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Hysteresis of changes of ultrasonic wave absorption coefficient in a magnetic fluid caused by the magnetic field

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Abstract

The magnetic fluids change their structure under the influence of an external magnetic field and do not return to the initial state after the magnetic field removal. It is supposed that the cluster formed in the fluid subjected to a magnetic field remains after the field has been removed. The resulting dependence of the ferrofluid properties on its magnetic history has been studied by the analysis of changes in the ultrasonic wave absorption coefficient.

Keywords: Magnetic fluid; Hysteresis; Ultrasonic absorption

1. Introduction

A magnetic fluid (ferrofluid) is a colloidal suspension of magnetic particles covered with a surfactant layer in a carrier liquid [1]. The structure of a magnetic fluid is changed under the influence of a constant external magnetic field. Colloidal particles form aggregates (clusters) which tend to join into a chain-like structures, which can be as long as hundreds of nanometers [2]. The process of cluster formation depends on the rate of changes of the external magnetic field [3–6].

One of the methods of studying changes in the ferrofluid structure is based on the measurements of changes in ultrasonic wave absorption under the influence of an external magnetic field. In this paper the authors study the behavior of the ultrasonic wave attenuation coefficient as a function of a constant external magnetic field applied at different sweep rate (time) and directions.

2. Method of measurements

The block diagram of the applied measuring system is shown in Fig. 1. Measurements of the changes of ultrasonic wave absorption coefficient were carried out by a pulse method using the MATEC apparatus [7]. An ultrasonic pulse propagating in the measuring cell undergoes a multiple reflection from the transducers and its subsequent echoes are recorded. Two selected adjacent pulses following separate paths reach a detector; from where signals proportional to their amplitudes are fed to a logarithmic amplifier. A change in the initial intensity of the logarithmic amplifier is proportional to the changes of the ultrasonic wave

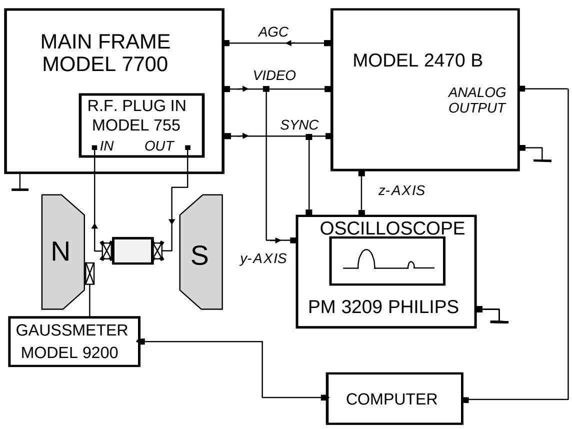

Fig. 1. Block diagram of the measuring system.

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absorption coefficient in a given medium. The system has been connected to a computer which permits con current reading of the value of the ultrasonic wave absorption coefficient and the value of an external magnetic field.

A slowly changing magnetic field was produced in an electromagnet controlled by a system of a programmable current source. It permitted an automatic sweep of the studied range of magnetic field at a given time (sweep times).

