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Effect of concentration on hydrodynamic size of magnetite-based ferrofluid as a potential MRI contrast agent

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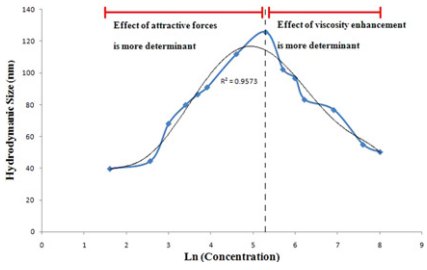
HIGHLIGHTS

- Stable magnetite-based ferrofluids were synthesized via co-precipitation method.
- Hydrodynamic size was evaluated via PCS technique.
- Effect of concentration was studied on hydrodynamic size.
- Stable ferrofluids were used as MRI contrast agents.

GRAPHICAL ABSTRACT



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ABSTRACT

In this work, ferrofluids containing dextran coated magnetite nanoparticles have been synthesized via co-precipitation method. FT-IR results verified presence of dextran molecules on the particles surface. TEM results showed that mean particle size is 7.23 nm, while mean hydrodynamic size determined via PCS technique varies between 39.8 and 125.8 nm depending on the ferrofluid concentration. The maximum hydrodynamic size was obtained in mid concentrations. To the best of our knowledge, effect of concentration on mean hydrodynamic size has not been systematically studied before. VSM results confirmed the superparamagnetic behavior of the synthesized nanoparticles with saturation magnetization of 57.82 emu/g. The stable ferrofluids were intravenously injected into mice and used as MRI contrast agent. Results showed that these ferrofluids can be considered as potential MRI contrast agents especially for imaging lymphatic system.

1. Introduction

Ferrofluids containing magnetic nanoparticles have been widely used in various biological applications such as drug delivery [1–3], MRI contrast agent [4–8] and cancer therapy via hyperthermia [9,10]. Antibody conjugation is one of the conventional approaches of particle and drug delivery into target tissues [11,12]. Surface charge, size, shape and other physical and morphological properties of nanoparticles have a great role in determining the target tissue. For example, large and aggregated particles are mainly accumulated in tissues such as liver and spleen, however smaller ones (20–40 nm) are phagocytosed by macrophages of lymphatic system and mainly absorbed in lymph nodes [5,13]. So, hydrodynamic size of particles dispersing in liquid media including core size and surfactant layer thickness is an important parameter in drug delivery into target tissues and organs. This parameter is

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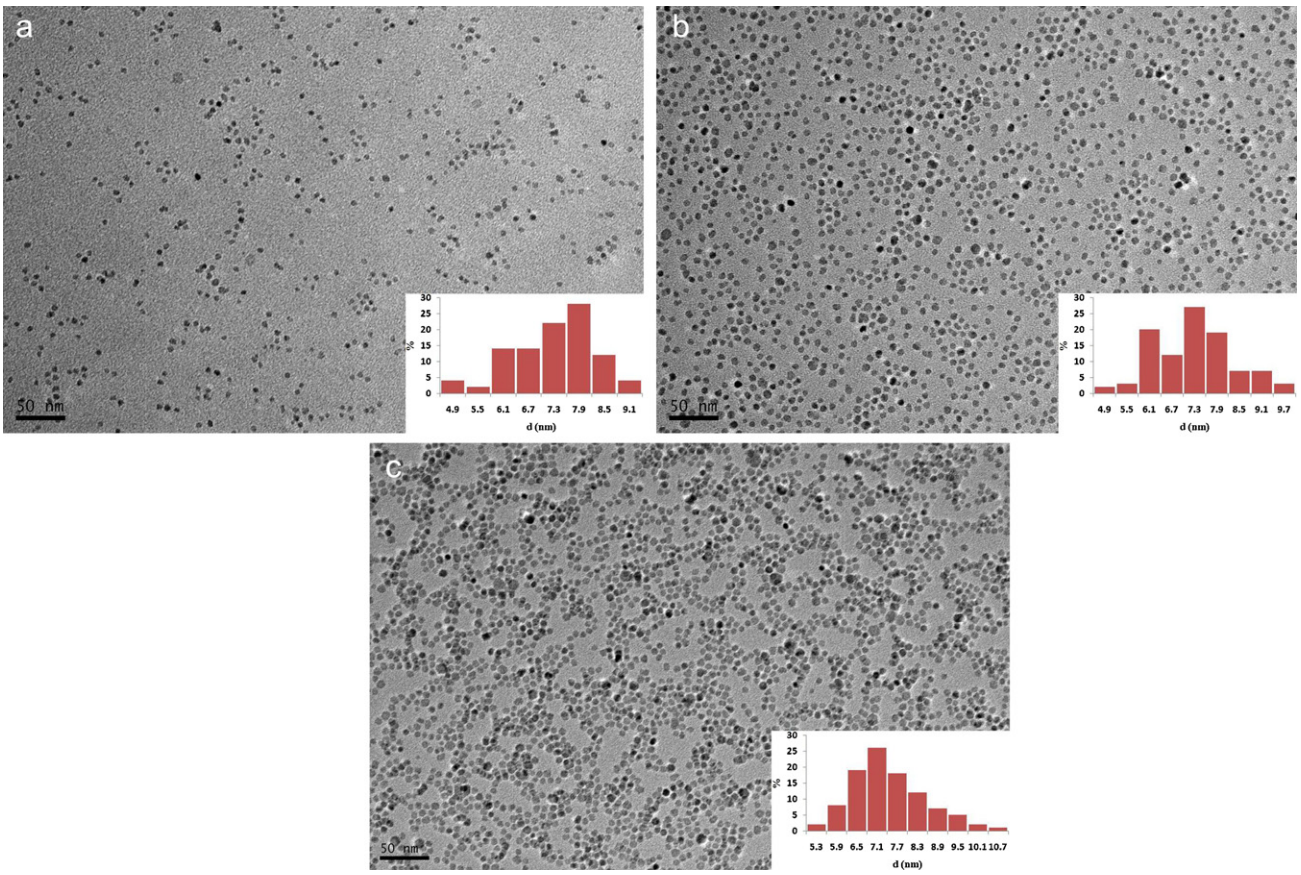

