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Synthesis and Specific Absorption Rate of Fe_3O_4 Nanoparticles

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Abstract: ***The sample of Fe_3O_4 magnetic nanoparticles (MNPs) was synthesized via co-precipitation method from ferrous and ferric solutions. X-ray diffraction (XRD) used to characterize the powder synthesized of Fe_3O_4. The average lattice parameter and the average size of Fe_3O_4 MNPs were a = 8.3 Å and t= 9.8 nm. Induction heater operated at low frequencies 100 kHz was used to study the heating rate ($\Delta T/\Delta t$ ^oC/ sec) and the specific absorption rate (SARW. g^{-1}) of the Fe_3O_4 MNPs and were found to be 0.025 ^oC/ sec and 105 W. g^{-1} respectively.***

Keywords: Magnetic nanoparticles, hyperthermia

1. Introduction

The capability of magnetic nanoparticles (MNPs) to act as effective heating agents for magnetic hyperthermia (MH) was demonstrated many years ago [1].

Fe_3O_4 MNPs have attracted much interest in the field of magnetic recording media such as audio and videotape, and high-density digital recording disks, data storage, magnetic fluids. Fe_3O_4 MNPs also used in the areas of medical care such as drug delivery systems (DDS), medical applications including radiofrequency hyperthermia (RFH), photo magnetic (PM), and magnetic resonance imaging (MRI), medical diagnostics, cancer therapy, microwave devices, magneto-optics devices, sensors, high and low frequency applications. Several studies have shown the Fe_3O_4MNPs energy absorption in alternative current magnetic field (ACMF) [2].

2. Experimental details

2.1 Sample preparation

Fe_3O_4 prepared by co-precipitating aqueous solutions of $(NH_4)_2$ $Fe(SO_4)_2$ and $FeCl_3$ mixtures, respectively, in alkaline medium (Fe^{+2}: Fe^{+3} = 1:2). The mixture is kept at 80 ^oC. This mixture is added to the boiling solution of NaOH (0.5 mol. is dissolved in 600 ml of distilled water) within 10 second under constant stirring. Magnetite is formed by conversion of metal salts into hydroxides, which take place immediately, and transformation of hydroxides into ferrites. The solution is maintained at 100 ^oC for 1.5 h. The Fe_3O_4 particles are washed several times by distilled water, the Fe_3O_4 particles are just dried at 100 ^oC for 1h [2,3].

2.2 X-ray diffraction

The Shimadzu X-ray Diffractometer (XRD-6000) in Department of Physics, King Fhad University of Petroleum and Minerals, Kingdom of Saudi Arabia was used in this study. The XRD-6000, an X-ray diffractometer analyzed crystalline states under normal atmospheric conditions. This method is nondestructive. X-rays focused on a sample fixed on the axis of the spectrometer (goniometer) were diffracted by the sample. The changes in the diffracted X-ray intensities measured, recorded and plotted against the rotation angles of the sample. The result is referred to as the XRD pattern of the sample. Computer analysis of the peak positions and intensities associated with this pattern enables qualitative analysis, lattice parameter determination and/or stress determination of the sample. Qualitative analysis may be conducted on the basis of peak height or peak area. The peak angles and profiles may be used to determine particle diameters and degree of crystallization, and are useful in conducting precise X-ray structural analysis. The XRD-6000 will accept various types of X-ray tubes, our sample of Fe_3O_4 analyzed by the standard Cu X-ray tube.

2.3 Induction heater

An induction heater operated at low frequencies and low powers (100 kHz and 100 W), was used to study the heating rate ($\Delta T/\Delta t$ ^oC/ sec) and the specific absorption rate (SAR W. g^{-1}) of the Fe_3O_4 MNPs was prepared previously.

3. Result and Discussion

3.1 Sample characterizations

The sample of Fe_3O_4 prepared, as described in the previous was characterized by X-ray diffraction (XRD) in the 2θ range from 10 to 80 degrees. The obtained result is shown in fig.1.

