Cancer cells extinction through magnetic fluid hyperthermia treatment produced by superparamagnetic Co-Zn Ferrite nanoparticles

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Supplementary Information

The heat dissipation by superparamagnetic nanoparticles is given by the following equation

\[
P = \mu_0 \chi'' fH^2
\]  \hspace{1cm} (4)

where \( P \) is the heat dissipation value, \( \mu_0 \) permeability, \( \chi'' \) denotes the AC magnetic susceptibility (imaginary part), \( f \) represents the frequency of the applied AC magnetic field, and \( H \) is the strength of the applied AC magnetic field. The susceptibility (\( \chi \)) is defined as \( M/H \) and can be expressed in terms of real (\( \chi' \)) and imaginary (\( \chi'' \)) terms (i.e. complex function) in an AC field. The imaginary term is related to heat-dissipation. If an assembly of MNPs is put into an alternating magnetic field of frequency \( f \) and amplitude \( \mu_0 H_{\text{max}} \), the amount of heat released by the magnetic nanoparticles during one cycle of the magnetic field simply equals the area of their hysteresis loop, which can be expressed as.

\[
A = \int_{-H_{\text{max}}}^{+H_{\text{max}}} \mu_0 M(H) dH
\]  \hspace{1cm} (5)

Then the SAR is

\[
\text{SAR} = Af
\]  \hspace{1cm} (6)

where \( f \) is the frequency of the AC magnetic field and it is expressed as \( f = \omega/2\pi \), \( M \) Magnetization and \( H \) applied magnetic field.
The specific absorption rate (SAR) was calculated by using following relation.

\[
SAR = c \frac{\Delta T}{\Delta t} \frac{1}{m_{magn}}
\]

(7)

where \( c \) is the sample-specific heat capacity, which was calculated as a mass weighted mean value of magnetite and water. The heat capacity of CZF is negligible because of its low concentration, and thus a heat capacity for water (4.18 Jg\(^{-1}\) K\(^{-1}\)) was taken as the sample’s heat capacity. \( \Delta T/\Delta t \) is the initial slope of the time-dependent temperature curve. Here, we considered time up 1–5 min to calculate the slope. The value of \( m_{magn} \) is considered as the amount of magnetite per total amount of manganite and water. The estimated SAR values were calculated by using equation (7) and were graphically represented. The induction heating ability of MNPS was tested at different currents (200–400 A i.e., 167–335 Oe) for 10 min, with the variation of particle concentration from 1, 2 and 5 mg mL\(^{-1}\) in water.