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Effects of the sweep rate of the magnetic field on the changes of ultrasonic wave velocity in magnetic fluid

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Abstract

An external magnetic field applied to a homogeneous magnetic fluid induces a change in its structure manifested as the appearance of chains of magnetic particles arranged along the direction of the field. This change implies changes in the acoustic and magnetic properties of the magnetic fluid such as the acoustic wave propagation velocity and coefficient of ultrasonic wave absorption, and in magnetisation. The paper reports results of a study on the influence of the magnetic field sweep rate and the magnetic fluid temperature on the value of ultrasonic wave velocity, proving that the degree of the aggregation of the magnetic particles (chain formation process) depends on the above-mentioned parameters.

Keywords: Magnetic fluid; Ultrasonic wave velocity

1. Introduction

A magnetic fluid (ferrofluid) is a colloidal suspension of magnetic particles covered with a surfactant layer in a carrier liquid [1]. Under the influence of an external magnetic field, a ferrofluid reveals very interesting properties. The magnetic particles join forming chains or columns arranged along the direction of the field. The process of the column formation, their width and the distance separating them depend on the magnetic field sweep rate [2,3].

The changes in the ferrofluid structure affect the acoustic properties of the fluid such as the propagation velocity and absorption coefficient of ultrasonic wave; so the ultrasonic spectroscopy can be used to investigate the structural changes in ferrofluids. The paper reports experimental results of a study on the changes of ultrasonic wave velocity as a function of the magnetic field sweep rate and temperature of the ferrofluid.

2. The method of measurements

The studies were performed in the water-based Fe_3O_4 magnetic fluid. The basic properties of the ferrofluid, such as the value of the saturation field, share viscosity, initial susceptibility and volume concentration are: 20 mT (at 27°C), <5 cP (at 25°C), 0.53, 3.5%.

The changes of ultrasonic wave propagation velocity as a function of the magnetic field were measured by the phase method [4]. The frequency of the ultrasonic wave was 1.6 MHz. The ferrofluid studied was placed in a thermostated closed measuring cell with a constant distance between two piezoelectric transducers (2.43 cm). The cell contained 10 ml of the ferrofluid. The magnetic field was generated by an electromagnet supplied with a programmed current source. The setup permits changes of the magnetic field intensity at different rates.

3. Experimental results

The ultrasonic wave velocity depends on the magnetic field intensity and the rate of its changes. Fig. 1 presents the changes of ultrasonic wave velocity as a function of

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the magnetic field intensity for different sweep rates for the parallel directions of the field and the wave propagation direction ($H \| k$) at 50°C. The application of an external magnetic field induces formation of chains of the magnetic particles. With increasing intensity of the magnetic field, the chains tend to be arranged in a quasi-periodical structure [5], so the compressive module of the ferrofluid and thus the ultrasonic wave velocity increase.

The change of the ferrofluid magnetisation $M_\|$ as a function of the magnetic field intensity increasing in the range 0–40 kA/m was also studied. The sweep rate of the magnetic field was kept constant at 80 A/ms. The values of magnetisation were calculated on the basis of the measurements of differential magnetic susceptibility $\chi_\| = \mathrm{d}M_\|/\mathrm{d}H$ [6]. The plot $M_\|(H)$ is shown in Fig. 2. A comparison of the character of the ultrasonic wave propagation velocity Δc (Fig. 1) determined at a low sweep rate of the magnetic field changed in the range 0–40 kA/m and the $M_\|(H)$ dependence (Fig. 2) shows that magnetisation must affect the ultrasonic wave propagation. The changes in the ferrofluid structure in a magnetic field involve the formation of clusters, which, on the one hand enhance the ferrofluid rigidity and on the other, bring contribution to the resultant magnetic moment of the sample.

The ultrasonic wave velocity increases with decreasing sweep rate of the magnetic field, which can be explained by the fact that at lower sweep rates, the chains formed are larger [3]. The ferrofluid develops the quasi-periodical structure at a lower field intensity for lower sweep rates of magnetic field ($\mathrm{d}H/\mathrm{d}t$) – Δc aims at constant value (Fig. 1). This conclusion is confirmed in Fig. 3.