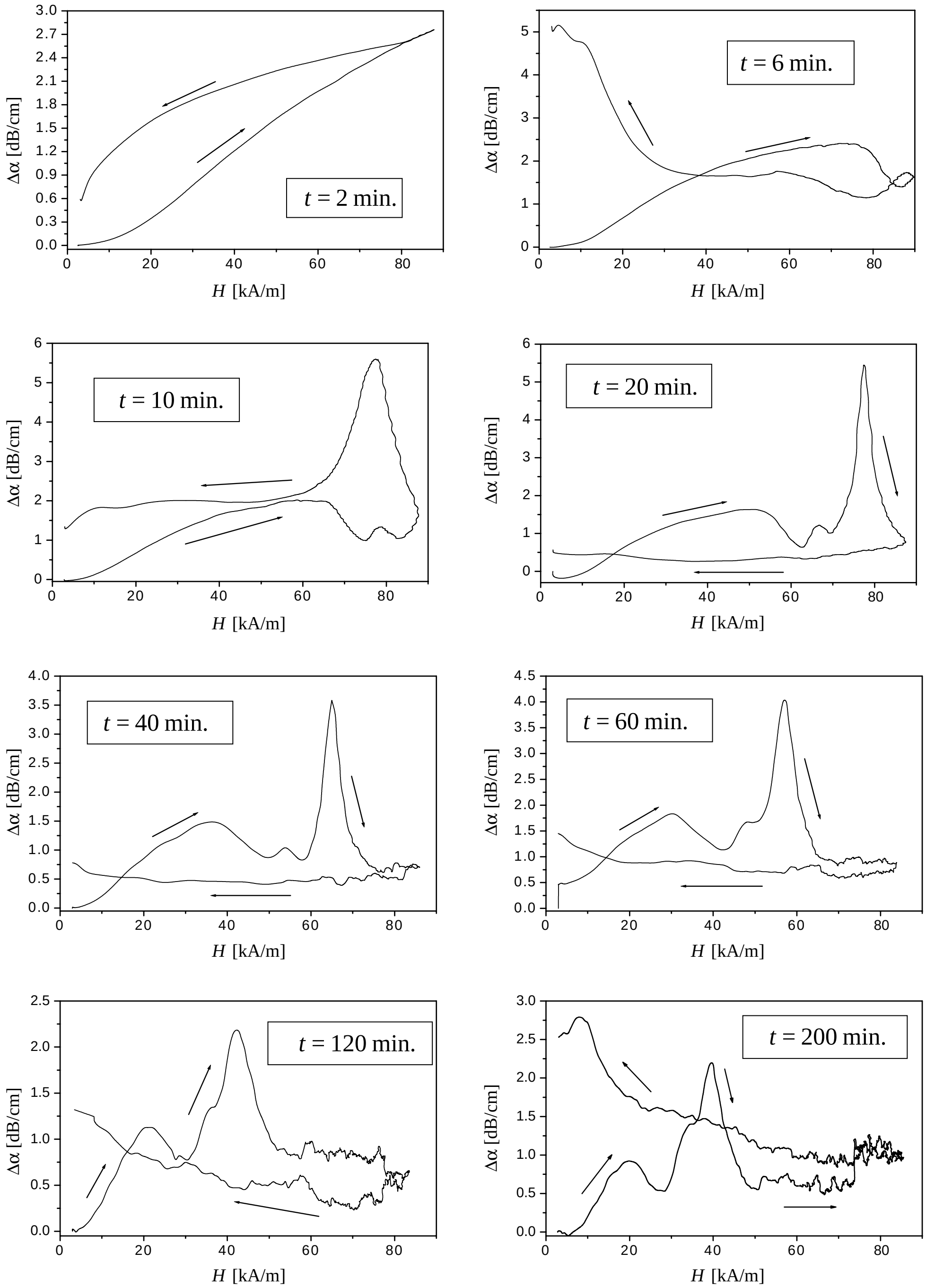

Fig. 2. Changes $\Delta\alpha$ in the absorption coefficient of an ultrasonic wave of frequency $f = 3.6$ MHz as a function of the magnetic field H when $H \| k$ and $T = 30°C$.

3. Experimental results

The studied medium was a magnetic fluid EMG-605, produced by Ferrofluid Corporation. The basic properties of this magnetic fluid, such as the saturation magnetization, viscosity, initial susceptibility and volume fraction are equal to 20 mT (at 27°C), <5 cP (at 25°C), 0.54, 3.5%, respectively.

The measurements were conducted at an ultrasonic wave frequency of 3.6 MHz, for the direction of

