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DETERMINATION OF THE PARTICLE CONCENTRATION IN DILUTED MAGNETIC FLUIDS USING FT-IR SPECTROMETRY

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Abstract
In the present article we have carried out FT-IR measurements and static magnetization curve measurements on a dilution serie of a magnetic fluid. FT-IR measurements revealed that the peak corresponding to the wavenumber of 637.5 cm^{-1} depends on the particle concentration within the investigated magnetic fluid sample. The dependence on the particle concentration of the absorbance of the magnetic fluid, corresponding to the wavenumber of 637.5 cm^{-1} obeys the Beer-Lambert law in the range of low particle concentrations. Based on this linear dependence, we have determined the particle concentration of other arbitrary diluted samples of the same initial magnetic fluid. We have found out a good agreement between the values of particle concentration obtained by means of Beer-Lambert law and those obtained from the static magnetization curve.
The experimental results alow us to assert that the FT-IR measurements and the Beer-Lambert law can be used in determination of particle concentration within magnetic fluids in the range of low particle concentrations.
Keywords: Magnetic fluid; Particle concentration; FT-IR spectra; Beer-Lambert's law.

1. Introduction

Magnetic fluids are stable colloidal systems consisting of single-domain magnetic particles dispersed in a nonmagnetic carrier liquid [1]. In order to prevent agglomeration, the magnetic particles are coated with a surfactant.

The phenomenological Beer-Lambert law [2] relates the absorption band intensity and the sample concentration, in the case of optically thin samples. For a single solute in a non-absorbing solvent, the Beer-Lambert law shows that the optical absorbance of the solution for any wavenumber, $\tilde{\nu}$ (or wavelength, λ) increases linearly with the solute concentration, *n*,

$$A(\tilde{\nu}) = a(\tilde{\nu})bn = -\log \tau(\tilde{\nu}) \qquad (1)$$

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where $\tau(\tilde{\nu})$ is the transmittance, $a(\tilde{\nu})$ is the absorption cross section at $\tilde{\nu}$, b is the sample path length [2]. For high concentrations of the solute, many systems exhibit deviations from the linear dependence (1) of the Beer-Lambert law. These deviations can be determined due to the effect of stray radiation, the insufficient resolution or by chemical effects [2]. Other causes of deviations from the Beer-Lambert law are the fluorescence in the sample, changes in the refractive index at high analyte concentration and the light scattering due to particles within the sample [3]. In Ref. [4] are also reported deviations from the Beer-Lambert law due to the dimerization process within the sample.

In this article the behaviour of the linear optical absorption of a magnetic fluid at different particle concentrations have been studied in order to show that, at low concentrations, FT-IR spectrometry can be involved for particle concentration determination of the magnetic fluids.

2. Experimental result and discussions

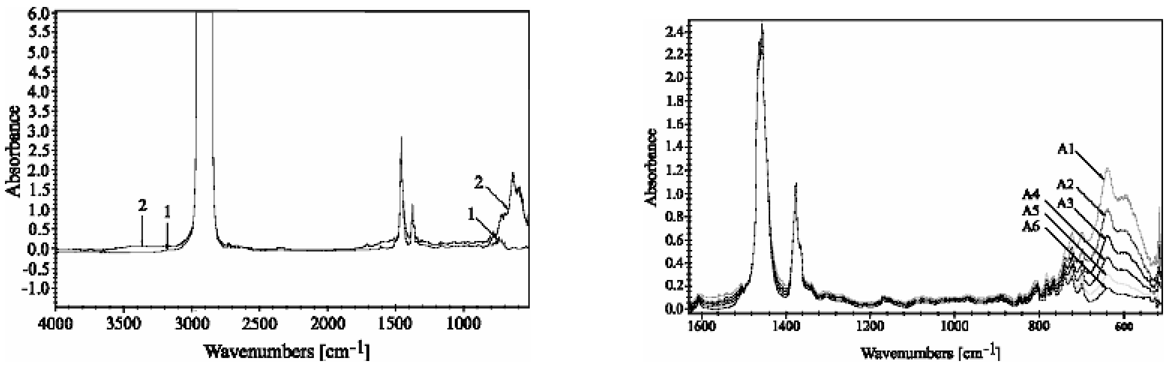
The investigated sample is a magnetic fluid, denoted *A*, with magnetite particles dispersed in kerosene. The colloidal particles of the magnetite (Fe_3O_4) used in sample *A* have been obtained by chemical co-precipitation of bivalent and of trivalent *Fe* salts with an excess of NH_3 in solution. Hydrofobization with technical oleic acid in the absence of the dispersion medium (kerosene) at a temperature of (75 - 80) ^{0}C, followed by a thermal treatment at 100 ^{0}C for 1.5 hours [5] has been used for the stabilization of magnetic colloidal particles of the magnetite.

