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THE EFFECT OF RATE CHANGES OF THE CONSTANT EXTERNAL MAGNETIC FIELD ON THE COEFFICIENT OF ULTRASONIC WAVE ABSORPTION IN POLYDISPERSIVE MAGNETIC FLUID

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In this paper are presented experimental results of changes of the ultrasonic wave absorption coefficient as the function of external magnetic field intensity, for different rates of magnetic field changes in a polydispersive magnetic liquid EMG-605 based on water. Measurements were performed for two frequencies of ultrasonic wave: 3.6 MHz and 6.12 MHz, where the directions of propagation of ultrasonic wave and external magnetic field were mutually parallel and perpendicular. This paper presents also the radii of detected spherical clusters formed in magnetic fluid under the influence of magnetic field.

1. Introduction

A magnetic fluid is a colloidal suspension of polydispersive magnetic molecules, covered with a layer of surfactants in a liquid carrier [1]. This layer as well as thermal motions prevent the molecules from binding and their precipitation.

Influencing a polydispersive magnetic fluid, the external magnetic field changes some of its properties, among others its viscosity [2, 3], magnetic susceptibility [4], and the ultrasonic velocity in the magnetic fluids [7]. The reason for such changes is the binding, under the influence of a magnetic field, of single molecules and formation of spherical clusters [7, 8]. By measuring the changes of the ultrasonic wave absorption coefficient during the sweeps of magnetic field, it is possible to detect clusters formed in the magnetic fluid, as well as to determine their size by applying the resonance ultrasonic wave absorption [7].

The process of cluster formation in a magnetic fluid depends on the rate of changes of the external magnetic field [9]. The work presents experimental results of changes of the ultrasonic wave absorption coefficient as the function of external magnetic field intensity for different rates of magnetic field changes (different rates of "sweeping"). Besides, the sizes of spherical clusters formed in the magnetic field were also determined.

2. Resonance absorption of ultrasonic wave in a magnetic field

A spherical cluster formed in a magnetic fluid, of a magnetic moment m, placed in a magnetic field B, is subjected to the mechanical moment T aligning it with the direction of the magnetic field. This moment is balanced by the moment following from the Newton's second law for rotation:

$$T = mB \sin\varphi = -I \frac{d^2\varphi}{dt^2} . \tag{1}$$

Thus we obtain:

$$\frac{d^2\varphi}{dt^2} + \frac{mB}{I} \sin\varphi = 0, \tag{2}$$

but for $\varphi < 0.1$ radian, we may approximately assume that $\sin(\varphi) \approx \varphi$, and thus we obtain an equation of harmonic oscillator motion:

$$\frac{d^2\varphi}{dt^2} + \omega_0^2 \varphi = 0, \tag{3}$$

where

$$\frac{\omega_0}{2\pi} = f_0 = \frac{1}{2\pi} \sqrt{\frac{mB}{I}} . \tag{4}$$

If the ultrasonic wave of the frequency f propagates in a magnetic fluid containing spherical clusters of the magnetic moment $m = VM_{\mathrm{cl}}$ and the inertia moment $I = 2V\rho_{\mathrm{cl}}r^2/5$, the energy of the wave is absorbed first by the translatory, and only then by the rotary degrees of freedom of the clusters.

If the magnetic fluid, in which an ultrasonic wave propagates, is subjected to a constant magnetic field of intensity changing from 0 to an undefined value, then at a certain value of magnetic induction B, the frequency of the ultrasonic wave f will be equal to the frequency of self-vibrations of clusters f_0. This will result in ultrasonic resonance wave absorption by the rotary degrees of freedom, which is reflected by the maximum value of absorbancy. The formula of resonance cluster frequency is the following [7]:

$$f_0 = \frac{1}{2\pi r} \sqrt{\frac{5M_{\mathrm{cl}}B}{2\rho_{\mathrm{cl}}}} , \tag{5}$$

where M_{cl} — cluster magnetization, ρ_{cl} — cluster density, r — cluster radius. Using expression (5) we can determine the cluster radius in the form:

$$r = \frac{1}{2\pi f_0} \sqrt{\frac{5M_{\mathrm{cl}}B}{2\rho_{\mathrm{cl}}}} . \tag{6}$$