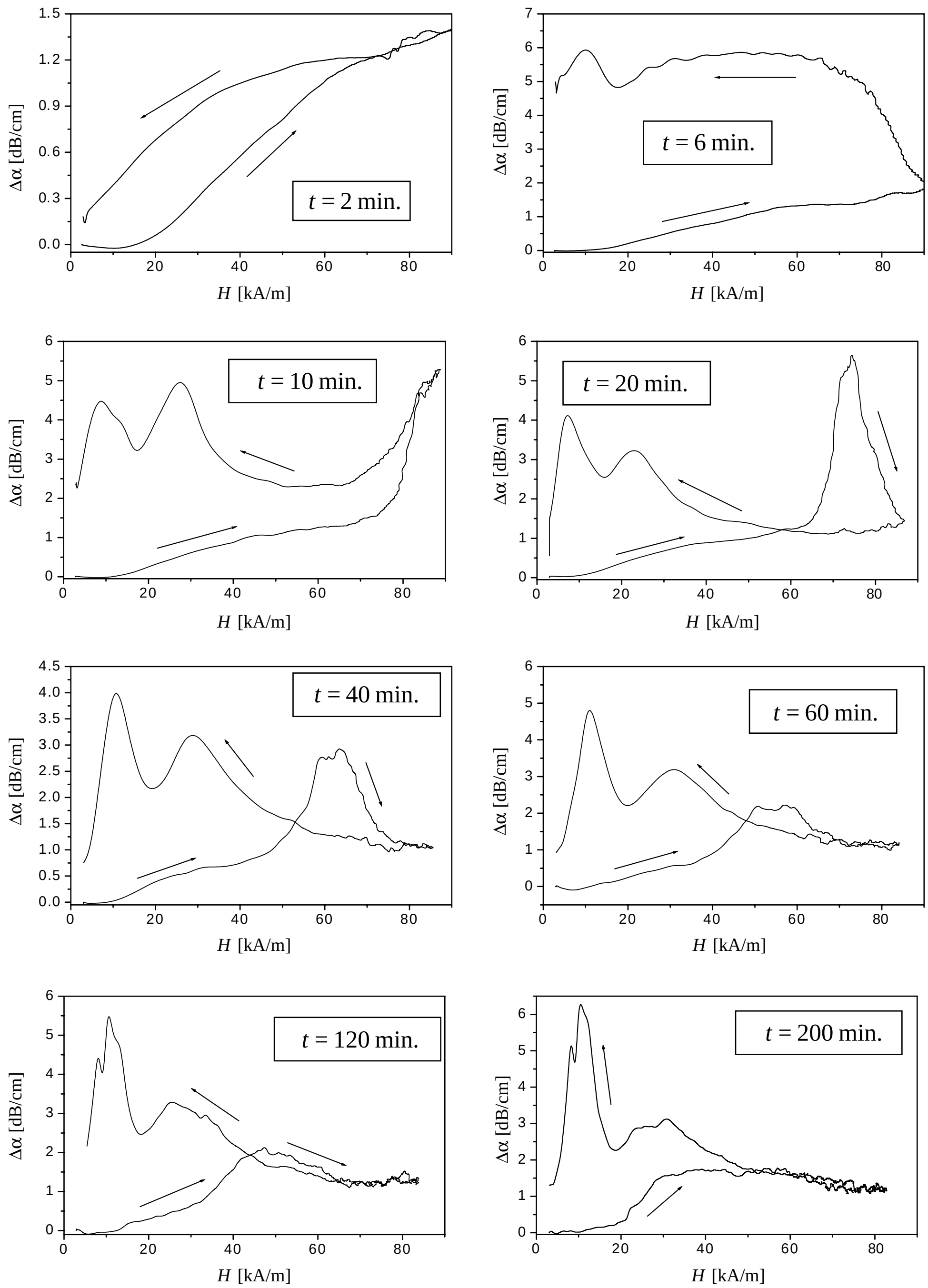

Fig. 3. Changes $\Delta\alpha$ in the absorption coefficient of an ultrasonic wave of frequency $f = 3.6$ MHz as a function of the magnetic field H when $H \perp k$ and $T = 30°C$.

ultrasonic wave propagation parallel or perpendicular to the direction of the external magnetic field. The magnetic field in the range 0–90 kA/m was swept with a rate (different sweep times) varying from 1.5 $\mathrm{kAm^{-1}\,s^{-1}}$ (the sweep time—2 min) to 15 $\mathrm{Am^{-1}\,s^{-1}}$ (200 min). The magnetic field intensity increased and decreased at the same rate. Figs. 2 and 3 show the dependence of ultrasonic wave absorption coefficient on the intensity of the external magnetic field for eight different sweeping times, when the direction of the ultrasonic wave propagation was parallel ($H \| k$) or perpendicular ($H \perp k$) to that of the external magnetic field, respectively. The ferrofluid temperature was 30°C.

The graphs show that with increasing magnetic field intensity, the absorption coefficient increases, and the character of the changes strongly depends on the rate of the magnetic field intensity increase (the sweep time). The formation of aggregates in the ferrofluid is indicated by the presence of maxima of the absorption coefficient changes [7,8]. With decreasing magnetic field intensity the character of absorption coefficient changes is different. The structure does not return to the initial state after the magnetic field has been removed. The changes of the ultrasonic wave absorption coefficient show a hysteresis. Probably not all clusters have disintegrated into single magnetic particles and small clusters made of a few or a few tens of particles still remain in the magnetic fluid. The maxima appearing in the dependence of the absorption coefficient as a function of a decreasing magnetic field seem to confirm our suppositions [7,8].

The results also prove an anisotropy of the magnetic fluid properties induced by the external magnetic field.

4. Summary

Magnetic fluid is a substance whose properties depend on its magnetic history. The established hysteresis of the ultrasound wave absorption coefficient proves that the structural changes in a ferrofluid are irreversible.

Acknowledgements

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