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ACOUSTIC AND MAGNETIC PROPERITIES DEPENDENCE OF RESTRUCTURING DIFFERENTS MAGNETIC FLUIDS SUBJECTED TO EXTERNAL MAGNETIC FLUID

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The influence of magnetic field intensity and temperature on acustic and magnetic proprieties was considered. Measurements were conducted at an ultrasonic wave frequency of 3.6 MHz, by a pulse method using the MATEC apparatus. The direction of ultrasonic wave propagation was parallel to the direction of the external magnetic field. The magnetic field range was 10–150 kA/m. The studies were performed for a selected temperatures. The results of this experiments suggested that in magnetic fluids there are different effects connect with restructuring this fluids.

Key words: magnetic fluid, ultrasonic absorption, magnetization.

1. Introduction

Ferrofluids show very interesting properties under an external magnetic field. It has been established that an external magnetic field induces structural changes in the magnetic liquid stimulating formation of the so-called clusters or chain-like. This process depends on the changes external magnetic field intensity. This paper reports a study of the effect of temperature and magnetic field intensity on the absorption coefficient of ultrasonic wave $\Delta\alpha$, extended on the results of magnetic properties measurements studing ferrofluids.

2. Acoustic properties of magnetic liquids

In this measurements ferrofluids (colloidal suspension of magnetic particles) with organic carrier liquid were used. Table 1 shows specification sheet of selected ferrofluids. The experiments contain measurements of changes in the ultrasonic wave absorption coefficient $\Delta\alpha$ in function of magnetic field intensity and the temperature of the magnetic fluid. Results of this experiment regarded the magnetic fluid history, which was studied by several authors for example GOTOH and CHUNG [1]. This phenomenon suggests that a part of the cluster formation of colloidal paticles in the magnetic fluid under the magnetic field remains after a removal of the field.

The changes of absorption coefficient of the ultrasonic wave in the ferrofluid subjected to an external magnetic field was measured by the pulse method [2]. The ferrofluid studied was placed in a special measuring cell containing two parallel transducers (emitter and receiver) distanced at 1.527 cm. The cell was located between the electromagnet pole pieces. The value of measurement error is about 1%.

Table 1. The physical parameters of the ferrofluid samples (FerroTec).

sample	saturation magnetization (25°C)	dynamic viscosity η (27°C)	density (25°C)	surface tension	thermal conductivity	pour point	expansion coefficient
	mT	$mPa \cdot s$	$kg \cdot m^{-3}$	$N \cdot m^{-1}$	$mW \cdot m^{-1} \cdot K^{-1}$	°C	$10^{-4}K^{-1}$
APG 832	22 ± 10%	200	1050	0.03	150	−51	7.50
APG 833	22 ± 10%	500	1060	0.03	150	−44	7.50
APG 834	22 ± 10%	1000	1070	0.03	150	−37	7.50

3. Results and discussion

Figure 1 presents the ultrasonic wave absorption coefficient changes as a function of temperature subjected to an external magnetic field of 50 kA/m for the ferrofluids: APG 832, APG 833, APG 834. With increasing temperature the acoustic wave absorption coefficient decreases, that is in consistence with theoretical prediction. This effect cannot fully explain the temperature dependence of the ultrasonic wave absorption coefficient [3] on viscosity. Additional increase of $\Delta\alpha$ is most probably caused by other factors such as scattering of the ultrasonic waves on magnetic particles and their clusters.

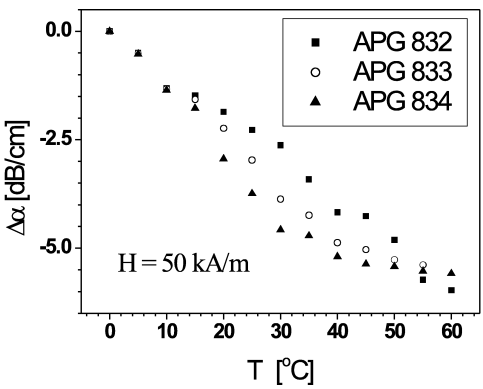

Fig. 1. Ultrasonic wave absorption coefficient changes as a function of temperature subjected to an external magnetic field of 50 kA/m.

The next experiment concerns the measurements of changes in the ultrasonic wave absorption coefficient $\Delta\alpha$ as a function of magnetic field intensity changes for the constant temperature. Figures 2 and 3 present the results of this experiments for different sweeping times, when the ferrofluid temperature was constant.