The ultrasonic wave propagation velocity was also studied as a function of the ferrofluid temperature. Fig. 4 presents the changes of ultrasonic wave velocity as a function of the magnetic field for different temperatures and at a constant sweep rate $\mathrm{d}H/\mathrm{d}t = 160$ A/ms. Fig. 5 illustrates the Δc changes as a function of the magnetic field sweep rate for the magnetic field intensity of 40 kA/m, for different temperatures. With increasing temperature the ferrofluid viscosity decreases and the formation of chains (columns) is easier and thus Δc increases. As follows from the above data, the changes in two different parameters affects the field sweep rate and the ferrofluid temperature leads to similar changes in the ferrofluid structure.

The formation of columns and their arrangement along the direction of the external magnetic field is confirmed by Fig. 6, showing the changes of ultrasonic wave velocity as a function of the magnetic field sweep

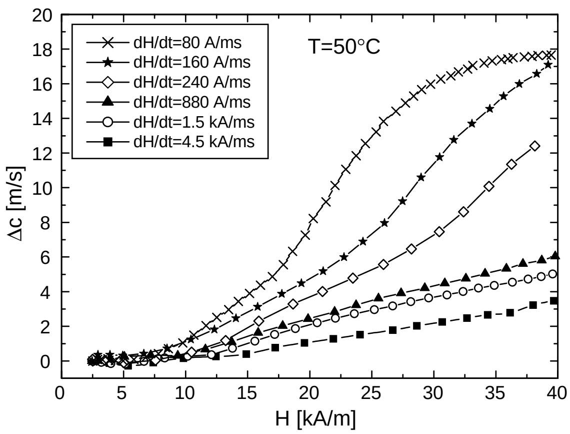

Fig. 1. The changes of ultrasonic wave (1.6 MHz) velocity in a ferrofluid as a function of the magnetic field intensity for different sweep rates, for the parallel directions of the field and the wave propagation.

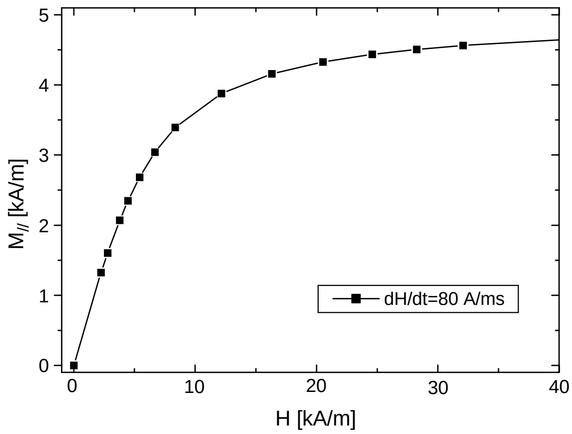

Fig. 2. The ferrofluid magnetisation as a function of increasing magnetic field at the parallel arrangement of the axis of the measuring coil and the magnetic field lines H_{DC}.

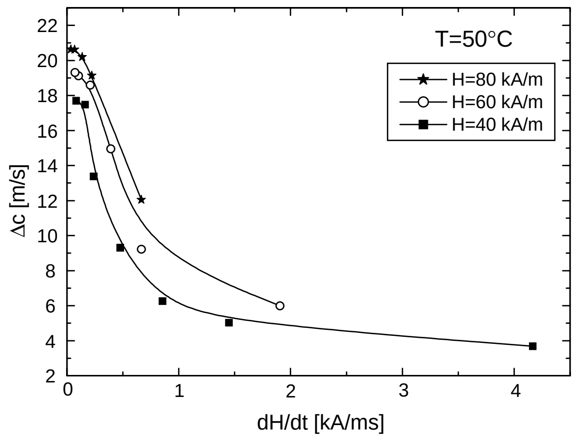

Fig. 3. The changes of ultrasonic wave (1.6 MHz) velocity in a ferrofluid as a function of the magnetic field sweep rate, at different values of its intensity, for parallel directions of the wave propagation and the magnetic field lines.

