LIGHT INDUCED STRUCTURALIZATION IN MAGNETIC FLUIDS WITH NEGATIVE SORET CONSTANT

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Introduction. The light induced heating of fluids can give rise to interesting phenomena, which depend upon the illumination character and the type of illuminated fluid. In colloidal fluids a temperature gradient invokes a flow of colloidal particles - thermodiffusion. This process is characterized by the Soret constant $S_{\mathrm{T}} = D_{\mathrm{T}}/D_{\mathrm{dif}}$, D_{dif} is the particle translation diffusion coefficient and D_{T} is the thermal diffusion coefficient.

An interesting feature of thermodiffusion in magnetic fluids is that positive ($S_{\mathrm{T}} > 0$) or negative ($S_{\mathrm{T}} < 0$) Soret effect can be observed, depending on the type of studied fluid. If a magnetic fluid with a positive Soret constant is illuminated, the flow of colloidal particles against the temperature gradient direction is present, i.e., the particles escape from the beam axis. In a magnetic fluid with a negative Soret constant the directions of the concentration flow and the temperature gradient are identical, i.e., the local temperature increase attracts the absorbing particles into a warmer region. In such magnetic fluid an interesting phenomenon can be observed - the creation of a structure with "islands" of enhanced concentration known as the light induced structuralization. Different techniques have been used to determine the Soret constant, particularly based on the thermodiffusion columns [1] or on the forced Rayleigh scattering (FRS) [2]. The Z-scan technique [3], commonly employed to investigate the nonlinear properties of a medium, allowed to make a classification of magnetic fluids based on the stabilization type, surfactant, carrier liquid and the material of colloidal magnetic particles. The forced Rayleigh scattering method consists in the creation of a concentration optical grating in the magnetic fluid, due to its interaction with the interference field of two laser beams. The light, passing through the sample, diffracts on the created concentration grating, thus the effect is also known as self-diffraction. In our previous work [4] we tried to give a more detailed theoretical description of the thermodiffusion process in magnetic fluids, now the aim was to simulate the structuralization in the magnetic fluid with a negative Soret constant and to confirm the negative value of this constant for the penthanol-based magnetic fluid.

1. Computer simulation. Our description of the thermodiffusion process in an illuminated magnetic fluid [4] yielded a non-linear equation describing the development of possible periodic in space (harmonic) inhomogeneity of the magnetic particle concentration

$$\frac{\partial n}{\partial t} = D_{\mathrm{dif}}(1 + S_{\mathrm{T}} K n I_0)\left(\frac{\partial^2 n}{\partial x^2} + \frac{\partial^2 n}{\partial y^2}\right), \tag{1}$$

where n is the concentration of colloidal magnetic particles and I_0 is the intensity of the illumination. The parameter K depends upon the absorption coefficient, the thermal conductivity coefficient of the studied fluid and the heat outlet coefficient. Using Eq.(1) the structuralization process can be explained. If the Soret constant fulfills the inequality

$$S_{\mathrm{T}} < -\frac{1}{Kn_0 I_0}, \tag{2}$$

($n = n_0 + \delta n$, n_0 - mean concentration), then an accidentally occurred concentration maximum will increase and a minimum - decrease. In other words, if a sample of magnetic fluid with the negative Soret constant is illuminated, then, after the intensity of the light reaches the value $I_0^c = 1/(Kn_0|S_{\mathrm{T}}|)$, a structure with "islands" of enhanced concentration will arise. It is because an instant fluctuation (which are always present) is amplified. Using the numerical integration of Eq.(2), a computer simulation of the development of such structure in the magnetic fluid with $S_{\mathrm{T}} < 0$ was made. Fig. 1 illustrates the state of a thin magnetic fluid sample with a developed concentration structure after the intensity reaches the critical value I_0^c.

