MAGNETIC NANOPARTICLES FOR HYPERTHERMIA APPLICATIONS

Mohamed DARWISH and Ivan STIBOR

Institute for Nanomaterials, Advanced Technology and Innovation, Technical University of Liberec, 461 17Liberec, Czech Republic, Mohamed.Darwish@tul.cz, Ivan.Stibor@tul.cz

Abstract

Magnetite and magnetic pentenoic acid nanoparticles were prepared by using co-precipitation process of Fe^{2+} and Fe^{3+} in the presence of ammonium hydroxide solution. The prepared magnetic nanoparticles were characterized by fourier transform infrared (FTIR), scanning electron microscopy (SEM), thermogravimetric analysis (TGA), vibrating sample magnetometer (VSM) and heating properties. When an alternating magnetic field is applied, magnetic materials are observed to heat as a result of losses and relaxation. The heat generated from samples was evaluated by exposing 20% and 30% magnetic particle suspension dispersed in distilled water an alternating current (AC) magnetic field for certain time. The comparative temperature rise of the magnetic nanoparticles against the exposure time (1-6 minute) in an AC field. Specific absorption rate (SAR) of the prepared magnetic nanoparticles finds out there promising applications in hyperthermia and to future work for binding drug on the surface of magnetic carrier.

Keywords: Magnetic nanoparticles, induction heating, hyperthermia

INTRODUCTION

Magnetic nanoparticles have attracted much interest because they are considered as a material with non-toxicity and biological compatibility. Supermagnetic nanoparticles show magnetism in the presence of an external magnetic field and do not retain any residual magnetism upon removal of the external magnetic field. The magnetic induction heating behavior of magnetic particles provides a benefit for biomedical applications, such as targeted drug delivery [1]. Magnetic nanoparticles (MNPs) transform the energy of the magnetic field into heat through two kinds of relaxation: Neel relaxation and Brownian relaxation [2]. The efficiency of the energy transformation is dependent on the strength and frequency of the magnetic field and the properties of the magnetic particles like mean size, width of size distribution, particle shape and crystallinity [3]. Conversion of dissipated magnetic energy into thermal energy in magnetic nanoparticles have great application within cancer. Artificially inducing hyperthermia to kill cancer cells by raising the temperature of a region of the body affected by cancer to 42-46°C locally without affecting the nearby healthy tissue [4].

The co-precipitation process is considered one of the easier and economic procedure for preparation of magnetic nanoparticles by precipitation of magnetic nanoparicles occurs in solution media. The size and the morphology of the prepared magnetic nanoparticles strongly depend on the type of iron salts used, the reaction temperature [5]. Magnetic nanoparticles tends to aggregate due to the presence of high surface energy between nanoparticles. One of the efficient methods not only decreasing aggregation among nanoparticles but also providing of functional groups on the surface of magnetic NP by the addition of a polymer layer on the surface by in situ preparation. Several types of organic layer capped superparamagnetic iron oxide nanoparticles were prepared by co-precipitation methods and used for hyperthermia therapy. Oleic acid and citric acid have been described in the literature [6-7]. Coatings by polymer layer on the surface of magnetite nanoparticles provides colloidal stability in water with surface functionality, allowing binding other molecules as drugs and therapeutic agents. In this study, magnetic nanoparticles were prepared by co-precipitation of Fe^{2+} and Fe^{3+} in the presence of basic medium. The prepared magnetite nanoparticles were characterized by IR, TGA, SEM, VSM and heating properties.

Heating properties of the prepared magnetic nanoparticles found out here are promising for application in hyperthermia.

1. EXPERIMENTAL WORK

1.1. Materials

Iron (III) chloride hexahydrate ($FeCl_3.6H_2O$), Iron (II) chloride tetrahydrate ($FeCl_2.\ 4H_2O$), ammonium hydroxide (26% NH_3 in H2O) and 4-pentenoic acid were purchased from Fluka AG and used as received.

1.2. Preparation of magnetite nanoparticles

Fe^{3+}/Fe^{2+} (molar ratio 2:1) were dissolved in distilled water (100 ml) and heated to 70 °C. Ammonium hydroxide (6 ml) was added quickly to the solution, which immediately produced deep black magnetite precipitates. The suspension was stirred for another 30 min at 70 °C to evaporate any trace ammonium salts. The product was washed several times with distilled water and after that, magnetite nanoparticles were dried in rotary evaporator at 40 °C, (25 mbar, 80 rpm) until forming the fine powder.