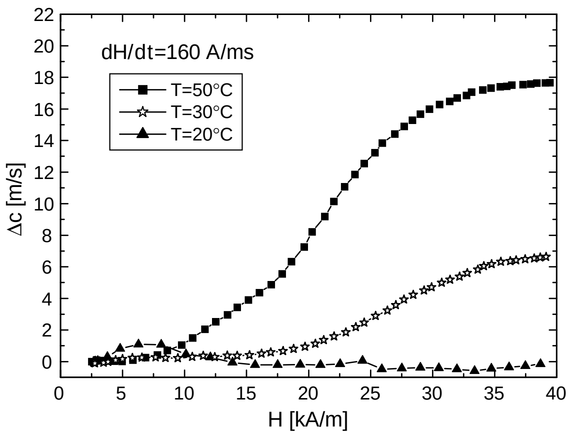

Fig. 4. The changes of ultrasonic wave velocity in a ferrofluid as a function of the magnetic field intensity at different temperatures, for parallel directions of the wave propagation

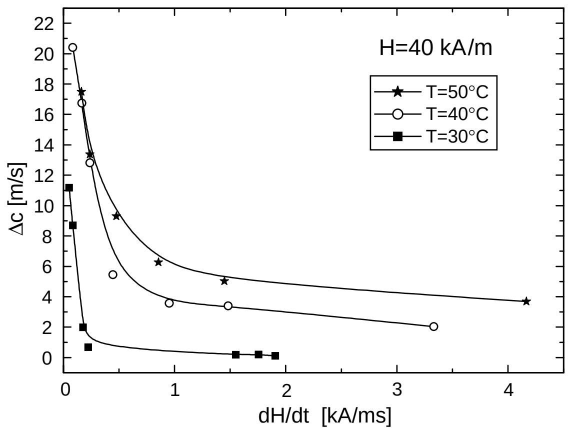

Fig. 5. The changes of ultrasonic wave velocity in a ferrofluid as a function of the sweep rate of the magnetic field for different temperatures, and for parallel directions of the wave propagation and magnetic field lines.

rate, for the parallel and perpendicular directions of the ultrasonic wave and the magnetic field lines. The changes are significantly greater for the parallel directions, which is explained by the easier propagation of the waves along the columns. With increasing $\mathrm{d}H/\mathrm{d}t$ the difference between the parallel and perpendicular direction decreases because of a decrease of the distance between the chains [7].

4. Summary

In conclusion, the ultrasonic wave propagation velocity in a ferrofluid changes under the effect of an

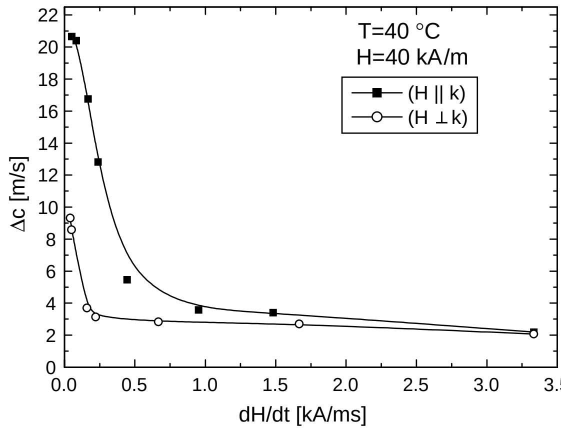

Fig. 6. The changes of ultrasonic wave velocity in a ferrofluid as a function of the magnetic field sweep rate at different temperatures, for parallel and perpendicular directions of the wave propagation and the magnetic field lines ($H \| k$) and ($H \perp k$).

external magnetic field, which testifies to changes in the ferrofluid structure. These changes involve formation of aggregations of magnetic particles whose size depends not only on the intensity of the magnetic field, but also on the sweep rate of its increase. The structure of the ferrofluid also depends on its temperature. Increasing temperature of the ferrofluid at a constant sweep rate of the magnetic field causes similar structural changes as the decreasing sweep rate of the magnetic field at a constant temperature.

Acknowledgements

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