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Magnetic and thermal properties of $CoFe_2O_4$ nanoparticles for magnetic hyperthermia treatment

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ABSTRACT

The sample of $CoFe_2O_4$ magnetic nanoparticles (MNPs) is synthesized via co-precipitation method from ferrous and ferric solutions. Transmission Electron Microscopy (TEM) and X-ray diffraction (XRD) were used to characterize the powder synthesized from the sample. The average lattice parameter and the average size of $CoFe_2O_4$ were a = 8.4 Å and t = 13 nm. The magnetization measurements of $CoFe_2O_4$ at room temperature up to a maximum magnetic field (H) of 9000 (Oe) by using vibrating sample magnetometer (VSM) homemade and saturation magnetization (M_s = 48 emu/g), remanent magnetization (Mr = 10.8emu/g) and coercive force (Hc = 240 Oe) were evaluated. Induction heater operated at low frequencies 100 kHz was used to study the thermal properties of the $CoFe_2O_4$. The results shown; the maximum temperature (T = 59 °C), the heating rate ($\Delta T/\Delta t$ = 0.027 °C/sec) and the specific absorption rate (SAR = 224 W/g).

1. Introduction

The magnetic nanoparticles (MNPs) have attracted much interest not only in the field of magnetic recording media such as audio and video tape, but also in the areas of medical applications such as drug delivery systems (DDS), magnetic resonance imaging (MRI), medical diagnostics, cancer therapy and magnetic hyperthermia treatment (MHT).

MNPs can be heated by the energy absorption when it exposure on the alternative current magnetic field (ACMF). The capability of MNPs to effective heating agents for MHT was demonstrated many years ago (Elbeshir et al., 2013; Torres et al., 2010).

MHT is a type of the cancer treatment in which the target is exposed to a temperature ranges 42- 46 °C, which is found to be more effective to cancer cells than to normal cells. Thermal effect of MNPs can be used to achieve the above purpose of thawing or recovery of tumor hyperthermia. More importantly, the nanoparticles can be inserted into the tumor cells and kill cancer cells effectively without damaging normal cells after the cells are heated to a certain temperature and maintain certain time in certain conditions (Elbeshir et al., 2013; Torres et al., 2010).

MHT can be used alone to cancer tumor treatment or together with the radiotherapy or the chemotherapy or the surgery. The hazard and the side effect of the radiotherapy, chemotherapy and the surgery are greater than the MHT. The MHT depend on two mean branches; the first one depends on the MNPs itself like; the size, the concentration, the magnetic and the thermal properties, while the second one depends on the ACMF like the frequency, the intensity and the power (Elbeshir et al., 2013; El Ghandoor et al., 2012a).

2. Experimental procedures

2.1. Raw materials

The raw materials are $(NH_4)_2$ Fe $(SO_4)_2$, $CoSO_4.7H_2O$, $FeCl_3$ and NaOH. The chemical co-precipitation methods were used to synthesize the $Co_xF_{(1-x)}Fe_2O_4$ magnetic nanoparticles (MNPs), are published in references (Elbeshir et al., 2013; Torres et al., 2010; El Ghandoor et al., 2012a;b; Elbeshir, 2015, 2016a). In this work, the sample of $CoFe_2O_4$ (x=1) was studied.

2.2. XRD and TEM characterizations

The size of $CoFe_2O_4$was characterized by the x-ray diffraction (XRD) and transmission electron

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microscopy (TEM) (Torres et al., 2010; El Ghandoor et al., 2012a;b)

2.3. Magnetization measurements of CoFe2O4 MNPs

The magnetization measurements were done via the second parts of $CoFe_2O_4$ samples at room temperature up to a maximum magnetic field (H) of 9000 (Oe) by using vibrating sample magnetometer (VSM) home- madeand parameters like specific saturation magnetization (M_s), coercive force (H_c) and remanence (M_r) were evaluated.

2.4. The thermal properties of CoFe2O4 MNPs

An induction heater operated at low frequencies and low powers (100 kHz and 100 W), was used to study the thermal properties (the maximum temperature T °C, the heating rate ΔT/Δt °C/min and the specific absorption rate SAR W/g) of $CoFe_2O_4$ MNPs which was prepared previously (Elbeshir et al., 2013; Elbeshir, 2015; 2016a;b; Motoyama et al., 2008).

