ACOUSTIC INVESTIGATION OF STRUCTURE OF MAGNETIC FLUIDS BASED ON TRANSFORMER OIL MOGUL

Jozef Kúdelčík[1], Peter Bury[1], Peter Kopčanský[2], Milan Timko[2]

[1] Department of physics, Žilinská univerzita v Žiline, Univerzitná 1, 010 26 Žilina
[2]Department of Magnetism, IEP SAS, Watsonova 47, 040 01 Košice
kudelcik@fyzika.uniza.sk

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1. Introduction

A transformer oil based magnetic fluids are colloidal suspensions of magnetic nanoparticles covered with a surfactant layer in transformer oils [1, 2]. The transformer oil with magnetic nanoparticles that is usually used for both high voltage insulation and power electronics cooling is subjected to extensive research to enhance its characteristics. The magnetic fluids should have better insulating and thermal properties. The dielectric breakdown strength of transformer oil, however, is strongly influenced by the aggregation effects of magnetic nanoparticles and can induce electric breakdown [3, 4].

One of the methods of studying changes in the magnetic fluid structure is based on the measurements of changes in the acoustic wave attenuation $\Delta\alpha$ under the influence of an external magnetic field [5-7]. The change of the acoustic attenuation of acoustic waves propagating through suspensions, in which magnetic nanoparticles constituting one phase are dispersed in a continuous second phase, can indicate characterized properties and structure of magnetic liquids. The interaction between the acoustic waves and the magnetic nanoparticles or clusters leads to additional attenuation of acoustic wave compared to that in the carried liquid.

Under the effect of an external magnetic field the nanoparticles of magnetic fluid become arranged into clusters, forming chains stiffening the liquid structure. Acoustic wave propagation in magnetic fluid placed in magnetic field was studied by several authors both theoretically and experimentally [2, 5, 6]. There are also computer simulations by Satoh [8] or Mendelev [9] who investigated aggregation phenomena in a polydisperse colloidal dispersion of ferromagnetic nanoparticles. All these works suppose that chainlike clusters are formed along magnetic field direction, but clusters can have various shapes. These shapes depend on both particle-particle and particle-field interactions. The experimental measurements of the acoustic attenuation as a function of magnetic field were made by several works [4-6, 10-13]. In this paper the authors study the influence of temperature on the changes of the acoustic attenuation in magnetic fluids based on transformer oil MOGUL caused by an external magnetic field measured.

2. Experimental results

The subject of the study was a magnetic fluid based on transformer oil MOGUL. The structure of magnetic fluids was investigated by acoustic methods. The magnetic fluid used in experiments consisted of magnetite nanoparticles ($FeO.Fe_2O_3$) with the mean diameter $d \approx 11$ nm, coated with oleic acid as a surfactant that were dispersed in transformer oil MOGUL. The basic properties of this magnetic fluid, such as the density, saturation magnetization and volume fraction were equal to 0.85 g/cm^3 and 3,2 mT for 1% magnetic fluid. Volume concentrations, average diameter and standard deviation of magnetic particles were determined from vibrating sample magnetometer measurements. The dependences of magnetic moment of samples on magnetic field were measured in the range of -2T to 2 T at room temperature (25 ^{0}C) (Fig. 1a). The ultrasonic wave absorption was measured for the frequency 12.65 MHz, as a function of magnetic field and for different temperature. The block diagram of the experimental arrangement was used as in the work [6, 7].

In our experiment the change of acoustic attenuation as the function of external magnetic field at various temperatures was measured. Fig. 1b shows the acoustic attenuation changes for both increasing and decreasing magnetic field for 2% MF. From the obtained results it can be seen that with increasing magnetic field the acoustic attenuation dramatically increases but only to around 60 mT. After reaching the maximum α decreases up to 120 mT when MF reach the stability and acoustic attenuation α continues only in slow increase. At decreasing magnetic field there is no maximum, only slow decrease to the initial state. At higher temperatures the development of α is similar.

