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Ferrofluid based on polyethylene glycol-coated iron oxide nanoparticles: Characterization and properties

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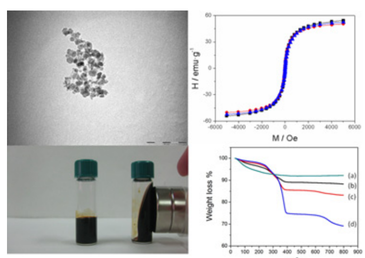
HIGHLIGHTS

- Ferrofluid formed by adsorption of unmodified polyethylene glycol.
- Effect of size and concentration of polyethylene glycol on properties of ferrofluid.
- High stability of ferrofluid derived from the steric repulsion among the polymer chains.

GRAPHICAL ABSTRACT



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ABSTRACT

We report here the development of stable aqueous suspensions of superparamagnetic iron oxide nanoparticles stabilized with unmodified polyethylene glycol (PEG) at four molecular weights (2000, 4000, 6000 and 10,000 Da) and several PEG/iron ratios. The obtained ferrofluid was an opaque dispersion of pH $\approx$ 5.0 with an iron content ranging from 15 mg mL^{-1} to 17 mg mL^{-1} (depending on the molecular weight of the PEG used), and a ζ-potential of 20 ± 2 mV. The diameter of uncoated particles determined by X-ray diffraction was $\approx$12 nm; a value that ensures superparamagnetic properties and suitability for use in hyperthermic therapy. When coated and determined by dynamic light scattering, the hydrodynamic diameter of the particles was 56 nm for the lowest PEG/iron ratio. Thermogravimetric analysis showed that the content of PEG in the ferrofluid ranged from 6.5% to 23.8%, depending on the different molecular weights and amount of PEG used. The interaction of PEG with magnetite is probably due to dipole–cation binding between the ether group of the polymer and the positive charge of magnetite. As regards physical stability, the ferrofluid was stable in the absence of salt over a period of more than two years.

1. Introduction

Ferrofluids are colloidal dispersions of small, single-domain magnetic particles suspended in a continuous phase whose rheological behaviour can be controlled by means of a magnetic field. Ferrous or ferric oxide is the main constituent of magnetic particles (ferromagnetic iron oxides, maghemite, γ-Fe_2O_3, and magnetite, Fe_3O_4, are the most frequently used and are also the only magnetic materials that are FDA approved for use in humans) [1], although pure transition metals such as cobalt and nickel are also employed. If magnetic particles have a mean diameter of $\sim$10 nm, thermal energy efficiently prevents sedimentation in a gravitational field or agglomeration produced by the dipole interaction resulting from the existence of a single magnetic domain in the particles. However, thermal energy does not prevent coagulation produced by the van der Waals forces that induce a strong short-range isotropic interaction [2]. To overcome this problem, the inorganic nanoparticle core must be coated with surfactants, polymers, polyelectrolytes, block copolymers or inorganic materials [3]. Once a ferrofluid is formed, and in the absence of a magnetic field, its behaviour is

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