The thermal properties and the energy absorption of $\alpha$-Fe$_2$O$_3$ nanoparticles at low frequency

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Abstract

The sample of $\alpha$-Fe$_2$O$_3$ synthesized via co-precipitation method. X-ray diffraction (XRD) used to characterized the powder synthesized of the $\alpha$-Fe$_2$O$_3$. The sample of $\alpha$-Fe$_2$O$_3$ was found as nanoparticle materials (NPs), which average size $t = 64.0$ nm. The maximum temperature was $46^\circ$C and the needed time to reach this temperature was 35 min with the concentration of 1.0 mg of $\alpha$-Fe$_2$O$_3$/1ml of deionizing water (DI). The heating rate ($\Delta T/\Delta t$ °C/sec) and the specific absorption rate (SAR W/g) of the $\alpha$-Fe$_2$O$_3$ NPs were found to be 0.03°C/sec and 126 W/g respectively.

Keywords: Magnetic nanoparticles, hyperthermia.

Introduction

Hyperthermia therapy (HT) 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[1,2].

The capability of magnetic nanoparticles (MNPs) to act as effective heating agents for magnetic hyperthermia treatment (MHT) was demonstrated many years ago. Iron oxide magnetic nanoparticles ($\alpha$-Fe$_2$O$_3$ MNPs) can improve cancer therapy by overcoming several limitations of conventional chemotherapy and hyperthermia. MNPs consisting of an iron oxide can be loaded with cytotoxic drugs, dispersed in a carrier fluid, injected into the bloodstream, and targeted to the tumor using an external magnetic field (MF). These particles release the drug following localization in the tumor, resulting in increased tumor drug concentration with minimal systemic toxicity. $\alpha$-Fe$_2$O$_3$ MNPs after localization generate heat, raising the temperature of the tumor and resulting in hyperthermia, If an alternating current magnetic field (ACMF) was applied. Several studies have shown the $\alpha$-Fe$_2$O$_3$ MNPs energy absorption in ACMF[2,3].

Experimental

The $\alpha$-Fe$_2$O$_3$ nanoparticles (MNPs) was synthesized by the following methodology. 0.7 M and 0.17 M of 1-butanol and n-octane were added into 10 ml of aqueous Cetyl Trimethyl ammonium bromide (CTAB) solution. 10 ml aqueous FeCl$_3$ (0.5M) and FeSO$_4$.7H$_2$O (0.25 M) solution were mixed to the micelles under magnetic stirring. The stirring was continued for 12 hours at the room temperature, resulting in the stabilization of reverse micelles solution. 5 ml of aqueous NaOH (0.2 M) solution was injected into the reverse micelles solution under magnetic stirring at 70 °C. The color of the solution instantly changed from brown to black after the injection and the product was separated by centrifugation using ethanol. The solid obtained after centrifugation was calcined at 300 °C for 4 h in air atmosphere. Color of the product was changed from black to reddish brown after calcination, which indicates the formation of single phase $\alpha$-Fe$_2$O$_3$ MNPs[4,5].

The X-ray diffraction patterns were recorded using Shimadzu (XRD-6000), target is Cu ($\lambda=1.4506$ Å), voltage is 40kV, current is 30mA. Divergence, scatter and receiving slit are 1 degree, 1 degree and 0.3 mm respectively. The range, mode and speed of scanning are 10 - 80, continues and 2 degree / minute respectively. The sampling pitch is 0.02 degree and the preset time is 0.6 second[5].