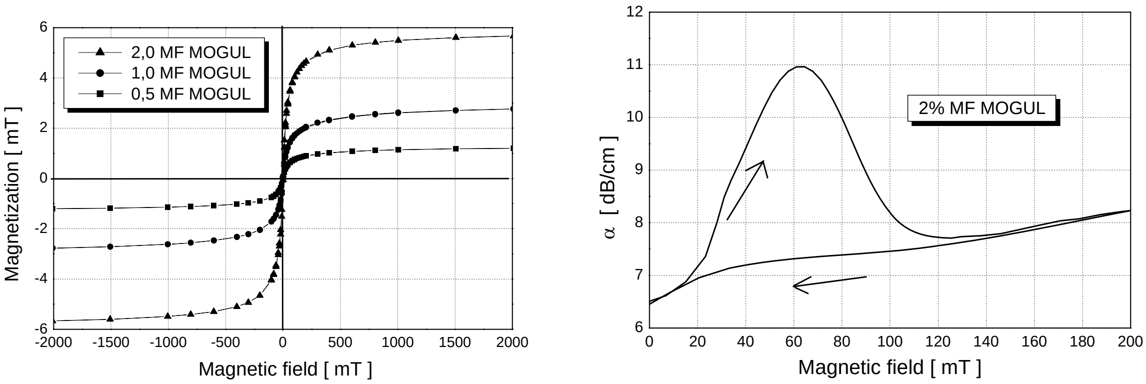

Fig.1: *(a) Magnetization curve for the magnetic fluid samples. (b) The dependence of the acoustic attenuation changes on external magnetic field for 2.0 % magnetic fluid measured at temperature 20 ^{0}C.*

Fig. 2 presents the acoustic attenuation changes in the MF subjected to a jumped magnetic field 150 mT for 30 min (50 min) and its behaviour after removal magnetic field. The acoustic attenuation was measured as a function of time under the following conditions: the magnetic field increased in 10 second to 150 mT, then this value of the magnetic field was constant for 30 min and finally the field decreased to zero in 1 second. The area between the broken lines corresponds to the range of time in which the magnetic fluid was subjected to a constant value of the magnetic field.

The observed changes in α were significant in MF subjected to the magnetic field. As soon as the magnetic field was applied to the MF the ultrasonic wave absorption coefficient significantly increased. This phenomenon was explained by progressing aggregation of magnetic particles in clusters [2, 6, 8, 10]. The occurring increase of acoustic attenuation α is the result of additional resonance absorption of the ultrasonic wave by the spherical clusters formed in the fluid [5]. But after 3 minutes it can be seen dramatic decrease of α. It can be result of collection of clusters to more complicated structure. With next increasing time, the value of α reaches a new state of equilibrium [2, 7, 8]. This behavior coincides with the previous dependence of α on the magnetic field (Fig. 1b).

After the magnetic field removal, the absorption coefficient drastically decreases but not right to the initial value. The lifetime of big clusters is in this case very small. In next five minutes acoustic attenuation slowly increases, the fluid structure needs some time to reach new the stable value.