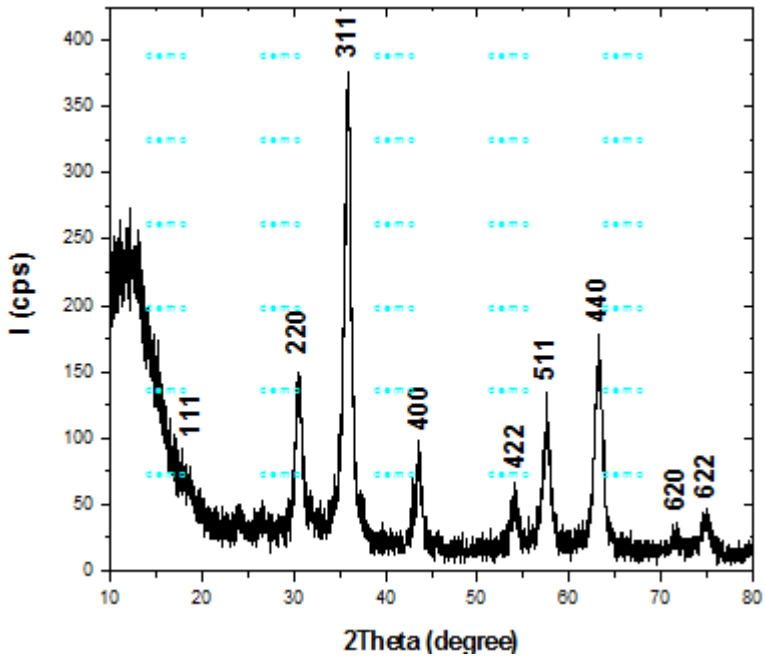

Figure 1: XRD for Fe_3O_4

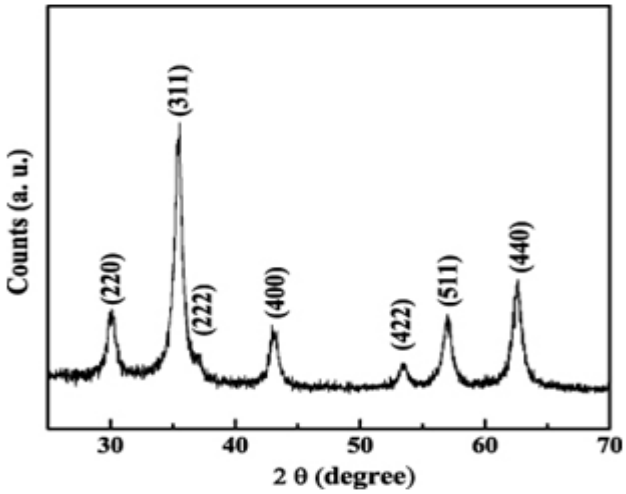

Figure 2: XRD for Fe_3O_4 [4]

Table 1: The parameters of the three strongest peaks

No	2 theta (deg.)	d (Å)	FWHM (deg.)	*t* nm	*hkl*	a(Å)
1	35.8583	2.50227	0.85940	9.80	2 1 1	8.299
2	63.1667	1.47077	0.92000	10.2	4 4 0	8.320
3	30.4993	2.92862	0.89470	9.30	2 2 0	8.283

To determine the prepared sample of Fe_3O_4size "t", the interplanar distance of the crystal "d_{hkl}" and the lattice parameter "a" from the XRD data, the peaks positions and the full width at half maximum of the three strongest peaks, shown in table1, are substituted in the Scherrer's formula (1) and Bragg's equation (2) are given by

$$t = \frac{K\lambda}{B\cos\theta} \qquad (1)$$

$$d_{hkl} = \frac{\lambda}{2\sin\theta} \quad ,, \quad d_{hkl} = \frac{a}{\sqrt{(h^2+k^2+l^2)}} \qquad (2)$$

Where; t is the thickness of the crystallite, a is the lattice parameter, *hkl* are Millar's indices, d_{khl} is the interplanar distance of the crystal, K~ 0.9 is constant depend on the crystallite shape, λ = 1.456 Å is x-ray wavelength of the Cu target, B is full width at half maximum (FWHM) and θ_B is Bragg's angle [2, 5, 6].