1.3. Preparation of magnetic pentenoic acid nanoparticles

1.9 g $FeCl_2 \cdot 4H_2O$ and 5.4 g $FeCl_3 \cdot 6H_2O$ are dissolved in 100 ml distilled water with mechanical stirrer for 1hr. 4g pentenoic acid is dissolved in 50 ml distilled water with mechanical stirrer for 1hr. A second solution was added to first solution and heated to 70 °C with mechanical stirrer for 1hr. 6 ml of ammonium hydroxide is added quickly to the resulting solution, producing deep black magnetite precipitates at once. The suspension has been stirred for another 30 min at 70 °C and finally washing several times with distilled water, magnetite nanoparticles were dried in rotary evaporator at 40 °C, (25 mbar, 80 rpm) until forming the fine powder.

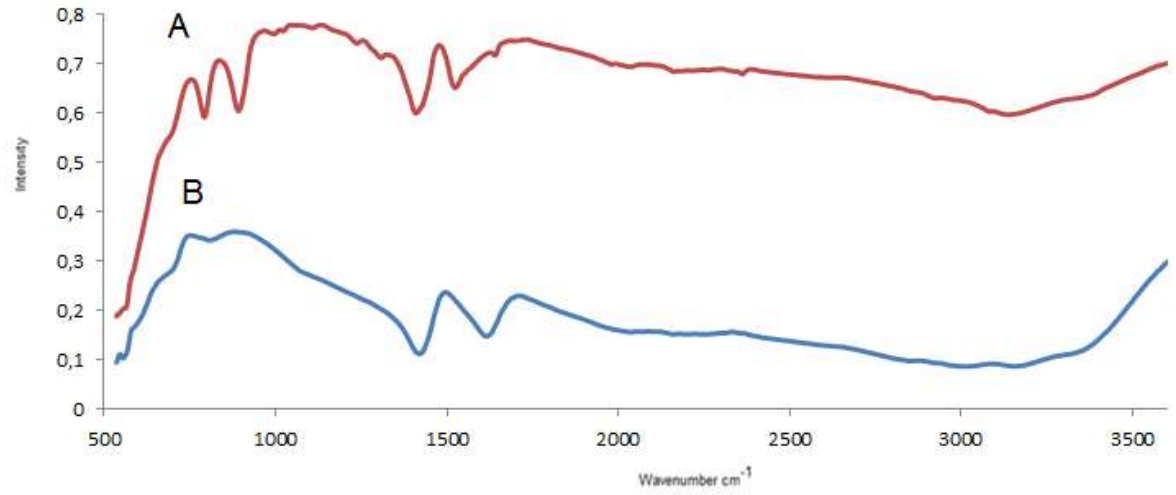
1.4. Characterizations

Fourier Transform Infrared (FTIR) was performed by bruker tensor 27 Infrared Spectrometer. Electron Microscopy images were obtained by FE-SEM (Zeiss ULTRA Plus equipped with a Schottky cathode) and software Smart SEM v5.05 (by Zeiss) for imaging operated at 1.5 kV. Magnetic properties were measured by vibrating sample magnetometer (VSM). Thermogravimetric Analysis (TGA) was measured by TA Instruments Q500. Heating properties were measured by Cheltenham induction heating limited with constant frequency (142 kHz) and power (0.1 KW) and the temperature was measured by infrared thermometer.

