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From Magnetic Fluid to Immobilized State: Reproducible Heating of Iron Oxide Nanoparticles under AMF and RMF

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Magnetic heating of iron oxide nanoparticles arises from Néel relaxation, Brownian rotation, and, in interacting systems, hysteretic losses; the relative contribution of each channel depends on surface chemistry, dipolar coupling, and mechanical confinement. Many hyperthermia studies still optimize specific absorption rate in liquid dispersions, although immobilization in tissue-like environments can suppress Brownian rotation and change the dominant dissipation pathway. Here we focus on reproducible heating after immobilization rather than on peak heating in an ideal magnetic fluid.

We study superparamagnetic iron oxide nanoparticles (8-12 nm), bare and coated with poly(caffeic acid) (PCA), poly(syringic acid) (PSA), polydopamine (PDA), or polynorepinephrine (PNE), under alternating magnetic fields (AMF) and high-frequency rotating magnetic fields (RMF). The coatings are used to tune interparticle interactions and particle-matrix coupling. The specific absorption rate (SAR) is measured calorimetrically for field amplitudes H = 1-5 kA/m and frequencies f = 100-300 kHz in liquid dispersions and hydrogels of different stiffness. Ultrasound-based viscoelastic measurements provide independent characterization of the evolving mechanical environment during gelation.

By combining intra-day and inter-day measurements with controlled variation of field conditions, gel stiffness, and polymerization time, we assess how confinement changes the balance between Brownian and Néel contributions to dissipation and how it modifies the relative efficiency of AMF and RMF excitation. This study provides a physically grounded route for selecting nanoparticle formulations with a reliable heating response under mechanically heterogeneous conditions relevant to magnetic hyperthermia.

Type:

Poster