2. Experiment. The structuralization of the magnetic particle concentration was experimentally observed in a penthanol-based magnetic fluid, sterically stabilized by a double layer consisting of oleic acid and dodecylbenzensulphonic acid (DBS) [5]. The used surfactant is anionic [6], thus according to the observations of Alves et al. [3], the Soret constant of the studied magnetic fluid should be negative and the structuralization of the particle concentration should be observed in the illuminated sample. A thin sample of magnetic fluid (thickness 100 μm) was lighted with a laser beam with $\lambda = 488$ nm, generated by the Zeiss Ar laser ILA 120 with power 150 mW. The radiant power in the sample was multiplied by a converging lens. The whole process, from the beginning of the heating to the structure development, was photographed from the ground-glass screen and then digitized.

The negative value of the Soret constant was also verified by the Forced Rayleigh Scattering experiment, whose set-up consisted of the Zeiss Ar laser, a beam splitter, a mechanical shutter, a thin sample of magnetic fluid (thickness 5 μm) and a photo detector connected to a PC. The beam splitter gave two coherent beams providing an interference field in the sample. The space period of the interference field was in the range from 5 to 200 μm.

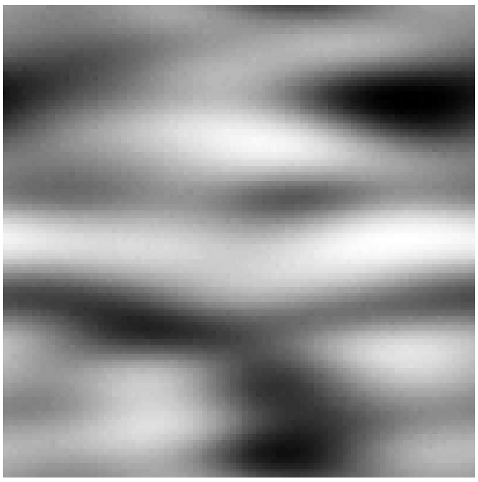

Fig. 1. The illustration of the developed structuralization in the magnetic fluid with $S_{\mathrm{T}} < 0$.

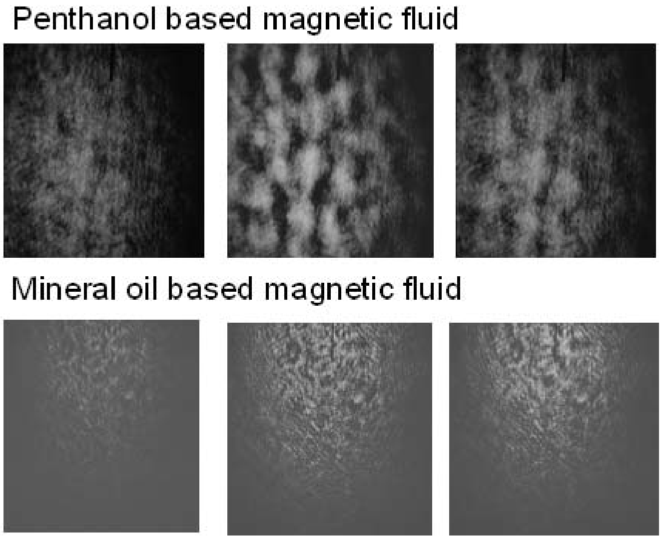

Fig. 2. The development of the structure with "islands" of enhanced concentration in a penthanol-based magnetic fluid; in a mineral oil-based magnetic fluid no structure has arisen.

3. Results and discussion. The structuralization of the magnetic particles concentration was observed in the penthanol-based magnetic fluid after the intensity of illumination reached the value of $I_0^c = 120$ mW. Using this value and typical values of $\lambda \sim 10^{-1}$ W/Km and $\alpha \sim 1$ cm^{-1}, the value of S_T was calculated to be of 10^{-2}K^{-1} order. Fig. 2 illustrates the situation in penthanol- and mineral oil-based magnetic fluid samples at the increasing intensity. It is evident that the in penthanol-based magnetic fluid the structure with "islands" of enhanced concentration has developed. This confirms the supposed negative value of the Soret constant of the penthanol-based magnetic fluid.

