DEPENDENCE OF SAR WITH NANOPARTICLES CONCENTRATION IN MAGHEMITE-BASED FERROFLUIDS

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The correct determination of the Specific Absorption Rate (SAR) of ferrofluids is an important issue in clinical applications in order to determine the optimun dose required to be effective in a medical hyperthermia treatment. Intuitively an increase in the active agent concentration would lead to an improvemt of the effectiveness. This increment is limited by the secondary effects and adverse effects that the overdosing may produce. In contrast, we observed that in the case that the agent is a magnetic nanoparticle, the increse of the concentration might enhance magnetic interactions that will decrease their heating performance.

The aim of this work is to determine if increasing ferrofluid concentration is always worthwhile in magnetic fluid hyperthermia. For this purpose, we have analyzed the nanoparticles concentration dependence of SAR in a maghemite-based ferrofluid. This ferrofluids has a narrow size distribution that allows optimizing SAR values. The results show that relaxation time is similar for most of the superparamagnetic particles in the ferrofluid, and dissipation is maximized when the ac magnetic field frequency is tuned with such time. However, factors like cluster formation or particle interactions may deviate the real SAR values from theoretical estimations.

The synthesis of highly crystalline and monodisperse maghemite nanoparticles was carried out in organic medium by the Hyeon method [1]. This procedure, which allows varying particle size by controlling the experimental parameters, is based on the thermal decomposition of iron pentacarbonyl in the presence of oleic acid. The resulting iron nanoparticles were transformed to monodisperse maghemite by controlled oxidation using trimethylamine oxide as a mild oxidant. The final concentration of the ferrofluid was 10.4 mg (γ-Fe_2O_3)/ml. The TEM image reveals the narrow size distribution of the sample under study, with average diameters of about 13±0.6 nm. Dinamic Light Scattering (DLS) measurements (not shown) reveal the absence of aggregates. Several dilution rows from the original sample were studied.

To determine the influence of interactions in the magnetic properties we have performed ac and dc measurements in the original sample and in two diluted ferrofluids. The ac measurements were performed by quenching the ferrofluid at 5K, so that each nanoparticle becomes immobilized and the magnetic interactions between dipoles can be considered to be the same as that in room temperature, when the solvent is liquid. The ac relaxation analysis provides attempt times that indicate the existence of magnetic interactions [2]. The magnetization curves at room temperature display different behaviors: for the original concentration and for 4.21 mg/ml, sample reaches saturation more slowly than for 1.72 mg/ml, indicating that those samples are more stable against magnetic orientation. These results suggest that dipolar interactions influence the magnetic response and that it is possible to enhance susceptibility by means of diluting the ferrofluid.

The SAR of both the original and the diluted samples was determined using a novel adiabatic magnetothermal setup [3], which provides accurate and reproducible values due to the possibility of measuring direct temperature increments with no heat losses. The obtained results have been discussed on the basis of the microstructure and magnetic properties. They indicate a noticeable SAR reduction with ferrofluid concentration. Indeed, for the most diluted sample, half the mass of nanoparticles can be used to obtain the same heating power than that achieved with the original ferrofluid. This effect implies that, before assigning a SAR value to a ferrofluid, it is recomended to make a concentration dependence study. It is also important to notice that, during the ferrofluid administration, concentration or even agglomeration of particles in the tissue can occur, and that could change heating efficiency.

References:

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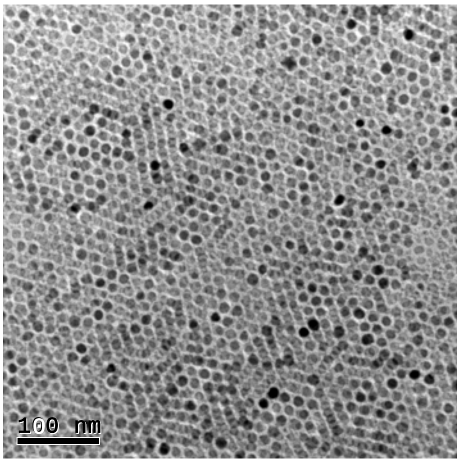
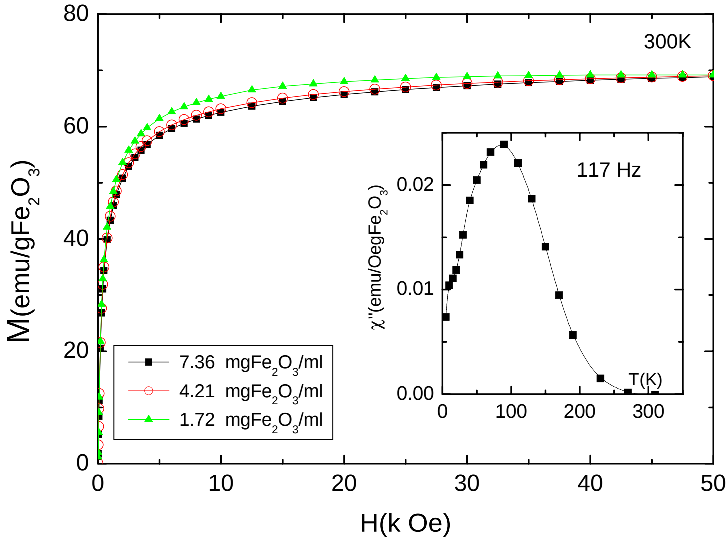
Figures:





Left: TEM image. **Right:** Magnetization curves at r.t.. **Inset:** χ'' of the original sample.