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LIGHT INDUCED STRUCTURALIZATION OF MAGNETIC PARTICLES IN MAGNETIC FLUIDS

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The light induced heating of colloidal magnetic fluids can give rise to interesting phenomena, which depend upon the illumination character and the type of the illuminated magnetic fluid. A very interesting phenomenon can be observed in magnetic fluids with negative Soret constant exposed to intensive illumination: the structuralization of the colloidal particles concentration caused by the nonlinearity present at intensive illumination.

Key words: magnetic fluid, structuralization, Soret constant, illumination, double layer, oleic acid, sodium dodecyl sulfate.

1. INTRODUCTION

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

An interesting feature of thermodiffusion in magnetic fluids is that the positive ($S_T > 0$) or negative ($S_T < 0$) Soret effect can be observed, depending on the type of the studied fluid. If a magnetic fluid with 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 magnetic fluid with 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 the 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. In the Z-scan technique the sample is moved along a single-focused Gaussian laser beam (defining a z axis) on both sides of the waist. The light intensity, transmitted through a small calibrated diaphragm far away from the waist, is measured as a function of the sample position z. The optical nonlinearity can we determined studying the light intensity. 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 directs on the created concentration grating, thus the effect is known as the self-diffraction too.

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 magnetic fluid with negative Soret constant and to confirm the negative value of this constant for kerosene-based magnetic fluid in which magnetite particles are stabilized by double layer oleic acid + anionic active detergent such as sodium dodecylsulfate (SDS).

2. COMPUTER SIMULATION

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

$$\frac{\partial n}{\partial t} = D_{dif}\left(1 + SKnI_0\right)\left(\frac{\partial^2 n}{\partial x^2} + \frac{\partial^2 n}{\partial y^2}\right) \tag{1}$$

where n is the concentration of colloidal magnetic particles and I_0 is the intensity of the illumination. The parameter K is expressed as $K=\alpha_{n0}/2\lambda\Omega^2$, where $2\pi/\Omega$ is period of illumination in the *x* direction, α_{n0} denotes the absorption coefficient corresponding to the unit volume concentration and λ is the thermal conductivity coefficient of studied fluid. Using Eq.(1) the structuring process can be explained. If the Soret constant fulfils the inequality

$$S < -\frac{1}{Kn_0 I_0}, \tag{2}$$

($n = n_0 + \delta n$, 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 negative Soret constant is illuminated, then, after the intensity of the light reaches the value $I_0^c = 1/(Kn_0|S|)$, a structure with "islands" of enhanced concentration will arise. It is because instant fluctuations (which are always present) are amplified.

Using the numerical integration of Eq.(2) a computer simulation of the development of such structure in magnetic fluid with $S < 0$ was made. Fig. 1 illustrates the state of a thin magnetic fluid sample with developed concentration structure after the intensity reached the critical value I_o^c.

Fig. 1 – The illustration of the developed structuring in magnetic fluid with $S < 0$.

3. EXPERIMENT

The structuralization of the magnetic particles concentration was experimentally observed in kerosene based magnetic fluid, stabilized by a double layer consisting of oleic acid and sodium dodecyl sulfate (SDS) as an anionic active detergent. The used surfactant is anionic [5], thus according to the observations of Alves *et al.* [3], the Soret constant of the studied magnetic fluid should be negative and the structuring 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 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.

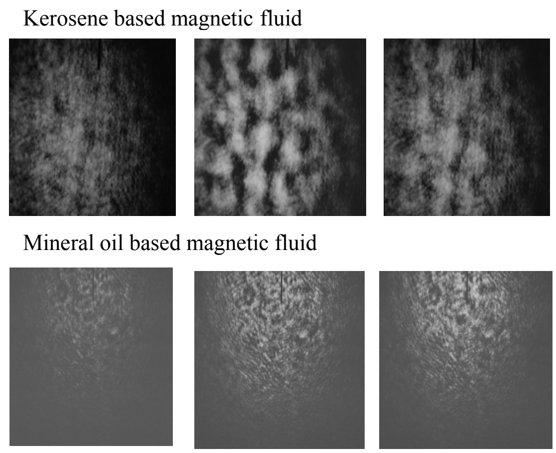

Fig. 2 – The development of the structure with "islands" of enhanced concentration in kerosene based magnetic fluid; in mineral oil based magnetic fluid no structure has arisen.

