Hysteresis losses and specific absorption rate measurements in magnetic nanoparticles for hyperthermia applications.

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Magnetic hyperthermia exploiting nanoparticles is currently a significant subject of research in the field of tumour treatment, with many open questions concerning the best choice of material, particles size and dose. A major issue consists in the difficulty of obtaining reproducible measurements of the specific absorption rate, i.e. of the amount of heat that is released by the magnetic nanoparticles submitted to an alternating electromagnetic field usually in the range of a few hundreds of kHz and with amplitudes of a few tens of mT.

To address this open issue, the specific absorption rate (SAR) of different families of particles (including magnetite and other Fe oxides, and ferrites with different substituting elements such as Co, Ni and Zn), prepared with different methods and having different sizes and shapes, has been measured using three approaches: static hysteresis loops areas, dynamic hysteresis loops areas and hypertermia of a water solution [1]. For dynamic loops and thermometric measurements, specific experimental setups have been developed, that operate at comparable frequencies (~69 kHz and ~100 kHz respectively) and rf magnetic field peak values (up to 100 mT). The hyperthermia setup has been fully modelled to provide a direct measurement of the SAR of the magnetic particles by taking into account the heat exchange with the surrounding environment in non-adiabatic conditions and the parasitic heating of the water due to ionic currents. Dynamic hysteresis loops are shown to provide an accurate determination of the SAR (see Fig. 1 for an example on a Ni-Zn ferrite) except for superparamagnetic samples, where the boundary with a blocked regime could be crossed in dynamic conditions. Static hysteresis loops consistently underestimate the specific absorption rate but can be used to select the most promising samples. A means of reliably measuring the SAR of magnetic nanoparticles, within the general subject of metrological traceability in medicine with a specific focus on magnetic hyperthermia, has therefore been developed by exploiting different approaches and by fully modelling the heat exchange processes in a custom-developed hyperthermia setup. The validity of the proposed methods is discussed.

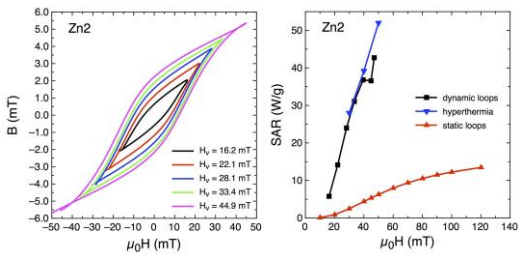

Figure 1. Dynamic hysteresis loops and specific absorption rate comparisons with three different techniques for a Ni-Zn ferrite sample.

[1] M. Coïsson, G. Barrera, F. Celegato, L. Martino, S.N. Kane, S. Raghuvanshi, F. Vinai, P. Tiberto, BBA General Subjects **1861** (2017) 1545.