

Synthesis of Fe₃O₄ nanoparticles for biomedical applications

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Abstract. Nano particles of Fe₃O₄ with the range of 6.9 and 14.2 nm. By using chemical coprecipitation method. Particle size effect according to magnetic properties were investigated together with the constant reaction and crystallization temperature. According to calculations peaks were indexed as cubic Fe₃O₄ for all samples. The hysteresis loops shows superparamagnetic nature. It was found that when Fe²⁺/Fe³⁺ ratio increase 50% the particle size increases approximately one fold. We also realized that chemical coprecipitation method is suitable for biomedical applications of Fe₃O₄ nano particles.

1.Introduction

Since fully exterminate of cancer cell is indispensable for accomplished treatment, total excision is the treatment of choice if possible. Depending on the location and the involvement of the tumor with surrounding tissues, surgery may not always be possible. Under these conditions, chemotherapy or radiotherapy becomes necessary. However, both therapy methods have been reported that have severe complications during treatment. They may harmful for the intact cells can be destroying them after several seance. Therefore the development of new techniques is inevitable. At the same time that could selectively carry molecules of the drugs to the diseased area without giving harm to the healthy tissues.

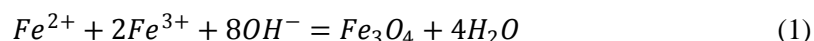
Recently developed nano medical technologies are suitable candidates particularly for cancer research. It has been easily used for examining and treating cancer cells because the excellent characteristics of nano scale particles may improve the medical effect of traditional chemotherapy or radiotherapy methodologies largely. Due to the high biosafety, easy availability, controllable and examinable characteristics according to other nanoparticles, magnetic iron oxide (Fe_xO_y) have been widely used in clinical applications in last decade [1-5]. For immunoassays, involving the use of magnetic nano reagents (MNR), which consist of bioprobe-coated MNP and liquid solvents, several magnetic technologies have been developed to improve the performance relative to the performance of current clinical methods such as the enzyme-linked immunosorbent assay (ELISA) and others [1]. Today many formation and fabrication methods have been examined to obtained sub-nano magnetic particles. such as micro-emulsion, and poly-process [6-8] and especially chemical coprecipitation, which is increasingly popular due to its simplicity, inexpensive equipment and potential for large scale production [9]. Particularly, particle size of 2 - 15 nm is found to be the best for clinical



applications, mainly for cancer treatments. However, methods of fabrication are generally getting difficult and onerous and needs too much attention to obtain physically and magnetically in good properties. In this work, we have focused on the fabrication of nano particles and effect of particle size on the physical, magnetic and electrical properties and results obtained are reported.

2. Experimental

In this work the Fe_3O_4 nanoparticles were prepared by chemical coprecipitation method similar to previously obtained research groups [9-11]. The starting materials were $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$, $\text{FeCl}_2 \cdot 4\text{H}_2\text{O}$ and $\text{NH}_3 \cdot \text{H}_2\text{O}$ (Alfa Aesar). A ferric salt solution and a ferrous salt solution were prepared from $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$, $\text{FeCl}_2 \cdot 4\text{H}_2\text{O}$ and deionized water. Then those two solutions mixed and heated to reaction temperature. Then the precipitant of $\text{NH}_3 \cdot \text{H}_2\text{O}$ solution was added into the mixed solution under high speed stirring (1000 rpm) for 25 min until pH 5 value. After that, sodium oleate containing approximately 22 wt % Fe_3O_4 was introduced in deionized water with an ultrasonic mixer. Then this solution was added into the reaction solution which was adjusted to pH 5 under stirring with 1000 rpm at room temperature. At the end 40-min crystallization at 125°C was carried out, followed by washing and freeze-drying. The chemical coprecipitation can be expressed as [6];



By using Eq.1, the pH value of the reaction was chosen to be 10 and the reaction temperature was 60°C when Fe^{2+} precipitated completely. We used $\text{NH}_3 \cdot \text{H}_2\text{O}$ as the precipitant to avoid rapid nucleus growth. The $\text{Fe}^{2+}/\text{Fe}^{3+}$ ratio was chosen between 0.6-0.9 and concentration of ferric salt solution was set at 0.16 mol/L as constant. The drying process was performed in vacuum oven to avoid oxidizing of Fe^{2+} . For structural analysis, X-ray Diffractometer (XRD), a Rigaku Dmax2 diffractometer with $\text{Cu K}\alpha$ radiation ($\lambda = 1.5406 \text{ \AA}$) in the 2θ range from 20° to 80° with scanning rate of $0.2^\circ/\text{s}$ was used. Magnetic properties were carried out using Vibrating Sample Magnetometer (Quantum design VSM-9T) between $\pm 9 \text{ T}$. Fourier transformed Infrared Spectrometer was used to identify the bond structure.

