Study of magnetic and structural properties of ferrofluids based on Cobalt-Zinc ferrite nanoparticles
J. López1, L. F. González-Bahamón2, J. Prado1, J. C. Caicedo1, G. Zambrano1, M. E. Gómez1, J. Esteve3, and P. Prieto4

1. Thin Film Group, Universidad del Valle, A.A. 25360, Cali, Colombia
2. Analytical Chemistry Laboratory, Universidad del Valle, A. A. 25360, Cali, Colombia
3. Department de Física Aplicada i Óptica, Universitat de Barcelona, Catalunya, Spain
4. Center of Excellence for Novel Materials, Universidad del Valle, Cali, Colombia

* Corresponding author: javierlo21@gmail.com

Abstract
Ferrofluids are colloidal systems composed of a single domain of magnetic nanoparticles with a mean diameter around 10 nm, dispersed in a liquid carrier. Magnetic Co$_{1-x}$Zn$_x$Fe$_2$O$_4$ (x = 0.25, 0.50, 0.75) ferrite nanoparticles were prepared via co-precipitation method from aqueous salt solutions in an alkaline medium. The composition and structure of the samples were characterized through Energy Dispersive X-ray Spectroscopy and X-ray diffraction, respectively. Transmission Electron Microscopy studies permitted determining nanoparticle size; grain size of nanoparticle conglomerates was established via Atomic Force Microscopy. The magnetic behavior of ferrofluids was characterized by Vibrating Sample Magnetometer; and finally, a magnetic force microscope was used to visualize the magnetic domains of Co$_{1-x}$Zn$_x$Fe$_2$O$_4$ nanoparticles. X-ray diffraction patterns of Co$_{1-x}$Zn$_x$Fe$_2$O$_4$ show the presence of the most intense peak corresponding to the (311) crystallographic orientation of the spinel phase of CoFe$_2$O$_4$. Fourier Transform Infrared Spectroscopy confirmed the presence of the bonds associated to the spinel structures; particularly for ferrites. The mean size of the crystallite of nanoparticles determined from the full-width at half maximum of the strongest reflection of the (311) peak by using the Scherrer approximation diminished from (9.5 ± 0.3) nm to (5.4 ± 0.2) nm when the Zn concentration increases from 0.21 to 0.75. The size of the Co-Zn ferrite nanoparticles obtained by Transmission Electron Microscopy is in good agreement with the crystallite size calculated from X-ray diffraction patterns, using Scherer’s formula. The magnetic properties investigated with the aid of Vibrating Sample Magnetometer at room temperature presented super-paramagnetic behavior, determined by the shape of the hysteresis loop. In this study, we established that the coercive field of Co$_{1-x}$Zn$_x$Fe$_2$O$_4$ magnetic nanoparticles and the crystal and nanoparticle sizes determined by X-ray Diffraction and Transmission Electron Microscopy, respectively, decrease with the increase of the Zn at%. Finally, our magnetic nanoparticles are not very hard magnetic materials given that the hysteresis loop is very small and for this reason Co$_{1-x}$Zn$_x$Fe$_2$O$_4$ nanoparticles are considered soft magnetic material.

Keywords: Chemical coprecipitation synthesis, Ferrofluids, nanoparticles, single domain, spinel structure, super-paramagnetism.

Acknowledgments
This work was supported by “El Patrimonio Autónomo Fondo Nacional de Financiamiento para la Ciencia, la Tecnología y la Innovación Francisco José de Caldas” Contract RC - No. 275-2011 and Universidad del Valle research project code 7703. Moreover, the authors acknowledge the Serveis Científico-Tècnics of the Universitat de Barcelona for TEM analysis.
References


Figures

**Fig. 1.** M vs. H hysteresis loop of Co$_{1-x}$Zn$_x$Fe$_2$O$_4$ magnetic ferrofluid as a function of Zn concentrations at room temperature.

**Fig. 5.** HRTEM images of Co$_{0.79}$Zn$_{0.21}$Fe$_2$O$_4$ nanoparticles at two different scales: a) 50 nm, b) 10 nm.