2. RESULT AND DISCUSION

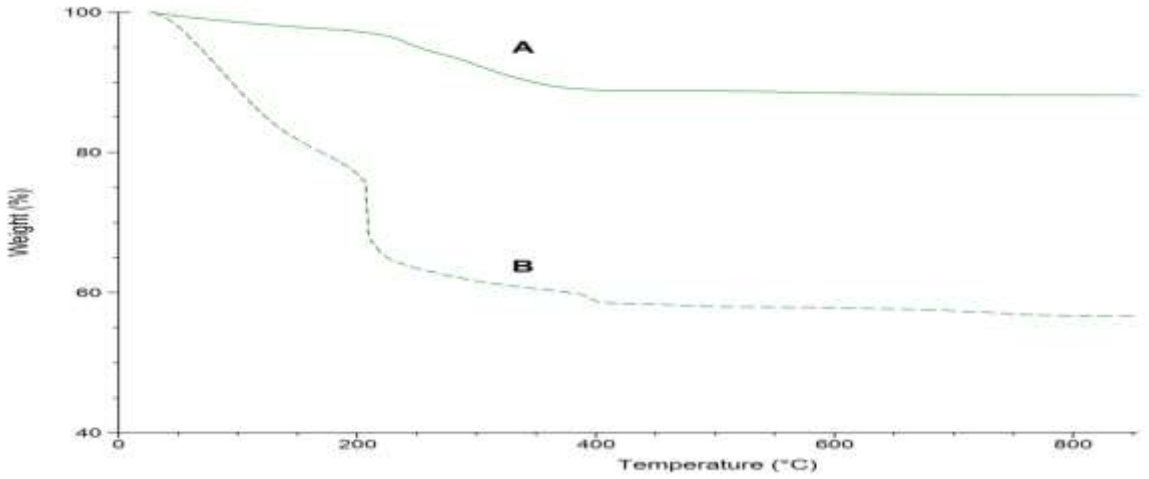
Magnetite and magnetic pentenoic acid nanoparticles were prepared by co-precipitation. This method consists of mixing ferric and ferrous ions in a 1:2 molar ratio in concentrated ammonium hydroxide solution at 70^0C temperature.

The presence of functional groups on the surface of the magnetite nanoparticles were detected by IR (Fig.1). Absorption weak peak at 550 cm^{-1} was corresponding to the Fe–O vibration related to the magnetite phase. Band at 3400 cm^{-1} was assigned to O–H stretching vibration. C-O stretch of carboxylic acid band appears in region 1310-1220 cm^{-1} and for =CH bend at 990 cm^{-1}, which indicates of presence of pentenoic acid on the surface of magnetite nanoparticles.



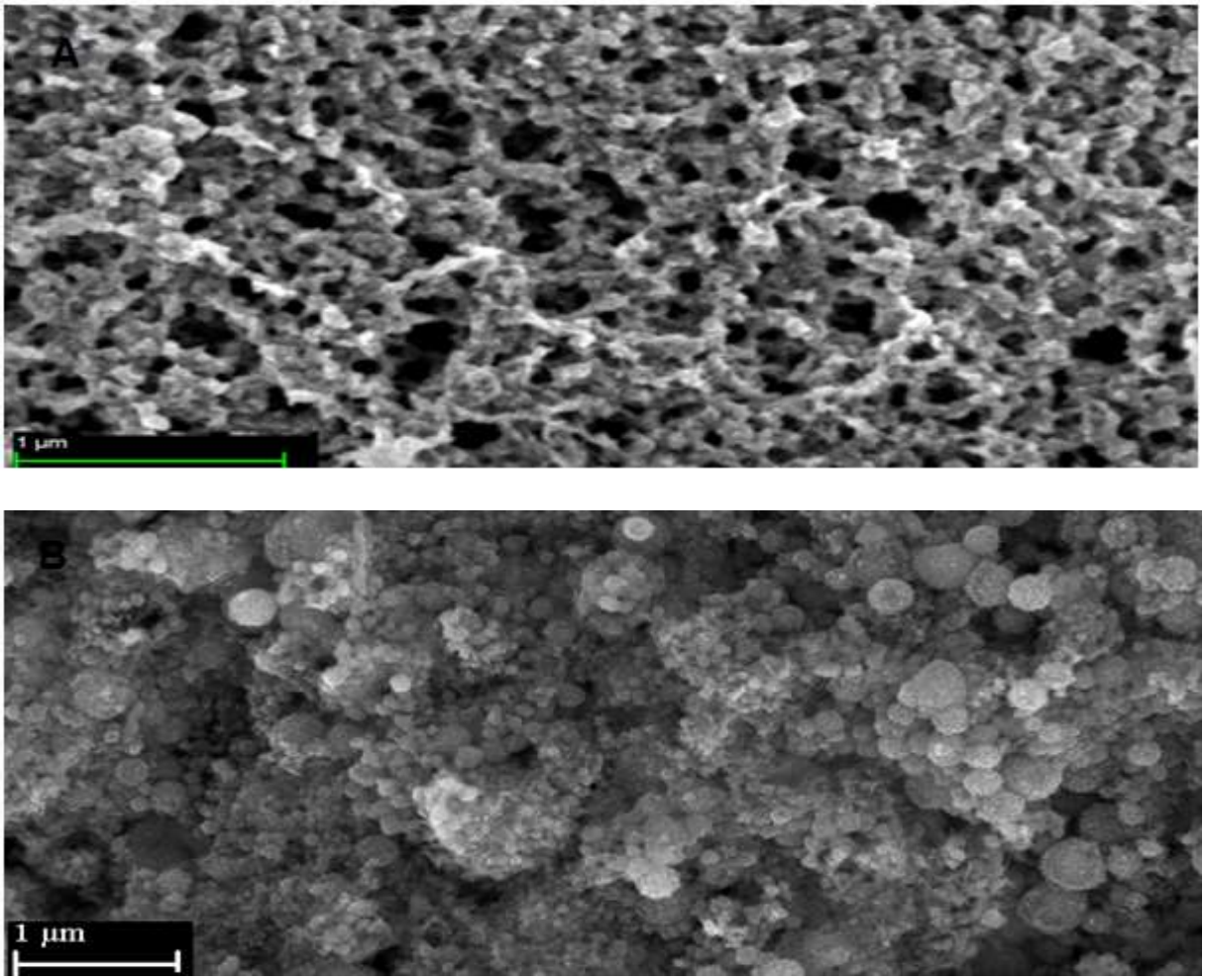
(Fig. 1) IR of (A) magnetic pentenoic acid nanoparticles and (B) magnetite nanoparticles