Fig. 1. TEM image of the synthesized sample at three concentrations: (a) 500 μg Fe/cc with mean particle size of 7.28 nm, (b) 2000 μg Fe/cc with mean particle size of 7.30 nm and (c) 3000 μg Fe/cc with mean particle size of 7.23 nm.

usually determined via DLS (dynamic light scattering) or PCS (Photon correlation spectroscopy) techniques and has been widely used for evaluation of aggregate size [14–16]. One major parameter ignored in all of these investigations is effect of particles concentration on the hydrodynamic size. In other words, the concentration in which hydrodynamic size is measured is not mentioned in these papers. This subject is investigated in the present work and has not been systematically studied before in the best of our knowledge.

In this study, stable ferrofluids containing dextran coated magnetite nanoparticles were synthesized via co-precipitation approach using ferrous and ferric salts and a basic reducing agent according to the general reaction (1) [17]:

$$Fe^{2+} + 2Fe^{3+} + 8OH^- \longrightarrow Fe_3O_4 + 4H_2O \quad (1)$$

The synthesized particles were characterized using XRD, TEM, VSM, FT-IR and PCS techniques. Finally, the stable ferrofluid was used as a MRI contrast agent for molecular imaging of mice lymphatic system. Results show that the synthesized ferrofluid can be considered as a potential MRI contrast agent.

2. Experimental

2.1. Materials and methods

All the chemical reagents used in this research were of analytical grade and used as received without further purification. The detailed synthesis process is described in the previous work [5]. Stable ferrofluids of dextran coated magnetite nanoparticles were synthesized via co-precipitation method using a conventional approach. Stoichiometric amounts of $FeCl_2{\cdot}4H_2O$ and $FeCl_3{\cdot}6H_2O$ for synthesizing 0.2 g Fe_3O_4 according to Eq. (1) were prepared and dissolved in distilled water in a three neck container using ultrasonic irradiation while Argon was blown into the solution. 0.6 g dextran 20000 kDa was added into solution too. After 5 min of ultrasonic irradiation, 0.4 molar NaOH was dropwise added into the solution until pH > 12. Ultrasonic irradiation was continued 30 min under Argon atmosphere. After that, HCl solution was added dropwise into the container under stirring until pH reached 7. The obtained stable ferrofluid was used for characterization and MRI testes in this work.

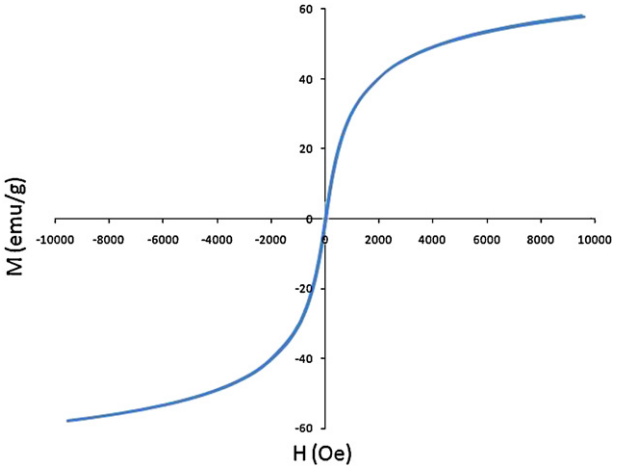

Fig. 2. VSM plot of the sample showing superparamagnetic behavior of synthesized nanoparticles.