3. Result and discussion

3.1. XRD and TEM analyses

In this study we used the x-ray diffraction (XRD) and the transmission electron microscopy (TEM) analysis of $CoFe_2O_4$ (El Ghandoor et al., 2012b). The results are shown in Figs. 1 and 2 and Table 1.

3.2. Magnetic characterizations of CoFe2O4 MNPs

According to Table 1, M_s are obviously smaller than that of their bulk values, M_s^{bulk}= 90 emu/g for $CoFe_2O_4$ [240], which can be attributed to the disorder canting spins (spin-glass-like) on the surfaces due to the coordination- number imperfection (Calero-DdelC and Rinaldi, 2007; Kumar et al., 2008).

The present results are compared with the published results in Davis and Mott (1970), where (M_s = 45.3 emu/g, M_r =11 emu/g and H_c= 270 Oe) to have a wider view and a deeper insight into the results, and it is found that the present results similar or nearly similar to the published and are listed in Table 1.

According to Davis and Mott (1970) and by viewing Fig. 3, it is easy considering the sample as soft magnetic materials. MNPs are believed to be promising for wide medical applications, such as drug delivery, bio separation, magnetic resonance imaging and magnetic hyperthermia treatment MHT (Calero-DdelC and Rinaldi, 2007).

3.3. The thermal properties of CoFe2O4 MNPs

First, 1 ml of deionizing water (DI) was exposed to the magnetic induction and no change on the temperature is noted. Then, 0.5 mg of MNPs was added to 1ml DI water and exposed to the same magnetic induction. The temperature of the samples is seen to increase with time. After 35 minutes the temperature reached 50 °C and remained constant up to 60 minutes exposure to the magnetic induction heating. Fig. 4 and Table 2 show these results.

The SAR value can be calculated by the following equation:

$$SAR = C\frac{\Delta T}{\Delta t} \times \frac{1}{m_{ferrite}}$$

where, C is the sample-specific heat capacity which is calculated as a mass weighed mean value of magnetite and water.is the initial slope of the time-dependent temperature curve, $m_{ferrite}$ is the magnetite content per mg of the sample tube (Elbeshir et al., 2013; Torres et al., 2010).

There are as good as the linear relations in the first rising of the temperature. We used the linear relations in 0 –10 minutes intervals for calculating the SAR value of the sample. The heating rate ΔT/Δt = 0.027 °C/sec and the SAR= 224 W/g.

