Abstract. Currently, the materials based on magnetic nanoparticles present as promising devices, capable of functioning in cancer treatments. In particular, magnetite nanoparticles are very effective in producing a quantity of heat necessary to cause lysis of tumor cells. However, heat distribution from particles must be effective within the body, and then the particles need to have close and homogeneous granulometry. Some factors have a direct influence on the particle size. One of these factors is the temperature synthesis. In this work, Fe$_3$O$_4$ nanoparticles coated with a polymer mixture of polyethylene glycol and polyvinyl pyrrolidone (PEG / PVP) were synthesized and synthesis temperature was varied. The effect of temperature on the particle size was evaluated from granulometry assays (direct analysis). The results indicate the significant participation of the temperature in the nucleation and growth process, and also the particle size distribution of the samples. Thus, temperature is an important parameter in controlling the size of the nanocomposite.

Keywords: magnetite nanoparticles, temperature, particle size.

INTRODUCTION

The magnetic nanoparticles are promise devices to alternative cancer treatments. In particular, magnetite shows good properties of heating when expose to alternating field. It means that the temperature increases at the application site of magnetic nanoparticles. It induces the cell to early apoptosis [1]. The magnetic field is not absorbed by living tissue and may be applied to deeper regions of the human body. When the magnetic particles
are under the influence of a variable magnetic field occurs a temperature gradient due to hysteresis losses. The amount of heat generated depends on the nature of the magnetic material and parameters of the external magnetic field. Tumor cells are destroyed at temperatures higher than 43ºC, while normal cells can survive at high temperatures [2]. However, not all particles are able to produce heat. They must have a specific size between 10 and 100 nm, for biomedical applications [3]. Then, it is very important controlling the size and size distribution of particles.

It is extremely relevant to evaluate the influences of reaction conditions such as: concentration of precursors and reaction temperature because this factors show direct influence at size, size distribution, phase and surface chemistry of nanoparticles [4].

In this work, the synthesis of magnetite nanoparticles was monitored from different values of temperature. And, the effect of temperature on size and size distribution was analyzed. The particles were synthetized by coprecipitation method and they were coated by a polymer mixture of polyethylene glycol and polyvinyl pyrrolidone (PEG / PVP). The material was characterized by direct analysis (Nanosight®) and indirect analysis (Scherrer equation, Langevin model and Rietveld analysis).

**THEORY**

The samples were synthetized by coprecipitation method, according to (A):

\[ \text{Fe}^{2+} + 2\text{Fe}^{3+} + 8 \text{OH}^- \rightarrow \text{Fe}_3\text{O}_4 + 4 \text{H}_2\text{O} \]  

(A)

The adopted synthesis temperatures were: 60, 70, 80 and 90ºC. The samples and their respect temperatures are showed at Table 1:

<table>
<thead>
<tr>
<th>Sample</th>
<th>Temperature [°C]</th>
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<tbody>
<tr>
<td>1</td>
<td>60</td>
</tr>
<tr>
<td>2</td>
<td>70</td>
</tr>
<tr>
<td>3</td>
<td>80</td>
</tr>
<tr>
<td>4</td>
<td>90</td>
</tr>
</tbody>
</table>

The samples were suspended in ultrapure water with no surfactant, according to dilution factor: 1:100 (% p/v).
After synthesis, the samples were dried at 40ºC for 24 hours. Then, the resulted solid was macerated and characterized by Nanosight® and indirect technics (Scherrer equation, Langevin model and Rietveld analysis).

The size distribution was obtained by Nanosight® equipment. This is a direct technique for particle size analysis that the magnetic core and the thickness of the coating layer are considered. The analysis is possible from observing the Brownian motion of the particles.

However, by indirect techniques only the magnetic core is available for analysis. It occurs because indirect techniques are obtained from other measurements which focuses only on magnetic core (for example: XRD and VSM).

The nanoparticle size could be estimated by Scherrer equation and XRD patterns of samples (B):

\[
D_{drx} = \frac{0.9 \lambda}{\Delta \cos \theta_B}
\]  

(B)

Where: \(\Delta = \sqrt{B^2_{med} - B^2_{st}}\); \(D_{drx}\) = average diameter of crystallite; 0.9 = constant that depends on the particle shape (sphere =0.94); \(\lambda\) = the wavelength of the electromagnetic radiation; \(\theta_B\) = Bragg diffraction angle; \(B_{med}\) = half-width (FWHM) and \(B_{st}\) = instrumental correction factor.