3. Result and Discussion

The results obtained and parameters used are summarized in Table 1. According to our experimental set up the best pH value was found to be 10 and during the experiments pH was set to constant value 10. However we know that the pH is an important factor for the chemical preparation of materials and the effect of pH on the materials is in progress however there exist valuable results in the literature explain the effects of pH for the nanomagnetic particles [12]. Figure 1 shows the XRD patterns of the Fe_3O_4 samples A1 and A4 with $\text{Fe}^{2+}/\text{Fe}^{3+}$ ratio 0.6 and 0.9 respectively. As seen in Figures 1a and b, no impurities or secondary phase peaks were found in samples. According to calculations peaks were indexed as cubic Fe_3O_4 for all samples. However, intensity of the peaks is slight decreased and widened when average particle size decreased as expected.

Table 1. Summary of parameters used and results obtained.

Sample no	pH	$\text{Fe}^{2+}/\text{Fe}^{3+}$	Ferric salt Con. (mol/L)	Reaction Temp. ($^\circ\text{C}$)	Cryst. Temp. ($^\circ\text{C}$)	Average Particle size (nm)	Mag. (emu/g)	Room temp. Res. (ohm)
A1	10	0.6	0.16	60	75	6.9	3.1	1.0
A2	10	0.7	0.16	60	75	8.6	6.8	1.0
A3	10	0.8	0.16	60	75	10.8	11.4	1.2
A4	10	0.9	0.16	60	75	14.2	15.7	1.3

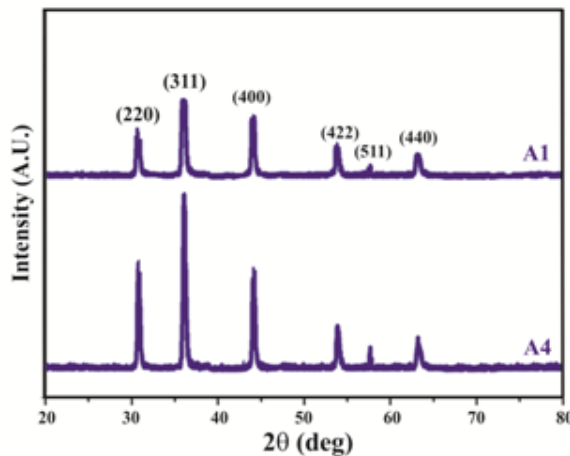


Figure 1. XRD results of a) sample A1 with particle size 6.9 nm and b) A4 14.2 nm.

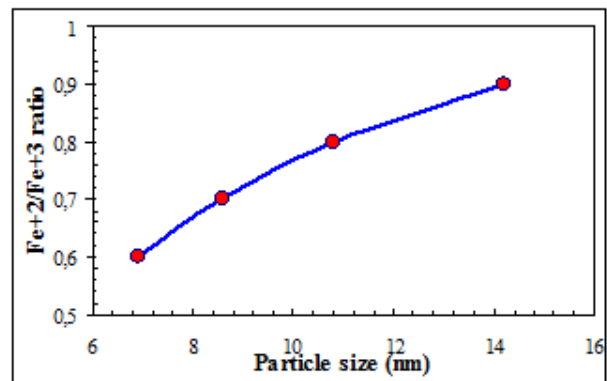


Figure 2. Particle size versus $\text{Fe}^{2+}/\text{Fe}^{3+}$ ratio of the samples prepared.

The grain size of the samples prepared was determined by using Scherer equation [12-14];

$$d = \frac{0,89\lambda}{B \cos \theta} \quad (2)$$

where, λ is the X-ray wavelength ($\text{Cu}_{\text{K}\alpha}=1.5406\text{\AA}$), θ is the peak position and B is the peak full width at half-maximum intensity ($FWHM$). According to calculations with Eq.1 the size of the particles were found between 6.9 and 14.2 nm, Table 1. The results obtained showed that $\text{Fe}^{2+}/\text{Fe}^{3+}$ ratio is playing a crucial role for the particle size. After third repeat of experiments we noticed that when $\text{Fe}^{2+}/\text{Fe}^{3+}$ ratio increase the average particle size increases, Table 1 and Figure 2. As seen in Figure 2 when $\text{Fe}^{2+}/\text{Fe}^{3+}$ ratio increase 50% the particle size increases approximately one fold. According to applications, for the biomedical use of these magnetic powders, needs to have particle size of less than 40 nm. Thought result obtained here in this work is reasonable at this stage. However, the effect of ferric salt concentration and reaction temperatures on the particle size and the magnetic properties is under progress.