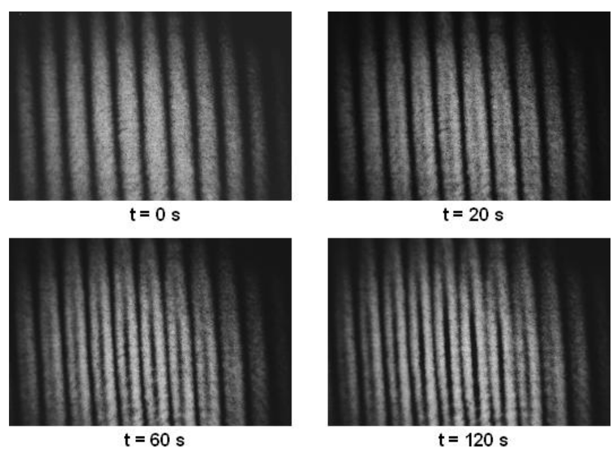

Fig. 3 – The shifted interference and concentration gratings in kerosene based magnetic fluid (derived from forced Rayleigh scattering for negative thermodiffusion).

4. RESULTS AND DISCUSSION

The structuring of the magnetic particles concentration was observed in the kerosene based magnetic fluid after the intensity of the illumination reached the value I_o^c = 120 mW. By means of the relation $|S| = 1/\left(Kn_0 I_0^c\right)$ using this value and typical values of $\lambda \sim 10^{-1}$ W/Km and $\alpha \sim 1$ cm^{-1}, the value of S is negative and was calculated to be of the 10^{-2} K^{-1} order (parameter K is defined in section 2).

Fig. 2 illustrates the situation in kerosene and mineral oil based magnetic fluid samples at increasing intensity. It is evident that in kerosene based magnetic fluid the structure with "islands" of enhanced concentration has developed. This confirms the supposed negative value of the Soret constant of the kerosene based magnetic fluid.

The negative value of the Soret constant was 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 kerosene 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 the sake of comparison Fig. 4 shows the situation observed in magnetic fluid with positive Soret constant, where both gratings overlap .

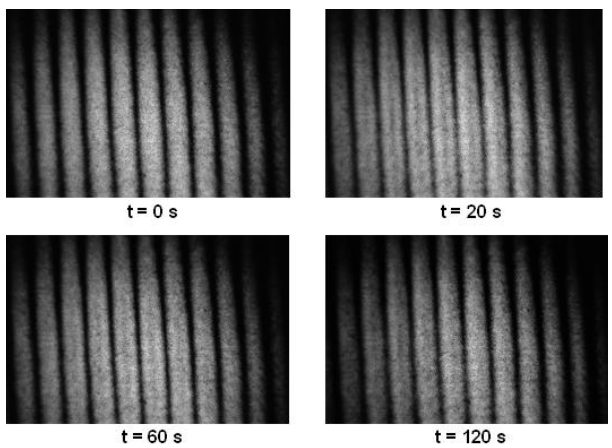

Fig. 4 – The overlap of interference and concentration gratings in mineral oil based magnetic fluid with S > 0.

5. CONCLUSION

In this work we have studied two magnetic fluids with positive and negative thermodiffusion. The results from forced Rayleigh experiments showed that in kerosene based magnetic fluid with negative Soret constant additional stripes were observed as a consequence of the attraction of magnetic particles into the warmer region. No such structure was observed in mineral oil based magnetic fluid with positive Soret constant where directions of the concentration flow and the temperature gradient are identical. To conclude, it can be said that the obtained results verified the negative value of the Soret constant in studied kerosene based magnetic fluid. The development of the structuring of the 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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