnetic fluids. (12th International Conference on Magnetic Fluids). Physics Procedia 9 (2010) 74–77.