The stability of magnetite nanoparticles and magnetic pentenoic acid nanoparticles was measured as a function of temperature by the TGA (Fig.2). Weight loose until 200^{0}C is mainly related to loosing of water and physical adsorbed layer of pentenoic acid. Above 200^{0}C occur decomposition of chemical layer bonding of pentenoic acid. Above 400^{0}C magnetic pentenoic acid nanoparticles shows higher residual and stability than magnetite nanoparticles, which related mainly to the presence of pentenoic acid layer.



(Fig. 2) TGA of and (A) magnetic pentenoic acid nanoparticles (B) Magnetite nanoparticles

The morphology of magnetite and magnetic pentenoic acid can be seen in SEM pictures. It was observed magnetite particles with a broad size distribution and that are usually agglomerated, even after surface modification as shown in (Fig.3).

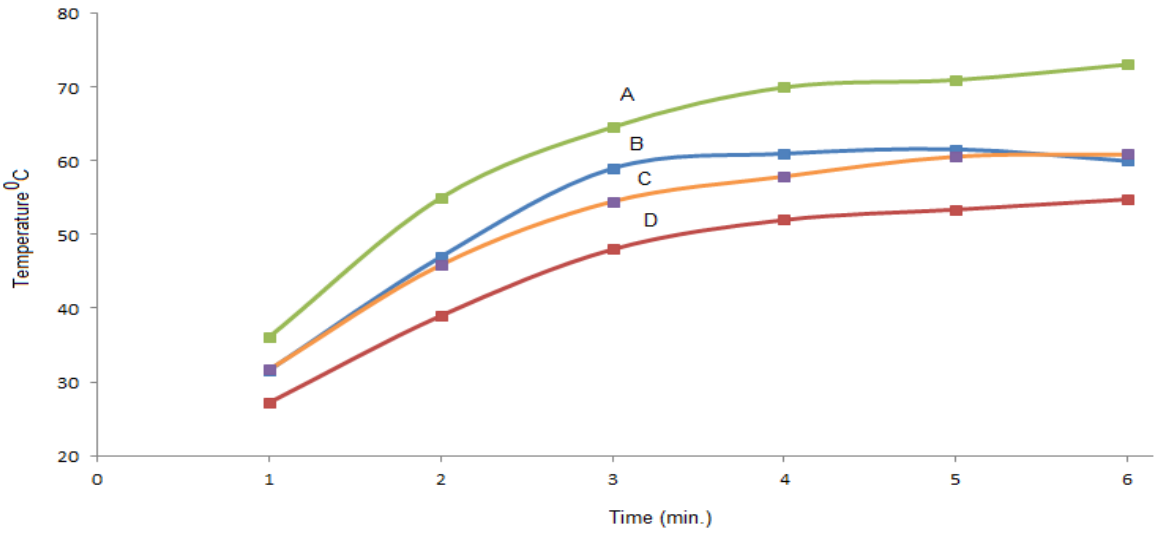


(Fig. 3) SEM of and (A) Magnetite nanoparticles (B) magnetic pentenoic acid nanoparticles

Magnetization saturation (Ms) is the maximum possible magnetization, whereby an increase in magnetic field, no changing in magnetization and become saturated. The magnetic properties of the prepared magnetite nanoparticles were investigated with VSM at room temperature. The values of Magnetization saturation (emu/g) found are 32,3 and 24,4 for magnetite nanoparticles and magnetic pentenoic acid nanoparticles respectively. The value of magnetic pentenoic acid nanoparticles is less than the values for uncoated magnetite nanoparticles due to the disordered surface spins as well as disordered magnetic structure [8].