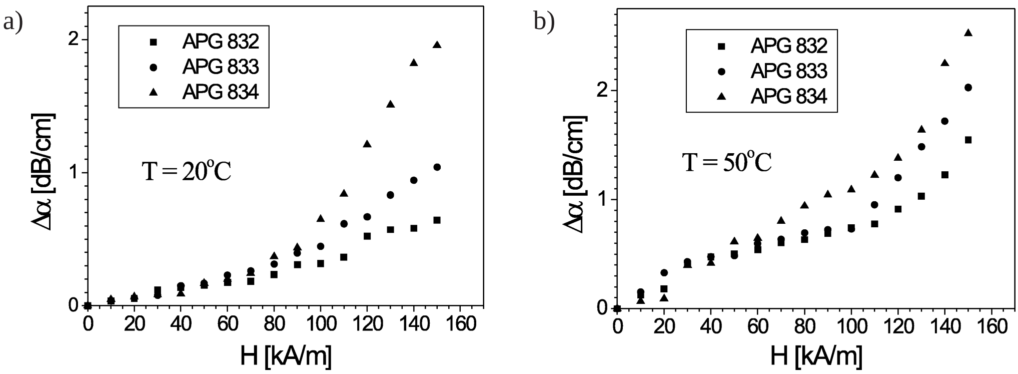

Fig. 2. Changes in the $\Delta\alpha$ as a function of magnetic field for sweeping time $t = 10$ min and the temperature: a) $T = 20°$C and b) $T = 50°$C.

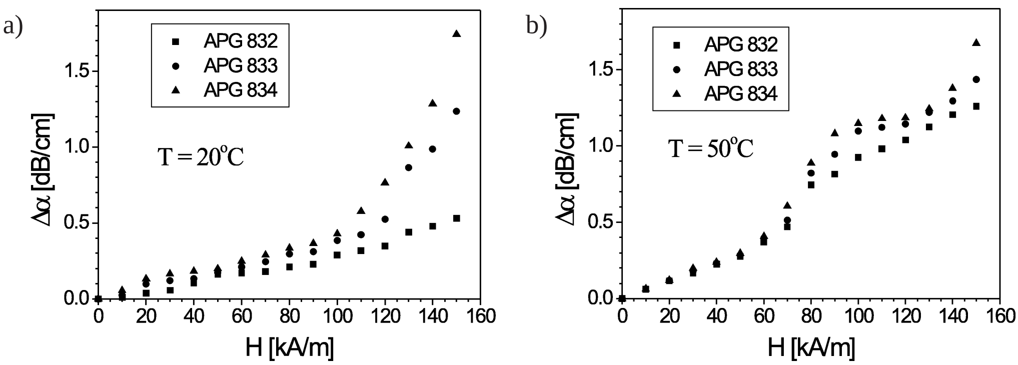

Fig. 3. Changes in the $\Delta\alpha$ as a function of magnetic field for sweeping time $t = 5$ min and the temperature: a) $T = 20°$C and b) $T = 50°$C.

This measurements show that for rapid changes of magnetic field process of $\Delta\alpha$ was slow, this means that restructuring of magnetic fluid could not keep up with magnetic field changes. For longer value of sweep times the clusters can be formed. The results presented on the above figures, shows that viscosity of ferrofluids has an large influence on the value of ultrasonic wave absorption coefficient. For example Fig. 2 shows the achievements of $\Delta\alpha$ for ferrofluids with different viscosity (Table 1). The observations show, that values of ultrasonic wave absorption coefficient are bigger for magnetic liquid with higher viscosity. With an increasing temperature the viscosity of the magnetic fluid decreases [4] and this is why clusters were easy formed. For low temperatures, high viscosity hampers movement of particles. Thus the viscosity of the magnetic fluid is possibly the factor responsible for cluster formation.

4. Magnetic properties of magnetic liquids

Several models based on orientation process of magnetic moments of dispersed particles are used to describe ferrofluid magnetization. When ferrofluids have not very big magnetic particles concentration Φ_V, resultant magnetization of the sample can be recognised as a superposition of elementary Langevin function, which describes particles fraction of suitable dimension.

Taking into account the dependence of magnetic moments on magnetic diameters, the magnetization can be written in the form [5]:

$$\begin{aligned} M_L &= n\int_0^\infty m(x)\,L(\xi)\,f(x)\,\mathrm{d}x, \qquad & L(\xi) &= \left(\coth\xi - \frac{1}{\xi}\right), \\ \xi(x) &= \frac{\mu_0\, m(x)\, H}{kT}, & m(x) &= \frac{\pi x^3}{6} M_S, \end{aligned} \tag{1}$$

where M_s – spontanic magnetization of the magnetite particles ($M_s = 446$ kA/m), Φ_V – volume concentration, $L(\xi)$ and ξ is the Langevin function and their parameter, m – magnetic moment of the particles, $f(x)$ – the distribution function of magnetic diameter x, H – the strength of the magnetic field, $k = 1.38 \cdot 10^{-23}$ J/K – Boltzmann's constant, T – the absolute temperature, $\mu_0 = 4 \cdot \pi \cdot 10^{-7}$ H/m, n – the number density of particles.