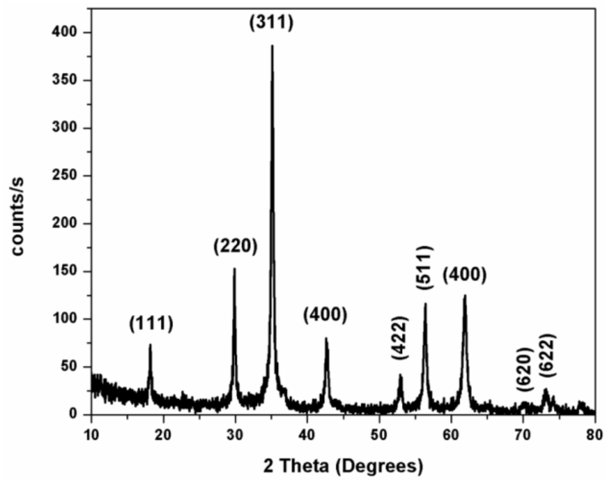

Fig. 1: XRD of $CoFe_2O_4$

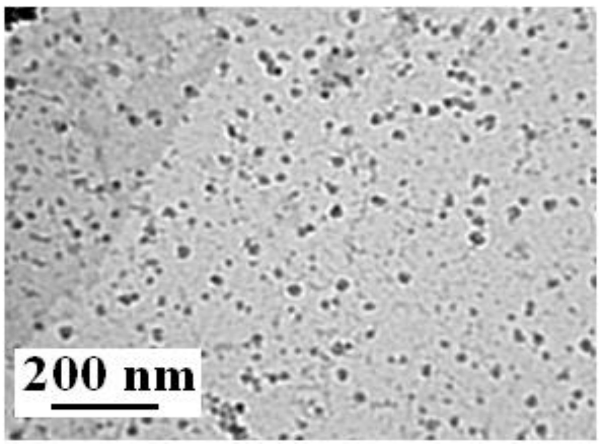

Fig. 2: TEM of $CoFe_2O_4$

4. Conclusion

The size of $CoFe_2O_4$ magnetic nanoparticles (MNPs) synthesized by chemical co-precipitation method after treatment at 100 °C was about 13 nm. XRD and TEM were used to characterize the size of $CoFe_2O_4$MNPs.

Table 1: The $CoFe_2O_4$ size estimated from XDR, TEM and magnetic properties

t (nm) estimated from XDR	t (nm) estimated from TEM	M_S (emu/g)	M_r (emu/g)	H_C (Oe)
12.1	14.76	48	10.8	240

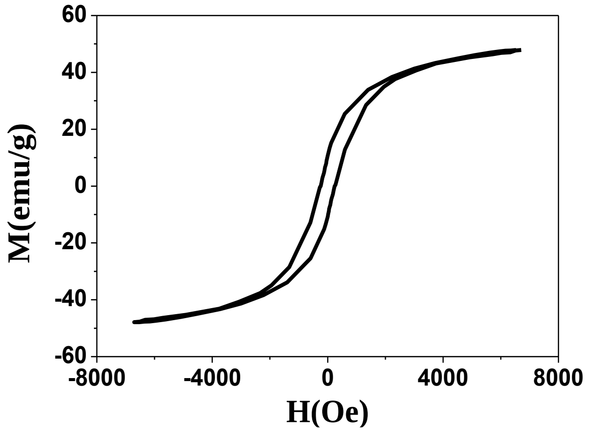

Fig. 3: (H Oe) and (M emu/g) of $CoFe_2O_4$ MNPs

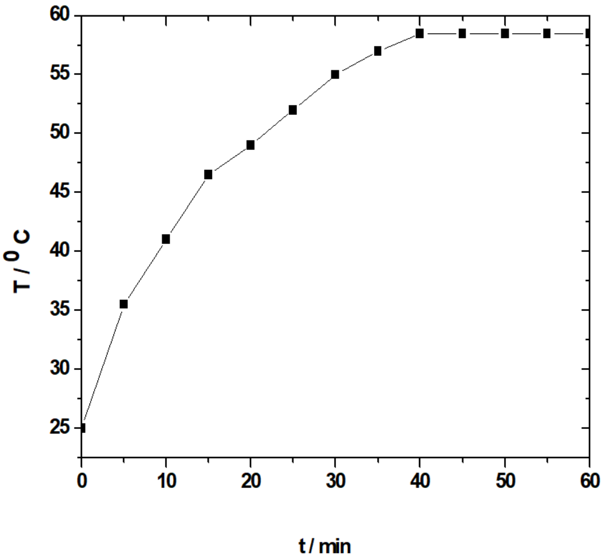

Fig. 4: $CoFe_2O_4$ MNPs heating rate

Table 2: The maximum temperature, heating rate and the specific absorption rate of 1.0 mg $CoFe_2O_4$ MNPs per 1 ml de-ionizing water

T (°C)	ΔT/Δ (°C/sec)	SAR (W/g)
59	0.027	224

VSM home-made was used to determine the saturation magnetization, remanent magnetization and coercive force, the results are: (Ms = 48emu/g, Mr = 10.8 emu/g and Hc = 240 Oe) respectively; of the $CoFe_2O_4$ MNPs.

The maximum temperature was 50°C and the needed time to reach this temperature was 35 min. with the concentration of 0.5 mg $CoFe_2O_4$/ 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 ΔT/Δt values of the $CoFe_2O_4$MNPs were founded to be 224 W/ g and 0.027 °C/sec respectively.

These values of the size, the thermal (energy absorption) and the magnetic properties of $CoFe_2O_4$ MNPs, indicate to use this sample in the magnetic hyperthermia treatment MHT.

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