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Use of the photoacoustic spectroscopy for characterization of magnetic fluid based on mamona oil

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Abstract. In this study the photoacoustic spectroscopy was used to investigate the interaction between colloidal suspended nanosized maghemite particles and molecules present in mamona oil (\textit{ricinus communis L}). Maghemite nanoparticles were used to produce a magnetic fluid sample dispersed in mamona oil (MF-Mamona oil). In the L-band region (600 to 900 nm) of the photoacoustic spectra we found the photoacoustic signal of sample MF-Mamona oil enhanced with respect to the signal of the purified mamona oil. This finding is claimed to be the signature of the strong interaction between the mamona oil’s molecules and the solid surface provided by the suspended nanosized maghemite particles.

1. Introduction
The worldwide scientific activity related to magnetic fluids (MFs) has grown enormously in the last two decades, mostly fostered by the opportunities of applications in the medical field. Magnetic fluids consist of surface-dressed nanosized magnetic particles suspended in a carrier liquid. The particular bare particle, its composition and size, the surface coating species and the carrier fluid characteristics are all important parameters to take into consideration while developing new samples. Properties of MF samples, in particular the biocompatible ones, derived from the bare magnetic particle nature and its surface molecular dressing as well as the characteristics of the carrier fluid the nanoparticles are suspended in. The requirement of improved colloidal stability is a key point while addressing the development of new MF samples for specific applications. This paper reports on the use of the photoacoustic spectroscopy (PAS) in the characterization of magnetic fluid samples based on mamona oil (\textit{ricinus communis L}) as the carrier fluid. The macroscopic properties of MF samples are largely affected by its microscopic structure, including here the particle-particle interaction and the interaction between the suspended particle and the molecules of the carrier fluid [1]. The very possibility of manipulation of MF samples (using gradients of magnetic fields) depends upon the above-mentioned interactions and is the basis of a huge variety of medical and industrial applications. Therefore, combination of biocompatibility and external manipulation allows localization of MF samples in biological sites, thus opening up many opportunities for applications. Purified mamona oil has several medicinal effects, acting for instance as antimicrobial laxative. In addition, purified mamona oil has been used to treat chilblain, hemorrhoids, skin diseases, constipation, and stomach disorders.
2. Material and Methods

Materials used in the present study include purified mamona oil, magnetic fluid containing maghemite nanoparticles suspended in mamona oil (MF-Mamona oil), aqueous-based magnetic fluid samples containing magnetite nanoparticles surface-coated with dextran (MF-Dextran) and dimercaptosuccinic acid (MF-DMSA). Different experimental techniques, namely X-ray diffraction (XRD), transmission electron microscopy (TEM) and photoacoustic spectroscopy (PAS) were used in the present study. The photoacoustic spectrometer used here is a home made system which has been already reported in the literature while investigating nanosized magnetic particles suspended in different carrier fluids [2-3].

3. Experimental data and analysis

The XRD of the nanoparticulated magnetic powder (see Figure 1) suspended in mamona oil confirms the maghemite phase. The XRD data obtained from the analysis of Figure 1 are collected in Table 1. Also, for comparison, the ASTM data of maghemite are collected in Table 1. In addition to the identification of the XRD lines, the Scherrer equation [4] was used to estimate the maghemite average diameter (around 8 nm) from the analysis of the (311) diffraction line.

![Figure 1. X-ray diffractogram of nanosized maghemite particles.](image)

Figure 2 shows the transmission electron microscopy micrograph of the nanoparticulated maghemite used to produce the MF-Mamona oil sample investigated in this study. The TEM micrograph reveals the sample’s polydispersity and the spherical shape of the magnetic units. The TEM data allows one to build the particle size histogram which was curve-fitted using the log-normal distribution function [5]. The histogram curve-fitting procedure provided the average particle diameter of 6.0 nm and diameter dispersity of 0.02. In the nanometer range differences in average particle size obtained from different techniques are very often and may reflect the approximations used to analyze the data or else may reflect differences regarding the quality of the data.
Figure 2. Typical TEM micrograph of the magnetic particles suspended into mamona oil.

Figure 3. Room-temperature photoacoustic spectra of purified mamona oil, MF-Mamona oil, BMF-Dextran and BMF-DMSA samples in the range of 300 to 1000 nm.

Figure 3 shows the photoacoustic (PA) spectra of the samples investigated in this study. The PA spectra of the purified mamona oil, BMF-Dextran and BMF-DMSA were included in Figure 3 for comparison with the PA spectrum of the MF-Mamona oil sample. Except for the purified mamona oil all MF samples show a strong PA signal around 370 nm (C-band), indicating the absorption of the bare magnetic nanoparticle [1-3]. The PA features appearing in the range of 400 to 500 nm (S-band) are typical of small polar functional groups (hydroxyl, thiol, amino) attached to solid surfaces or
associated to macromolecules [1-3]. As can be observed in Figure 3 the S-band associated to the three MF samples are similar and quite different from the S-band of the purified mamona oil. The difference is due to the absence of nanoparticulated material within the purified mamona oil. The L-band appearing in the 600 to 900 nm range is different for all samples. The L-band has been related to long chain molecules, increasing in intensity for molecules attached to solid material’s surface. Note that the PA signal level above 900 nm is about the same for the purified mamona oil and for the MF-Mamona oil sample. However, the PA signal level for all bands (C-, S- and L-band) is higher for the FM-Mamona oil sample than for the purified mamona oil. This is due the presence of the nanosized magnetic particles which provides the solid surface for interaction with the mamona oil’s molecules. This finding is particularly enhanced for the L-band region (600 to 900 nm).

4. Conclusion

The photoacoustic spectroscopy was successfully used to investigate the interaction between the suspended nanosized maghemite particles and the mamona oil’s molecules in the MF-Mamona oil sample. In particular, the difference in photoacoustic signal intensity at the L-band region indicates the strong interaction of the mamona oil’s molecules and the suspended nanosized maghemite particles in the MF-Mamona oil sample. Nevertheless, except for the photoacoustic signal intensity, features observed in the L-band region are similar for both the purified mamona oil sample and the MF-Mamona oil sample, indicating the contribution of the interacting mamona oil’s molecules to the photoacoustic signal. These findings reveal the photoacoustic spectroscopy as a promising experimental technique to probe the interaction between the hosting oil’s molecules and suspended nanosized particles. The observed interaction may represent a key aspect while using MF-Mamona oil for clinical purposes as the biologically-active molecules dispersed in mamona oil can be externally manipulated via gradients of magnetic fields, thus providing a way to target biological sites.

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Table 1. XRD peaks and intensity of both the nanoparticulated magnetic powder and the ASTM data for maghemite.

| hkl  | Nanoparticulated magnetic powder | ASTM data for maghemite |
|------|---------------------------------|-------------------------|
|      | 2θ (degrees) | intensity | 2θ (degrees) | intensity |
| 220  | 30.278       | 44        | 30          | 30.122     |
| 311  | 35.719       | 100       | 100         | 35.455     |
| 400  | 43.322       | 24        | 20          | 43.099     |