The adjustments by Langevin model (C) and using hysteresis curves of samples have also produced data about particle size.

\[
M = M_s \left[ \coth \left( \frac{\mu H}{K_B T} \right) - \left( \frac{K_B T}{\mu H} \right) \right]
\]

(C)

Where: \(M_s\) is saturation magnetization; \(K_B\) is Boltzmann constant; \(H\) is applied field, \(M\) represents magnetic response, \(T\) is absolute temperature (K) and \(\mu\) is magnetic moment of each particle (\(\mu=M_s \pi D^3\)).

The Rietveld analysis was performed by an adjustment in the diffractogram. The refinement was done using the magnetite Bragg parameters. The procedure was satisfactory for all samples, indicating that the magnetic core is composed of Fe\(_3\)O\(_4\).
Table 2 shows the results of particle size data.

Table 2. Particle size of samples

<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>18.57</td>
<td>20.58</td>
<td>99.0</td>
<td>33</td>
</tr>
<tr>
<td>2</td>
<td>15.70</td>
<td>28.74</td>
<td>72.1</td>
<td>26</td>
</tr>
<tr>
<td>3</td>
<td>15.90</td>
<td>22.57</td>
<td>102.0</td>
<td>23</td>
</tr>
<tr>
<td>4</td>
<td>15.71</td>
<td>28.71</td>
<td>46.7</td>
<td>266</td>
</tr>
</tbody>
</table>

According to Karimi at. al. [5] the most suitable particles to *in vivo* applications are between 5-20 nm. The results obtained by Rietveld analysis show that all samples are within the desired range, with good agreement between experimental and theoretical diffraction patterns.

Analyzing the results obtained by the Scherrer method the samples are in good condition for use *in vivo* (10-30 nm). It is noteworthy that, as a report by Kalska-Szostak et. al.[6] the Scherrer formula describes the average size on the coherent diffraction zone that sometimes it is not exactly the same data as the real average particle size. This may cause ambiguity, particularly in the case of coated particles. However, it is a good technique to estimate the particle diameter and it is used in several studies of nanoscale particles.

The parameter $\mu$ from Langevin equation has physical meaning and refers to the magnetic moment of the particles and it is used to estimate the average diameter of particles. From the results it can be seen that the samples can be used *in vitro* (10 ~ 100 nm).
From Nanosight analysis, size distribution was obtained according to the Figure 1:

![Figure 1. Size distribution of samples](image)

From the analysis of Figure 1 it is possible to observe that as the temperature is increased the particle size distribution becomes irregular. The sample synthesized at 60ºC shows small size and homogeneous particle size distribution. It suggests that milder synthesis temperatures contribute to narrow particle size distribution. Furthermore, there is an indication that temperature at 60 º C is suitable to adsorption of the coating and results in a thin layer around the core. It contributes to good protection against oxidation and particle isolation (avoiding formation of agglomerates). As the temperature of the reaction medium is high, there is an increase in the irregularity of the peaks in the particle size distribution curves, indicating the coexistence of fine and agglomerated particles. The sample 4 (synthesized at 90ºC) showed the worst result (large particles and irregular particle size distribution).

Temperature is a factor that influences strongly the nucleation and growth mechanisms [7]. By increasing the temperature of system, the agitation of molecules increases. The results indicate that agitation disturbs the reaction medium and it causes irregularity in the distribution of the particles.
Conclusions

The temperature is an important factor to be considered in the synthesis of magnetite nanoparticles. It is due to strong influence in the nucleation and growth mechanisms. When the temperature increases, the particle size becomes bigger and particle size distribution shows irregular shapes. It indicates that mild temperatures contribute to form a thin layer around the magnetic core, in other words, it contributes to a proper adsorption of the coating and high temperatures cause uncontrolled adsorption. Temperature around 60ºC is appropriated to precipitate magnetite nanoparticles that show small size and regular particle size distribution.

Therefore, is very important to control the heating rate of synthesis. It can ensure magnetic nanoparticles with a thin layer and satisfactory coating against oxidation.

ACKNOWLEDGEMENTS

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REFERENCES


