Thermal study of ferromagnetic nanoparticles coated with mesoporous silicon oxide

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Background – Magnetite (Fe_3O_4) superparamagnetic nanoparticle (NPs) systems are a promising option for applications in biomedicine such as hyperthermia therapies, drug delivery, imaging. Fe_3O_4 NPs with less than 20 nm in size have unique properties being capable of following a magnetic field and lose magnetization when this field is removed. This reduces the risk of nanoparticle aggregation, avoiding a negative impact. Incorporating an external matrix of mesoporous SiO_2 allows to combine the properties of Fe_3O_4 and silicon, which are important to reduce its toxicity with the advantage of load drugs or markers within the mesoporous SiO_2 matrix. In this work, a simple methodology to synthesize these nanocomposites, using the co-precipitation method for the development of Fe_3O_4 nanoparticles and using the modified Stöber method to incorporate the mesoporous SiO_2 matrix was developed. The thermal characterization of the nanoparticles by thermal lens and thermal wave resonant cavity (TWRC) techniques were used.

Methods – NPs Fe3O4 were elaborated from two different processes, by precipitation and heating. NPs with a particle size of 20 nm were obtained and characterized by EDS to determine their composition. Before SiO_2 shell coating, the Fe_3O_4 NPs were modified with citric acid to obtain better dispersibility. 0.02 g of Fe_3O_4 NPs and citric acid were dissolved in deionized water with mechanical stirring for 1 h in a flask. Another solution mixed with 10 ml of distilled water, 50 ml of absolute alcohol, 5 ml of aqueous ammonia and 0.2 g of CTAB was mechanically stirred at room temperature for 10 min and then injected into the above flask. After that, 1 ml of TEOS, which will serve as silicon precursor was added. The mixture solution was continuously stirred for 2 h, which was named Fe3O4@-SiO2 [1,2]. Thermal analyzes were performed with the TWRC and thermal lens (TL) techniques.

Results – Figure 1 shows the characteristic spectrum of the evolution of the signal by the TWRC technique for a measurement of Fe_3O_4 nanofluid. The straight line is the best fit of the equation Eq. 1 to the experimental values of 6 measurements. The fit constant (q) was found by means of the slope of the line. The value of the thermal diffusivity of distilled water was obtained by this same technique. The thermal diffusivity is 1.3 $x10^{-3}$ cm^2/s for a concentration of 0.1 mg/mL, increases with the size of the NPs, showing a thermal enrichment of 80% for a constant weight concentration. Fig 1 shows the phase signal as a function of the scan distance of the resonator in the liquid sample. This value is

important to determine the thermal diffusivity based on the size of the particle, concentration and coverage of the NPs, for heat transport in medical applications.

$$Ln(V(L,\alpha,\omega)) = ln(Const(\omega)) + ln(e^{-qL}),\ q = \sqrt{\frac{\pi f}{\alpha_l}} \qquad \text{Eqn.1}$$

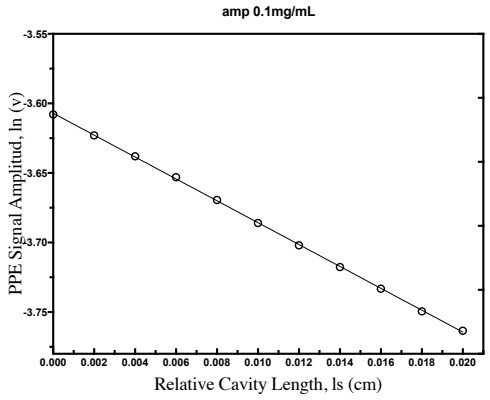

Fig. 1. PPE signal amplitude v.s, relative cavity length for Fe_3O_4 nanofluid. The continuum line is the best fit for the experimental values.

Conclusions – In summary, the thermal diffusivity of magnetic nanofluids was measured for 3 different particle sizes using two photothermal techniques TL and TWRC, obtaining a growth of diffusivity as a function of size. The results of the amplitude of the TWRC signal were similar to the thermal diffusivity of TL, in agreement for the thermally transparent region. Therefore, in the inverse process of the signal phase of the TWRC technique, the thermal diffusivity is higher than the diffusivity of the TL. The obtained values of thermal diffusivity by TWRC were similar to the values reported in the literature. Possibly the increase of the thermal diffusivity is related to the precipitation of the NPs in the resonant cavity, concentration and due to the cover of the NPs with the Fe oxide.

References

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