3. The measuring method

A diagram of the applied measuring system is shown in Fig. 1. The measurements of the changes of ultrasonic wave absorption coefficient were carried out by a pulse method using the MATEC instruments. The ultrasonic pulse propagating in the vessel undergoes multiple reflections from the walls of the converters, due to which it is possible to record both the pulse and its subsequent echoes. So, two adjacent pulses are chosen, each following a different trajectory to reach the detector, from which signals proportional to their amplitudes are led to a logarithmic amplifier. A change of the initial intensity of the logarithmic amplifier is proportional to the changes of the coefficient of ultrasonic wave absorption of a given medium. A detailed description of this phenomenon is given in [7]. The system was lined up with a computer which at the same time performs the readout of the value of ultrasonic wave absorption coefficient and the value of the external magnetic field.

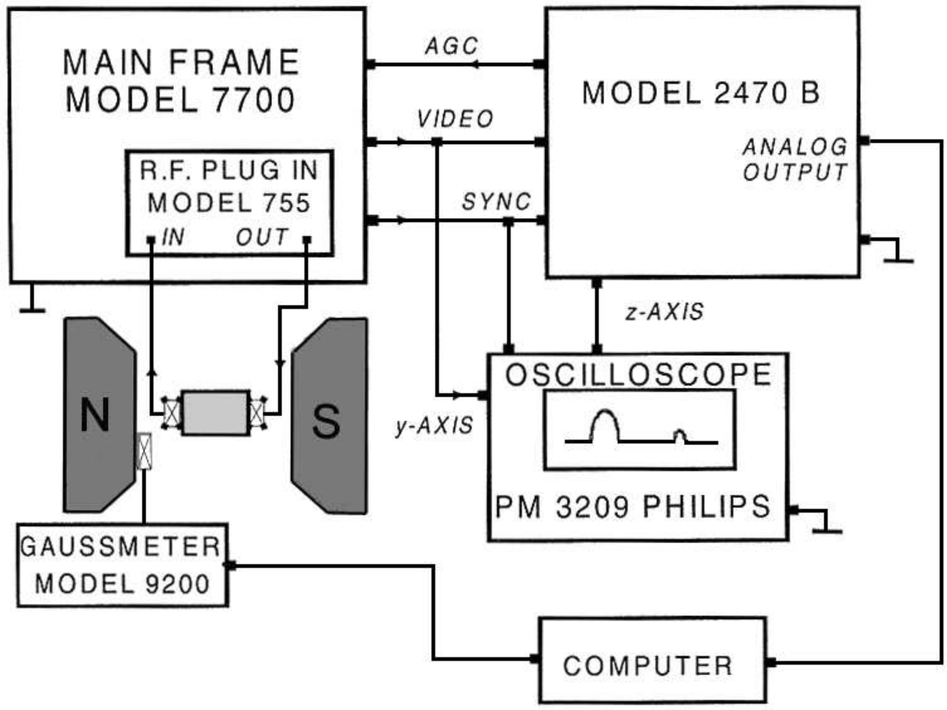

Fig. 1. A block diagram of the measuring system.

A slowly changing magnetic field was produced in the electromagnet which was controlled with a system of a programmed current generator. The system enabled automatic sweeps of a given range of a magnetic field at a given time.

4. Experimental results and their analysis

In our case, the studied medium was a magnetic liquid with a symbol of EMG-605 produced by Ferrofluidics Corporation. This liquid is based on water in which magnetite molecules of a 10 nm diameter, covered with layer of oleic acid, are suspended.

The measurements were carried out at the temperature of 20°C, for two frequencies of the ultrasonic wave: 3.6 MHz and 6.12 MHz. Experiments were performed for two cases: when the directions of propagation of the ultrasonic wave $\mathbf{k}$ and external magnetic field $\mathbf{H}$ were either parallel or perpendicular.