2.1. Heating properties

When an alternating magnetic field is applied, magnetic materials are observed to heat as a result of losses occurring due to the internal rotation of the magnetization and the rotation of the MNP in a viscous medium. The heat generated from samples was evaluated by exposing 20% and 30% magnetic nanoparticle suspension dispersed in distilled water an alternating current (AC) magnetic field for certain time. The comparative temperature rise of the magnetic nanoparticles against the exposure time (1-6 minute) in an AC field. Also, it was obvious rise of temperature by increasing in concentration of samples from 20% to 30% as shown in (Fig.4). In induction heating curves of nanoparticles it is seen that the heating temperature increases with increasing time until reaches equilibrium, where the heating rate become to equal to the cooling rate. It was observed that the prepared magnetic nanoparticles under of applied magnetic field the temperature can reach to 45 ^{0}C, which is sufficient for cancer treatment.



(Fig. 4) Heating properties of Magnetite nanoparticles (A) 30%,(C)20% and Magnetic pentenoic acid nanoparticles (B) 30%, (D) 20%

CONCLUSIONS

Co-precipitation method is an efficient and economical method for preparation of one-pot functionalized magnetic nanoparticles. Heating properties of nanoparticles synthesized are promising. Such material could find application in hyperthermia drug release.

ACKNOWLEDGEMENTS

The results of this project LO1201 were obtained through the financial support of the Ministry of Education, Youth and Sports in the framework of the targeted support of the "National Programme for Sustainability I", the OPR&DI project Centre for Nanomaterials, Advanced Technologies and Innovation CZ.1.05/2.1.00/01.0005 and the Project Development of Research Teams of R&D Projects at the Technical university of Liberec CZ.1.07/2.3.00/30.0024.

LITERATURE

[1] CAO, J., WANG, Y.,YU, J., XIA, J., ZHANG, C., YIN, D., URS, U., HAFELI, O., Preparation and radiolabeling of surface-modified magnetic nanoparticles with rhenium-188 for magnetic targeted radiotherapyJ. Magn. Magn. Mater., 2004, 277, 165

[2] DEBYA, P. Polar Molecules, Chemical Catalog Company, New York, 1929.

[3] MA, M., WU, Y., ZHOU, J., SUN, Y., ZHANG, Y., GU, N. Size dependence of specific power absorption of Fe_3O_4 particles in AC magnetic field. J Magn Magn Mater, 2004, 268(1–2), 33–39

[4] ROSI, N., MIRKIN, C. Nanostructures in biodiagnostics, Chem Rev, 2005,105, 1547–1562,.

[5] AN-HUI, L., SALABAS, E., SCHUTH, F., Magnetic Nanoparticles: Synthesis, Protection, Functionalization, and Application: Review, Angewandte Chemie International Edition, 2007,46, 1222–1244

[6] JADHAV, V., PRASAD, A., KUMAR, A., Mishrab, R., Dharad, S., BABU, K., PRAJAPAT, C.,MISRAD, N , NINGTHOUJAMB, R., PANDEY, B. VATSA R., Synthesis of oleic acid functionalized Fe_3O_4 magnetic nanoparticles and studying their interaction with tumor cells for potential hyperthermia applications, Colloids and Surfaces B: Biointerfaces, 2013, 108,158–168

[7] CHERAGHIPOUR E., JAVADPOUR, S., MEHDIZADEH, A., Citrate capped superparamagnetic iron oxide nanoparticles used for hyperthermia therapy, J. Biomedical Science and Engineering, 2012, 5, 715-719

[8] QU, J., LIU, G., WANG, Y., HONG, R.Preparation of Fe_3O_4–chitosan nanoparticles used for hyperthermia, Adv. Powder. Technol, 2010, 21, 461–467.