Figure 4 present magnetization of the magnetic fluid samples as a function of magnetic field intensity changes (for two ferrofluids: APG 832 and APG 833).

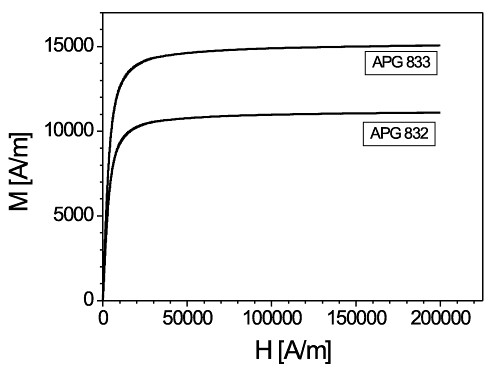

Fig. 4. The magnetization M, as a function of magnetic field H for samples APG 832 and APG 833.

Figure 5 shows differential magnetic susceptibility as a function of magnetic field intensity changes in ferrofluids: APG 832 and APG 834. Fitting function of magnetic susceptibility to measurement results makes it possible to evaluate the size of average magnetic core in the ferrofluids [6]:

$$d = \sqrt[3]{\frac{6m}{\pi M_S}}\,. \tag{2}$$

Table 2 shows the results of the size of average magnetic diameter.

Table 2. Magnetic diameter for ferrofluids.

Sample	APG 832	APG 833	APG 834
magnetic diameter	13.2 nm	13.6 nm	13.9 nm

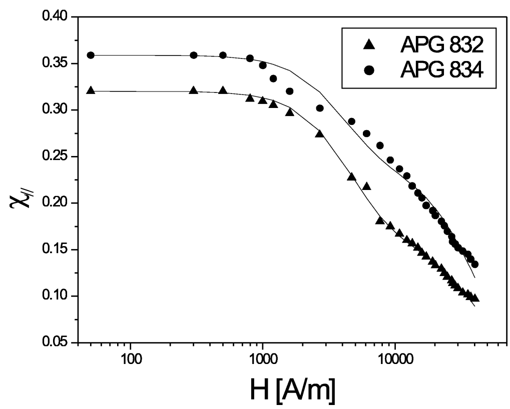

Fig. 5. Experimental values of differential magnetic susceptibility in ferrofluids APG 832 and APG 834 and the theoretical functions best fitting them.

5. Conclusion

The changes in ultrasonic wave absorption coefficient are influenced by the temperature of the magnetic liquid. In ferrofluids ultrasonic wave absorption coefficient decreases with increasing temperature. The reason of these changes is the temperature change in viscosity, monotonously decreasing with increasing temparature. It is possible that the viscosity of the magnetic fluid is the factor liables for cluster formation. The reconstruction process of the magnetic fluid structure is mainly determined by magnetic interactions. In addition, magnetic measurements makes it possible to evaluate the size of average magnetic core in the ferrofluids, which participate in process of restructurization.

Performance measurements of changes in the ultrasonic wave absorption coefficient in function of magnetic field intensity and the temperature were only the introduction to the next study of $\Delta\alpha$. In the future the results were developed by the measurements of changes $\Delta\alpha$ in function of frequency.

Acknowledgment

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References

[1] GOTOH K., CHUNG D. Y., *Ultrasonic attenuations in magnetic fluids*, J. Phys. Soc. Jpn., **53**, 2521–2528 (1984).

[2] SKUMIEL A., *The effect of temperature on the anisotrophy of ultrasound attenuation in a ferrofluid*, J. Phys. D: Appl. Phys., **37**, 3073–3079 (2004).

[3] JÓZEFCZAK A., SKUMIEL A., REGULSKA P., *Temperature dependence of the ultrasonic wave absorption coefficient in ferrofluid subjected to external magnetic field*, Molecular and Quantum Acoustics, **25**, 53–58 (2004).

[4] VAIDYA S. P., METHA R. V., *Temperature dependence of the ultrasonic velocity in a magnetic fluid subjected to an external magnetic field*, J. Magn. Magn. Mater., **39**, 82–84 (1983).

[5] RASA M., *Magnetic properties and magneto-birefringence of magnetic fluids*, Eur. Phys. J., **E2**, 265–275 (2000).

[6] SKUMIEL A., *Magnetic and acoustic properties of water-based ferrofluids*, Molecular and Quantum Acoustics, **24**, 123–134 (2003).