Figures 2 and 3 present the dependence of changes of the ultrasonic wave absorption coefficient as a function of external magnetic field intensity for different times t of sweeping of the magnetic field for frequencies 3.6 MHz and 6.12 MHz respectively, when the directions of ultrasonic wave propagation and external magnetic field overlap ($\mathbf{H} \parallel \mathbf{k}$). It follows from the figures that with the increase of intensity of the external magnetic field, the absorption coefficient increases too, and the character of the changes largely depends on the rate of changes of the magnetic field (the rate of sweeping t). For fast changes of magnetic field (a short rate of sweeping), the increase of absorption coefficient is probably caused by a classical processes, i.e. by changing viscosity of the ferroliquid. As the rate of the external magnetic field sweeping increases, the structure of fluid undergoes some changes too: in the magnetic field the clusters are formed, what is indicated by the appearance of maxima on the plots. For very slow changes, very clear maxima can be observed, which are a consequence of the resonance absorption of the ultrasonic wave by spherical clusters. For $f = 3.6\,\mathrm{MHz}$ and $t = 50\,\mathrm{min}$, the average radius of the cluster $r = 210\,\mathrm{nm}$, while for $f = 6.12\,\mathrm{MHz}$ and $t = 78.5\,\mathrm{min}$, $r = 98\,\mathrm{nm}$. The radii differ significantly, which indicates that in the magnetic field clusters of various sizes are formed. The above cluster radii were determined on the basis of formula (6).

Figures 4 and 5 are presenting the dependence of changes of the ultrasonic wave absorption coefficient in the function of external magnetic field intensity for different times t of sweeping of the magnetic field, for frequencies 3.6 MHz and 6.12MHz respectively, when the direction of ultrasonic wave propagation is perpendicular to the direction of the external magnetic field ($\mathbf{H} \perp \mathbf{k}$). It can be noticed that, as in the previous case, with a decreasing rate of the changes of magnetic field the structure of liquid undergoes some changes, and for longer sweeping times the maxima appear as a result of resonance absorption of ultrasonic wave by spherical clusters. For $f = 3.6\,\mathrm{MHz}$ and $t = 50\,\mathrm{min}$, the absorption should be attributed to clusters of the size ranging from $194-216\,\mathrm{nm}$, while for the frequency $f = 6.12\,\mathrm{MHz}$ and $t = 79.5$ — to the clusters of the average size $r = 92\,\mathrm{nm}$, as it follows from formula (6).

The revealed character of changes of the ultrasonic wave absorption coefficient as a function of external magnetic field intensity for perpendicular direction of ultrasonic wave propagation and magnetic field, differs from that observed for the parallel alignment. These results confirm the anisotropic character of magnetic fluid.

For a given frequency f and a given time t of the magnetic field sweeping and with the use of the method of resonance absorption of ultrasonic wave, spherical clusters of almost the same size (within the limit of an error) were found both for the perpendicular and parallel directions of propagation of ultrasonic wave and magnetic field. This confirms the effectiveness of the method presented in the paper [7].