The electron photomicrograph analysis of the studied magnetic fluid, allowed the determination of the dimensional distribution of the magnetite particles. The mean value of the physical diameter of the particles is $D_m=11.4\ nm$, and the standard deviation $\Delta = 2.4\ nm$.

From the magnetization curve of the sample A the particle concentration and the saturation magnetization were determined. The resulted values are: $n_0(A) = 3.84 \cdot 10^{22}\ m^{-3}$ and $M_\infty(A) = 11.32\ kA/m$. The thickness of the solid non-magnetic shell has been considered to be $0.84\ nm$ [6] and the saturation magnetization of the bulk material is considered $M_S=477.5\ kA/m$.From the initial magnetic fluid (sample A), six samples have been obtained by successive dilution with kerosene, at a dilution ratio 2/3, from the initial magnetic fluid (sample A), and we denoted these sample A1, A2, A3, A4, A5 and A6. The particle concentration within these samples has been calculated from the magnetization curve of each sample, using the mean magnetic diameter obtained from the electron photomicrograph analysis. The results are: *n(A1) = 2.51* $\cdot 10^{22}$ m^{-3} , *n(A2) = 1.71* $\cdot 10^{22}$ m^{-3} , *n(A3) = 1.14* $\cdot 10^{22}$ m^{-3} , *n(A4) = 0.76* $\cdot 10^{22}$ m^{-3} , *n(A5) = 0.51* $\cdot 10^{22}$ m^{-3} , *n(A6) = 0.34* $\cdot 10^{22}$ m^{-3} .

The FT-IR measurements were carried out with a NEXUS 470 FT-IR spectrometer from NICOLET, in the spectral range (4000 - 400) cm^{-1}. For the mid-IR frequency region a Ever-Glo source, a KBr beamsplitter and a DTGS detector were used. We have used a NaCl cell, with the thickness of *0.12 mm* .

The FT-IR spectra of the carrier liquid of the magnetic fluid (kerosene) and of the initial magnetic fluid sample (sample A) are shown in figure 1a). The FT-IR spectra of the diluted samples A1, A2, A3, A4, A5 and A6 are displayed in figure 1b).



a) b)

Fig.1. FT-IR spectra a) of the carrier liquid (1) and of the initial magnetic fluid sample A (2); b) of the diluted samples A1, A2, A3, A4, A5 and A6 .

As we can observe from the fig.1, the peak corresponding to the wave number 637.5 cm^{-1} is a characteristic of the investigated magnetic fluid sample, the absorbance depends on the sample concentration. The dependence of the absorbance, $A(\tilde{\nu})$, on the relative particle concentration, n/n_0, corresponding to the peak of 637.5 cm^{-1} is shown in figure 2. One can observe that the dependence of $A(\tilde{\nu})$ on n/n_0 is linear in the range of low concentrations (up to $n/n_0 = 0.35$), being in good agreement with the Beer-Lambert law. In the range of low concentrations the experimental results are well fitted by the equation (2).

$$A(\tilde{\nu}) = 2.2 \cdot (n / n_0) \qquad (2)$$

This equation can be used to calculate the particle concentration of other dilutions of the initial magnetic fluid. In order to demonstrate that FT-IR spectrometry can be involved for the concentration determination of the magnetic fluids of low concentrations, we have prepared, by dilution of the starting sample A, another three magnetic fluid samples; we denoted these X1, X2 and X3. In Fig.3a) are shown the FT-IR spectra of the samples X1, X2 and X3. Measuring the absorbance, $A\ (\widetilde{\nu}),$ for each sample, corresponding to the peak of 637.5 cm^{-1}, we obtained the following values: $A\ (\widetilde{\nu})_{X1} = 1.25$, $A\ (\widetilde{\nu})_{X2} = 0.75$ and $A\ (\widetilde{\nu})_{X3} = 0.48$. Using these values and the equation (2) we have calculated the particle concentration of the samples X1, X2 and X3, resulting the following values $n(X1)=2.16\cdot10^{22}m^{-3}$, $n(X2)=1.3\cdot10^{22}m^{-3}$ and $n(X3)=0.83\cdot10^{22}m^{-3}$.