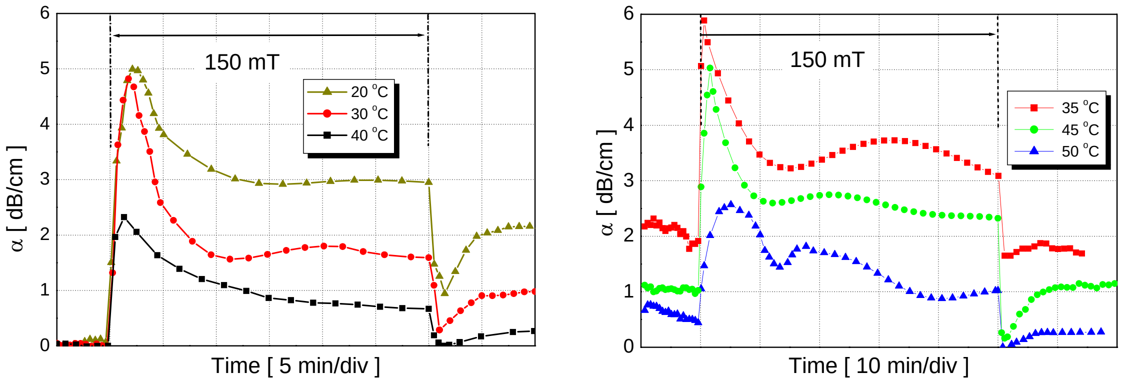

Fig. 2: *Experimental data of changes in the acoustic attenuation for jump change of the magnetic field to value 150 mT measured at temperatures 20 ^{0}C, 30 ^{0}C, 40 ^{0}C (a) and 35 ^{0}C, 45 ^{0}C, 50 ^{0}C (b).*

3. Discussion

It is known that the interaction between the external magnetic field and the magnetic moment of the nanoparticle in magnetic fluids leads to the aggregation of nanoparticles to new structures [2, 6, 8, 10]. These structures enlarge with the magnetic field and this process has the influence on the value of the acoustic attenuation. In our previous works [6, 7] or other experimental works [10, 11] it was observed that the acoustic attenuation initially increases with increasing magnetic field. This effect can be explained by several parameters. One of is the time constant of creation of higher structures of nanoparticles. Others are temperature or viscosity of given magnetic fluids. However, following progress at higher magnetic field can be different depending on the structure changes caused by developing of cluster shape in individual cases.

In result presented in Fig 1b it is interesting that there is big change of acoustic attenuation between 40 – 100 mT. Similar measurement was made by Jozefczak et all [5] with water-based biocompatible MF. This phenomenon can be explained by processing aggregation of magnetic nanoparticles in thin chainlike – clusters. With increasing magnetic field α increases because of the viscosity of MF increases. The maxima in α are the result of an additional resonance absorption of ultrasonic wave by the spherical clusters formed in fluid. With next increasing magnetic field the process of clustering continues, but with new important features. Existed clusters connect together forming bigger clusters, what consequently decreases the number of chainlike or smaller clusters. These processes have influence on the value of the acoustic attenuation – dramatic decreases of its value. At ~120 mT MF reaches a new state of equilibrium in the structure of nanoparticles, that is only slight function of external magnetic field.

The case of jump change of magnetic field (Fig. 2) fully corresponds to previous results. In the first minute after the jump change of magnetic field acoustic attenuation significantly increased. This phenomenon as it was already mentioned can be explained by aggregation of nanoparticles to chain-like clusters that starts over 40 mT as it can be seen from Fig. 1b. In this case the magnetic fluid does not reach some new state but there is following big decrease of α that takes around 3 minutes. In this situation the magnetic field has value 150 mT and we know that from 80 mT (Fig. 1b) new process of clustering is presented. So that after 10 minutes the studied magnetic fluid reaches the new state of equilibrium. As it can be seen from Fig. 2 this equilibrium state as well as whole development of structure depends on the temperature of magnetic fluid.

4. Conclusion

The influences of both magnetic field and temperature on the structures of investigated magnetic fluids based on the transformer oil MOGUL were observed using acoustic spectroscopy. The effect of external magnetic field on the creation of clusters of nanoparticles in magnetic fluids was confirmed and their influence on the development of attenuation was described. In this type of magnetic fluid complicated structures of clusters at magnetic field over 100 mT are created. These structures are than at higher magnetic field almost stable. This state of equilibrium is not function of time. Measurements also confirmed that the lifetime of these structures or clusters is very short. The further investigation of the time and temperature dependences of the acoustic attenuation on the magnetic field at different concentrations of magnetic nanoparticles and various direction of magnetic field are necessary to understand all processes in this magnetic fluid.

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