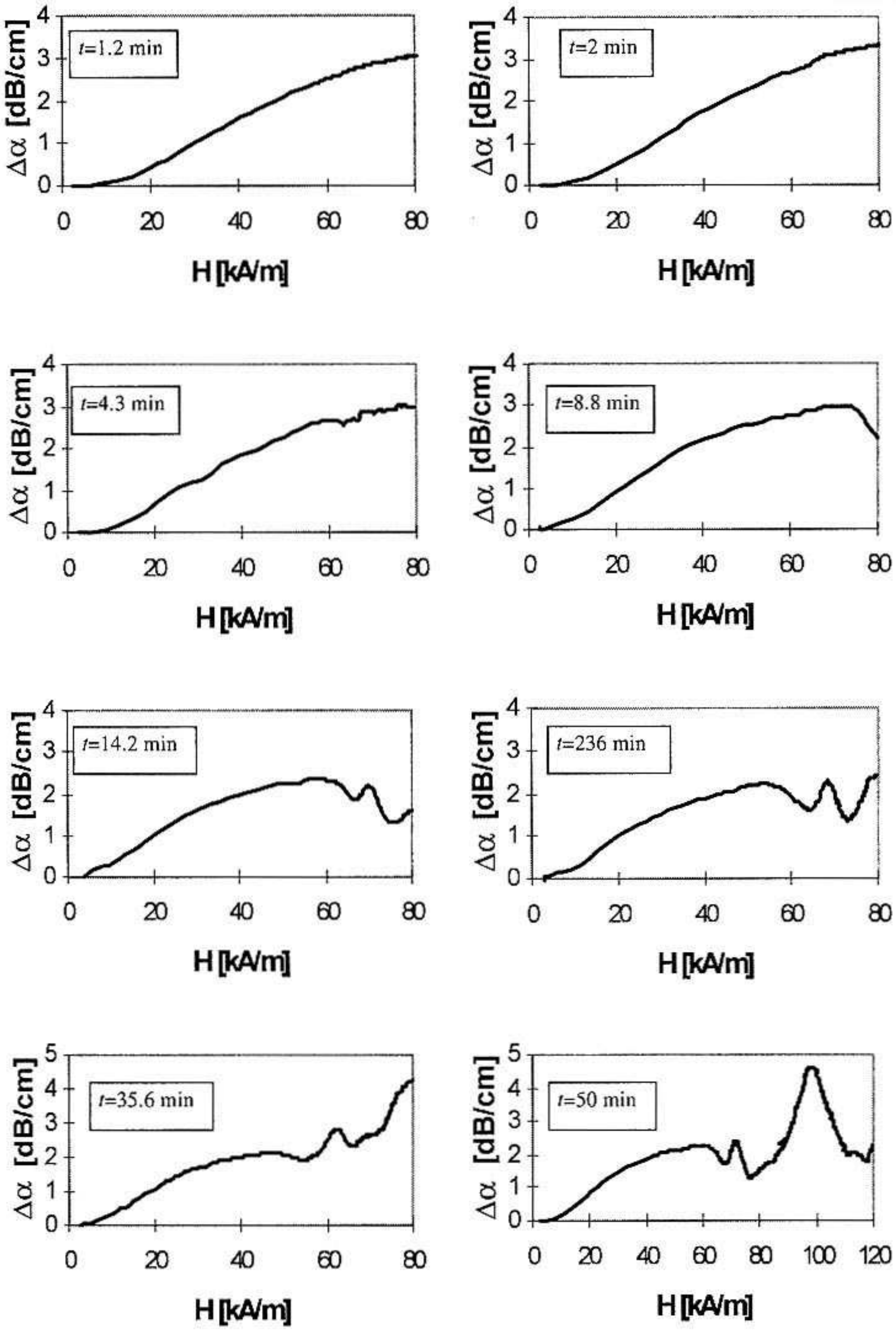

Fig. 2. Dependence of changes $\Delta\alpha$ of ultrasonic wave of the frequency $f = 3.6\,\mathrm{MHz}$ as a function of magnetic field intensity $\mathbf{H}$, where $\mathbf{H} \parallel \mathbf{k}$.