An induction heater operated at low frequencies and low powers (100 kHz and 100 W), was used to study the energy absorption as the heating rate ($\Delta T/\Delta t$ °C/sec) and the specific absorption rate (SAR W/g) of the $\alpha$-Fe$_2$O$_3$ MNPs was prepared previously.
Result and discussion

To determine the size \( t \) of the \( \alpha-\text{Fe}_2\text{O}_3 \) was prepared, from the XRD data, the peaks positions and the full width at half maximum FWAHM 'B' of the three strongest peaks, shown in the table1, were substituted in the Scherrer's formula (i):

\[
t = \frac{K\lambda}{B \cos \theta}
\]

Where; \( t \) is the size of the crystallite, \( K \approx 0.9 \) is constant depend on the crystallite shape, \( \lambda = 1.4506 \text{ Å} \) is x-ray wavelength of the Cu target, \( B \) is full width at half maximum (FWHM) and \( \theta_B \) is Bragg's angle \([6,7,8]\).

The XRD patterns fig.1 indexing of the prepared \( \alpha-\text{Fe}_2\text{O}_3 \) showed that this sample is cubic. The crystal structure, the size and the lattice parameter in good agreement with published data fig.2. Such a small size indicates that the \( \alpha-\text{Fe}_2\text{O}_3 \) sample is the magnetic nanoparticles MNPs \([9]\).

![Fig.1 XRD for \( \alpha-\text{Fe}_2\text{O}_3 \)](image)

![Fig.2 XRD for \( \alpha-\text{Fe}_2\text{O}_3 \)](image)

**Table1 The parameters of three strongest peaks of \( \alpha-\text{Fe}_2\text{O}_3 \) MNPs XRD pattern**

<table>
<thead>
<tr>
<th>No.</th>
<th>2theta (deg.)</th>
<th>FWHM (deg.)</th>
<th>d (Å)</th>
<th>t (nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>33.12</td>
<td>0.1378</td>
<td>2.7043</td>
<td>56.7</td>
</tr>
<tr>
<td>2</td>
<td>35.6014</td>
<td>0.1574</td>
<td>2.5218</td>
<td>49.9</td>
</tr>
<tr>
<td>3</td>
<td>54.0396</td>
<td>0.0984</td>
<td>1.6970</td>
<td>85.4</td>
</tr>
</tbody>
</table>

**The thermal properties of \( \alpha-\text{Fe}_2\text{O}_3 \) MNPs**

To study the energy absorption of \( \alpha-\text{Fe}_2\text{O}_3 \) MNPs, the heating rate \( \Delta T/\Delta t \) and specific absorption rate (SAR) value of the \( \alpha-\text{Fe}_2\text{O}_3 \) MNPs, a suspension of 1ml de-ionizing (DI) water + 1mg of \( \alpha-\text{Fe}_2\text{O}_3 \) 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 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°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 \( \alpha-\text{Fe}_2\text{O}_3 \) and the heat released towards the environment were equal that is shown in fig.3\([10,11]\).
Fig.3 $\alpha$-Fe$_2$O$_3$ heating rate

The SAR value can be calculated by the following equation

$$SAR = C \frac{\Delta T}{\Delta t} \frac{1}{m_{fe}}$$  (ii)

Where; C= 4.185 J g$^{-1}$K$^{-1}$ is the sample-specific heat capacity which is calculated as a mass weighted mean value of magnetite and water. $\Delta T/\Delta t = 0.03$°C/ sec is the initial slope of the time-dependent temperature curve, $m_{fe}$ = 1 mg is the ferrite content per mg of the sample tube$^{[12]}$.

There are as good as the linear relations in the first rising of the temperature fig.3. The linear relation in 0–10 minutes intervals was used to calculate the SAR value of the $\alpha$-Fe$_2$O$_3$ MNPs by equation $ii$ and it equal 126 W/ g.

Conclusions

The average size of the $\alpha$-Fe$_2$O$_3$ magnetic nanoparticles MNPs was prepared by co precipitation method, was estimated to be 64.0 nm. The maximum temperature was 46 °C and the needed time to reach this temperature was 35 min with the concentration of 1.0 mg of $\alpha$-Fe$_2$O$_3$/ 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 $\alpha$-Fe$_2$O$_3$ MNPs were founded to be 126 W/ g and 0.03 °C/ sec, these values indicating to use this sample in the magnetic hyperthermia treatment MHT.

References

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