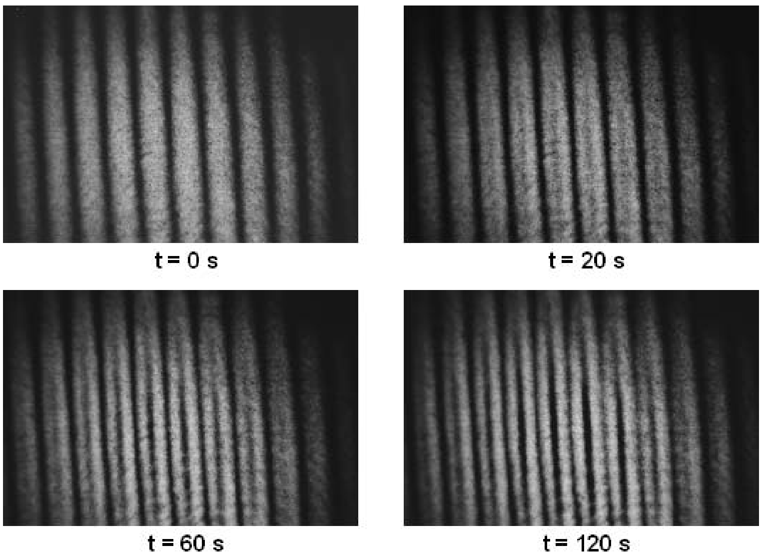

Fig. 3. The shifted interference and concentration gratings in a penthanol-based magnetic fluid (supposed $S_\mathrm{T} < 0$).

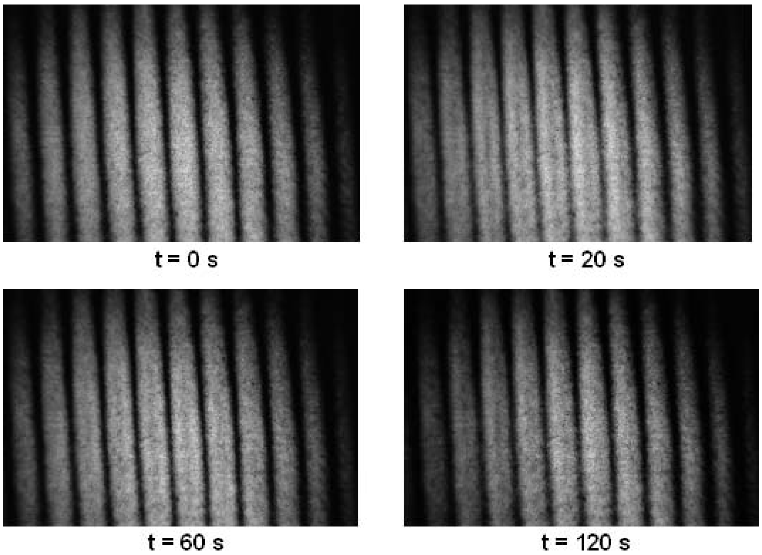

Fig. 4. The overlap of interference and concentration gratings in a mineral oil-based magnetic fluid with $S_{\mathrm{T}} > 0$.

The negative value of the Soret constant has been also verified by the forced Rayleigh Scattering experiment. In this case a concentration grating was created in the interference field of two coherent laser beams. Fig. 3 shows the picture from the ground-glass screen, which illustrates the situation observed in the penthanol-based magnetic fluid. Here the created concentration grating is shifted according to the interference one, as the particles are attracted to the hot regions (light stripes in the interference grating). For comparison, Fig. 4 shows a situation observed in the magnetic fluid with positive Soret constant, where both gratings overlap.

4. Conclusion To conclude, it can be said that the obtained results verified the negative value of the Soret constant in the studied penthanol-based magnetic fluid. The development of the structuralization of magnetic particles concentration in an illuminated thin sample, after the illumination intensity reaches some critical value I_0^c, was numerically simulated and then verified experimentally.

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