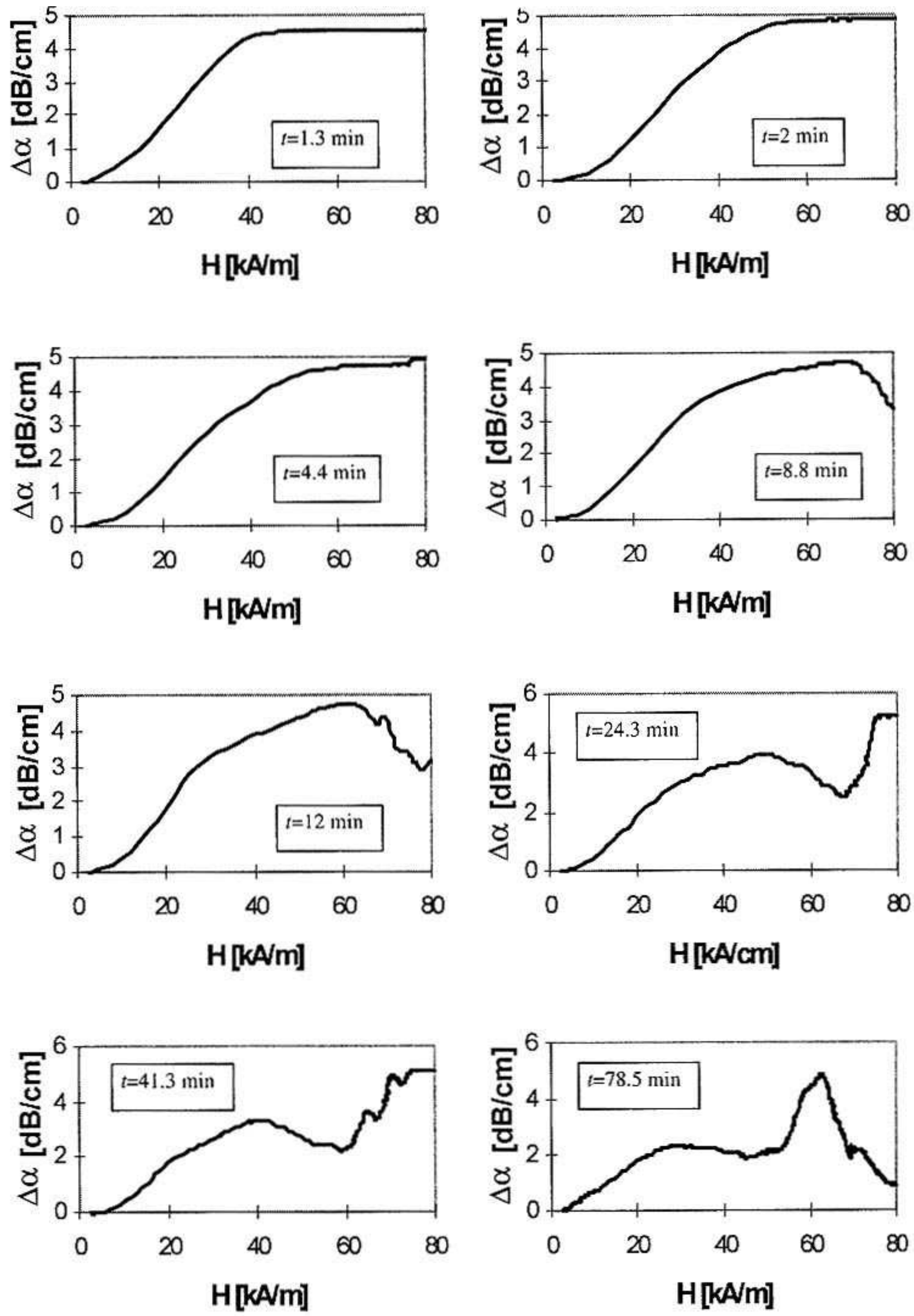

Fig. 3. Dependence of changes $\Delta\alpha$ of ultrasonic wave of the frequency $f = 6.12$ MHz as a function of magnetic field intensity $\mathbf{H}$, where $\mathbf{H} \parallel \mathbf{k}$.