The XRD patterns indexing of the prepared Fe_3O_4showed that this sample is cubic with average lattice parameter is 8.3 Å and the average size is 9.8 nm. The crystal structure, the size and the lattice parameter in good agreement with published data fig.2. Such a small size indicates that the Fe_3O_4 sample is the magnetic nanoparticles MNPs [4].

3.2The SAR of Fe_3O_4 MNPs suspension

To determine the heating rate $\Delta T/\Delta t$ and specific absorption rate SAR value of the Fe_3O_4 MNPs, a suspension of 1ml de-ionizing (DI) water + 1mg Fe_3O_4 MNPs was prepared.

First, 1 ml of DI water was exposed to the magnetic induction and no change on the temperature is noted. Then, 1 mg of Fe_3O_4 MNPs was added to 1ml DI water and exposed to the same magnetic induction; the temperature is seen to increase with the time. After 35 minutes the temperature reached 46^{o}C and remained constant up to 60 minutes exposure to the magnetic induction heating. The temperature no longer changed over time when it reached to a certain value because the heat generated by the absorbed electromagnetic energy of Fe_3O_4 and the heat released towards the environment were equal that is shown in fig.3 [7, 8].

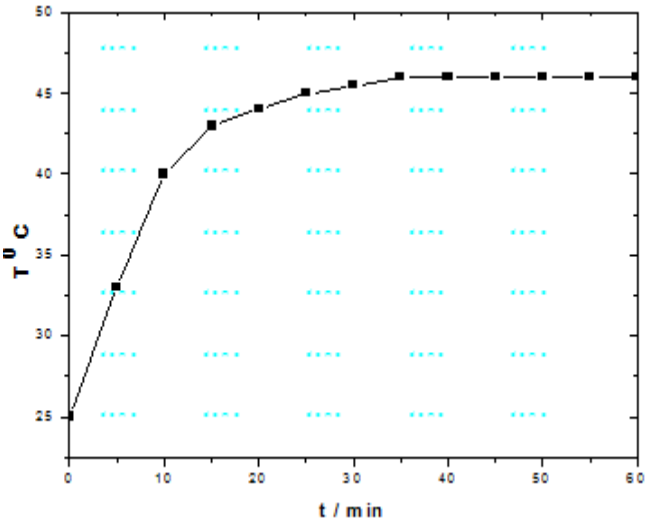

Figure 3: Fe_3O_4 heating rate

The SAR value can be calculated by the following equation

$$SAR = C \frac{\Delta T}{\Delta t} \frac{1}{m_{ferrite}} \quad (3)$$

Where; C= 4.185 J g $^{-1}$K $^{-1}$ is the sample specific heat capacity which is calculated as a mass weighed mean value of magnetite and water. $\Delta T/\Delta t$ = 0.025 ^{o}C/ sec is the initial slope of the time dependent temperature curve, m $_{ferrite}$ =1 mg is the ferrite content per mg of the sample tube [8].

There are as good as the linear relations in the first rising of the temperature fig.3. We used the linear relation in 0 – 10 minutes intervals for calculating the SAR values of the samples Fe_3O_4MNPs by equation (3). We find that the SAR value equal105 W. g $^{-1}$.

4. Conclusions

The average size and the lattice parameter of the Fe_3O_4 magnetic nanoparticles sample MNPs was prepared by co precipitation method were estimated to be 9.8 nm and 8.3 Å respectively.

The maximum temperature was 46^{o}C and the needed time to reach this temperature was 35 min with the concentration of 1.0 mg Fe_3O_4/ 1ml of deionizing water. The temperature no longer changed over time when it reached to a certain value. The specific absorption rate SAR and the heating rate$\Delta T/\Delta t$ values of the Fe_3O_4 MNPs were founded to be105 W. g $^{-1}$and0.025^{o}C/ sec, these values indicating to use this sample in the magnetic hyperthermia treatment MHT.

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