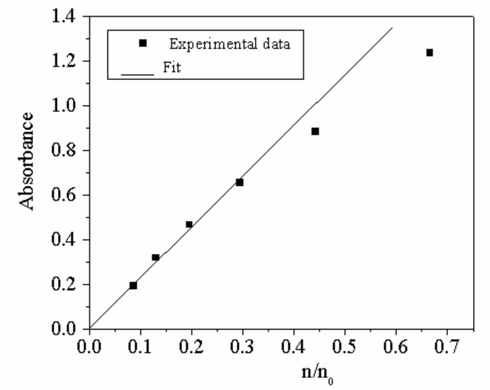
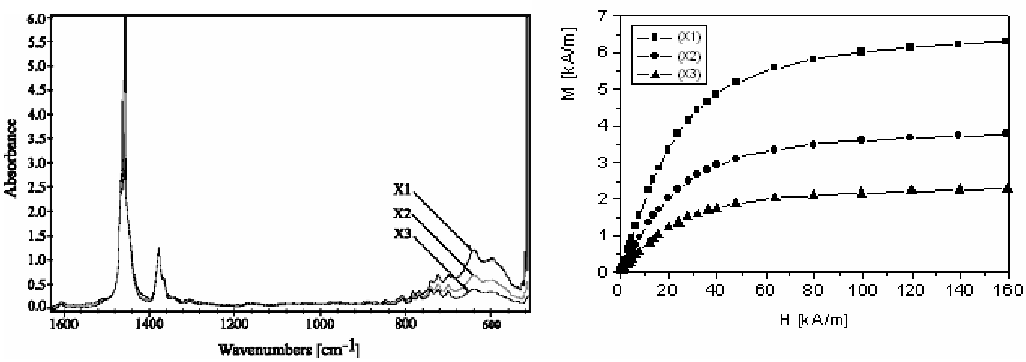


Fig.2. The dependence on the relative particle concentration, n/n_0 of the absorbance, $A(\widetilde{\nu})$ corresponding to the peak of 637.5 cm^{-1}.



a) b)

Fig.3. a) FT-IR spectra of three diluted samples of unknown particle concentrations, obtained from the initial magnetic fluid (sample A); b) the magnetization curve of the magnetic fluid samples X1, X2 and X3.

In order to verify these results for concentration as determined by means of FT-IR spectrometry, the particle concentrations have been also determined by means of the magnetization curve method. The resulted values for the saturation magnetization of the samples were $M_{\infty}(X1) = 6.77\ kA/m$, $M_{\infty}(X2) = 4.06\ kA/m$ and $M_{\infty}(X3) = 2.44\ kA/m$ (see fig.3b)). The particle concentration, n_m, was determined from saturation magnetization and was based on the mean magnetic diameter as resulted from the electron micrograph. The values obtained were: $n_m(X1) = 2.28 \cdot 10^{22} m^{-3}$, $n_m(X2) = 1.38 \cdot 10^{22} m^{-3}$ and $n_m(X3) = 0.83 \cdot 10^{22} m^{-3}$, being in a good agreement with the values *n(X1)*, *n(X2)* and *n(X3)* as resulted by means of FT-IR spectrometry.

3. Conclusions

FT-IR measurements revealed that the peak corresponding to the wavenumber of 637.5 cm^{-1} is characteristic to the investigated magnetic fluid sample, its amplitude depending on the particle concentration within the sample. We have observed that the dependence of the absorbance of a magnetic fluid, $A(\tilde{\nu})$ on the particle concentration is linear in the range of low particle concentrations, being in agreement with the Beer-Lambert law. Based on this linear dependence, we have determined the particle concentration of other arbitrary diluted samples of the same initial magnetic fluid. We have found out that the values of particle concentration obtained by means of Beer-Lambert law and those obtained from the static magnetization curve are in good agreement. The experimental results allow us to assert that the FT-IR spectrometry and the Beer-Lambert law can be used in determination of particle concentration within diluted magnetic fluids. This experimental technique is recommended in case of low particle concentrations where the dependence on the particle concentration of the absorbance of a magnetic fluid is linear.

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