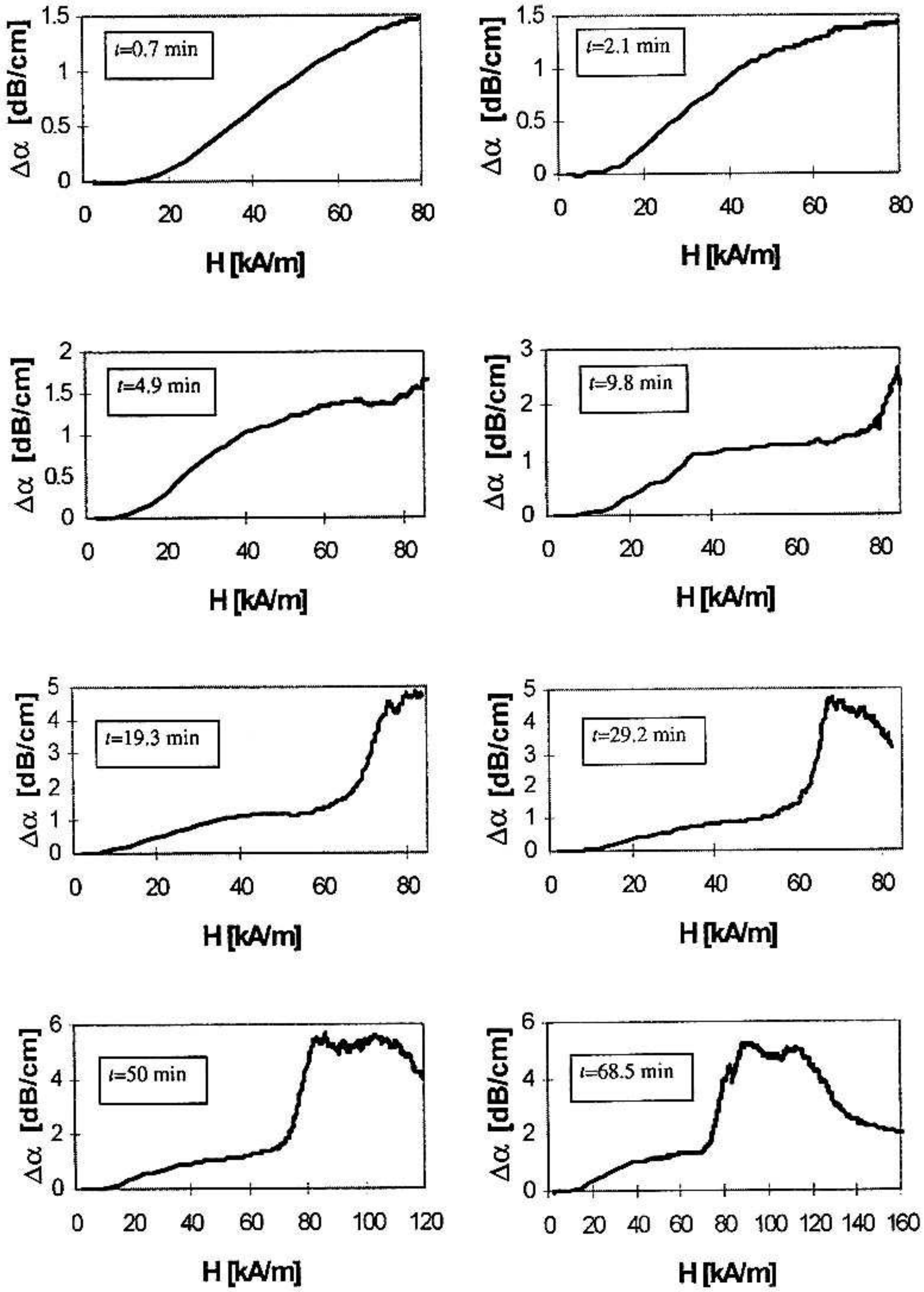

Fig. 4. Dependence of changes $\Delta\alpha$ of ultrasonic wave of the frequency $f = 3.6\,\mathrm{MHz}$ as a function of magnetic field intensity $\mathbf{H}$ where $\mathbf{H} \perp \mathbf{k}$.

