Adiabatic versus non-adiabatic determination of specific absorption rate of ferrofluids

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In magnetic fluid hyperthermia for cancer treatment [1] a biocompatible fluid based on magnetic nanoparticles is introduced into tumours, so that the heat generated by the nanoparticles under an alternating magnetic field destroys cancerous cells. The minimization of the invasive character of this technique requires the use of magnetic nanoparticles with large heating power, that allowing the clinical dose to be reduced.

The heating efficiency of these fluids is determined by the specific absorption rate (SAR), defined as $SAR = (1/m_{MNP})\cdot C\cdot(\Delta T/\Delta t)$, where m_{MNP} is the mass of dissipating material , C, the heat capacity of the whole sample, and ΔT, the sample temperature increase during the ac-field application interval, Δt.

Current non-adiabatic SAR installations (see [2,3] for example) cannot use the above incremental expression since heat losses (conduction, radiation, convection) are not minimized. Then, an approximate procedure is followed, in which SAR is calculated as SAR=$C\ \beta\ /\ m_{MNP}$, where β is the initial slope of the temperature-time curve during ac-field application. However, this initial-slope method may derive wrong SAR values, even in adiabatic conditions. On the one hand, if a sample does not present high diffusivity values and/or the heat sources (MNP) are heterogeneously distributed (for example, in nanocomposites), the onset of the magnetic field would create a transient-state temperature distribution. Then, depending on the part of the sample in contact with the sensor, different temperature-versus-time trends can be recorded, and initial slopes may not reproduce the real generated heating power. On the other hand, heat losses in non-adiabatic installations may be significant at early times, and be present in the temperature-versus-time slope even in the initial linear trend.

To overcome these limitations, we have developed the first adiabatic magnetothermal setup [4], in which the sample undergoes only a weak net heat exchange with the surroundings. In such conditions, the generated heat can be considered to be entirely invested in the sample temperature raise, allowing direct measurement of ΔT, and providing more precise SAR values.

The measurements performed on a copper sample provided comparison between experimental and theoretical values: adiabatic conditions gave SAR values only 3% higher than the theoretical ones, while the typical non-adiabatic method underestimated SAR by 21%. These results have allowed to evaluate for the first time the accuracy in SAR determination by calorimetric methods.

Moreover, we have pointed the improvement of the incremental over the initial-slope method by estimating the errors arising from the use of the initial-slope approximation both in adiabatic and in non-adiabatic conditions [5]. For this purpose, we carried out several experiments on a commercial magnetite aqueous ferrofluid from Chemicell GmbH, namely the fluidMAG-UC/A, with different isolating conditions, temperature sensors and sample-sensor contacts.

Our comparative experiments have demonstrated that non-adiabatic determination of SAR may cause small to appreciable errors, depending on factors such as sample characteristics, type of temperature sensor, sample-sensor contact, isolating degree, etc. Moreover, it is quite difficult to infer or control, and consequently, to correct such errors. Non-adiabatic determination allows comparison between different samples measured in the same setup and with the same conditions, but may not give the correct SAR values to be used to reproduce final temperatures in 'real' applications, that is, in tissues or patients. In addition, the use of different non-adiabatic setups and measuring conditions makes the comparison of results from different authors in the literature very difficult. All these problems could be minimized by using an adiabatic incremental determination of SAR.

References:

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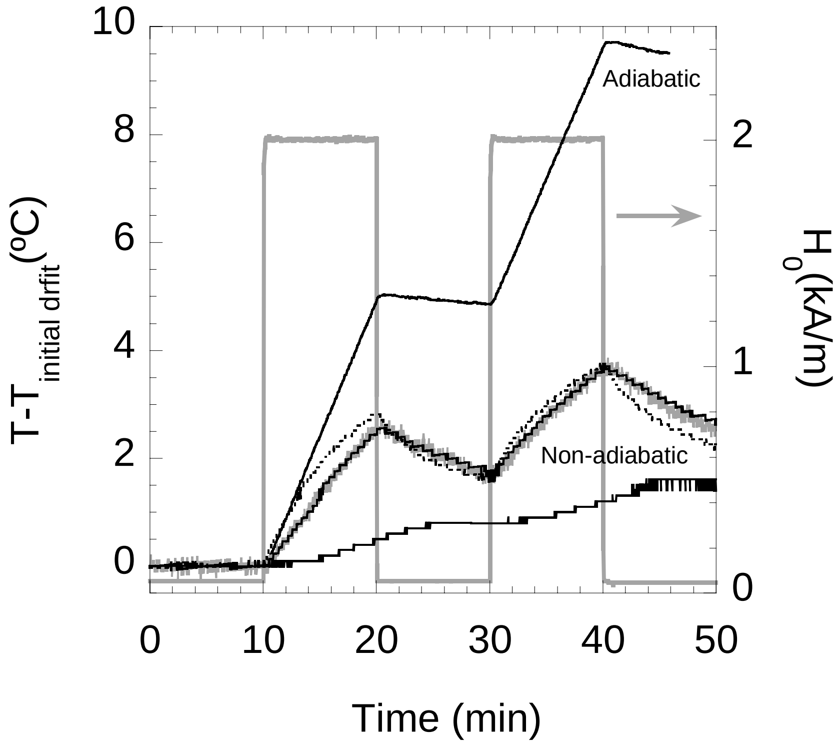
Figure:



Comparison between adiabatic and non-adiabatic temperature-versus-time characteristics of fluidMAG-UC/A at an ac-field frequency of 109 kHz. Non-adiabatic experiments were performed with different isolating conditions, temperature sensors and sample-sensor contacts. The ac-field amplitude sequence corresponds to the grey line, right scale.