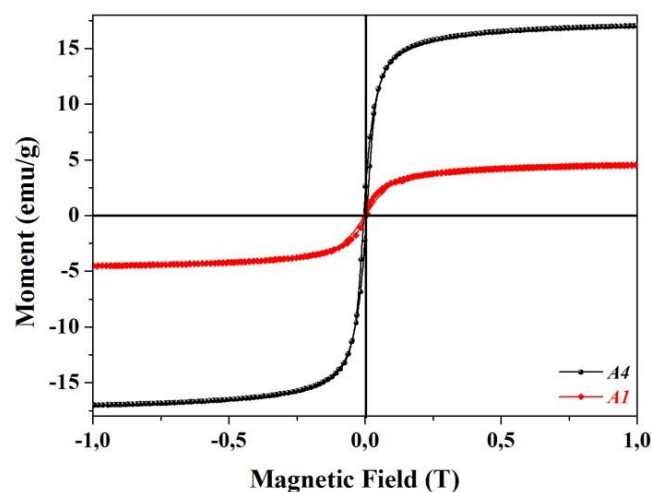


Figure 3. M-H curves of the sample A1 and A4 at room temperature.

Figure 3 shows the magnetization versus magnetic field graphs of sample A1 and A4. The hysteresis loops shows superparamagnetic nature. For both cases low saturation magnetization obtained and they showed no remanence, which is the typical property of Fe_3O_4 metallic samples. The saturation points were obtained at 3.1 and 15.7 emu/gr for A1 and A4 samples respectively indicates particle size effect for the magnetic properties of the samples prepared. Samples with small particle size showed low magnetization than the large particle samples. Figure 4.

Figure 5 shows the FT-IR graph of sample A4. All samples were showed similar trend and well known Fe-O vibration modes, 587, 1384 and 800 cm^{-1} of Fe_3O_4 were obtained. Whereas the peaks obtained at 1633 and 3408 cm^{-1} are attributed to the stretching vibrations of $-\text{OH}$ and $\text{OH}-$ absorbed Fe_3O_4 nano particles as obtained previously by other research groups [9, 12]. We did not obtain any other peaks between 1650 and 3400 cm^{-1} as obtained previously and assigned to the $-\text{CH}$, $-\text{C H}_2$ and $-\text{CH}_3$ [9,15].

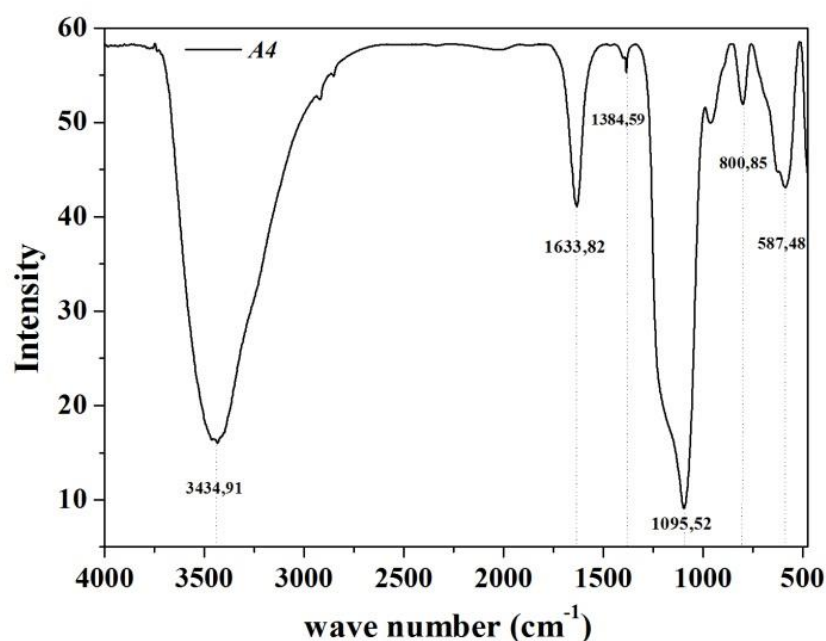


Figure 4. FT-IR graph of sample A4 at room temperature as an example.

4. Conclusion

We have successfully prepared high purity Fe_3O_4 nano particles using chemical coprecipitation method with particle size between 6.9 and 14.2 nm for biomedical applications. We found that particle size effective on the magnetic properties of the Fe_3O_4 nano material and this properties will be very important for the medical processes particularly for the cancer treatment of the defective cells. It was considered, according to magnetic properties of the prepared samples, the heat capacity of the small particles will be suitable for the heat absorption even during the small magnetic field applications than the larger particles. We did not get any different result on the room temperature resistance which is a positive effect for applications. We realized that chemical coprecipitation method is a suitable method for spherical and subnano Fe_3O_4 particles.

References

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