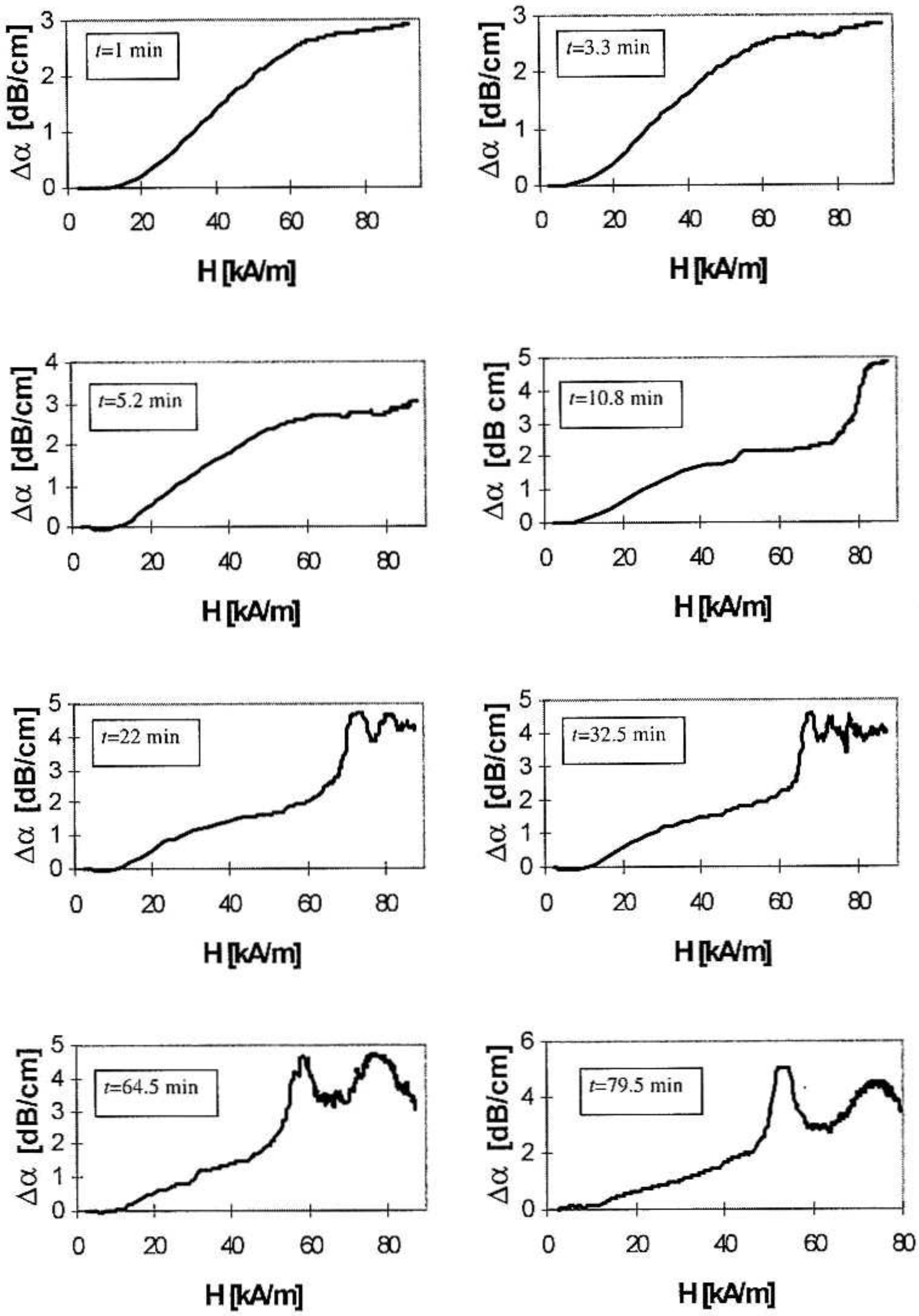

Fig. 5. Dependence of changes $\Delta\alpha$ of ultrasonic wave of the frequency $f = 6.12\,\text{MHz}$ as a function of magnetic field intensity $\mathbf{H}$ where $\mathbf{H} \perp \mathbf{k}$.

5. Summary

A polydispersive fluid is an anisotropic medium, the structure of which changes under the influence of a variable magnetic field. These changes depend on the rate of magnetic field changes: the slower are the changes of the magnetic field, the greater will be the transformations of the structure. This process was recorded in order to study the dependence of the coefficient of ultrasonic wave absorption as a function of the intensity of external magnetic field, for different rates of its sweeps.

When performing these measurements it was also possible to detect spherical clusters formed in the liquid as well as to determine their size. In the studied fluid, clusters of a radius ranging from 92 – 98 nm and 194 – 216 nm were found.

Acknowledgement

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