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A smart combination: A study on viscosity influences on SMART RHESINS using COMPASS

J. Günther[a,*] · J. Feye[b,c] · T. Kampf[a,d] · M. A. Rückert[a] · T. Reichl[a] · R. Tietze[e] · P. W. Roesky[c] · E. S. Rösch[b,c] · V. C. Behr[a] · P. Vogel[a,f]

[a]Department of Experimental Physics 5 (Biophysics), Julius-Maximilians-University Würzburg, Germany
[b]Faculty of Engineering, Baden-Württemberg Cooperative State University Karlsruhe, Germany
[c]Institute of Inorganic Chemistry, Karlsruhe Institute of Technology (KIT), Germany
[d]Department of Diagnostic and Interventional Neuroradiology, University Hospital Würzburg, Germany
[e]Department of Otorhinolaryngology, Head and Neck Surgery, Section of Experimental Oncology and Nanomedicine (SEON), Else Kröner-Fresenius-Stiftung-Professorship, University Hospital Erlangen, Germany
[f]Pure Devices GmbH, Rimpar, Germany
*Corresponding author, email: Johanna.Guenther@physik.uni-wuerzburg.de

Abstract

To enable reliable quantification of magnetic nanoparticles, new methods for preventing interaction of particles with their physiological environment are necessary. An innovative approach are SMART RHESINs, where conventional nanoparticles are encapsulated in hollow nanospheres. Here, a detailed study on Perimag® based SMART RHESINs has been performed utilizing critical offset magnetic particle spectroscopy (COMPASS) to show that the influence of the surrounding medium, which was varied in viscosity, on the particle system can be suppressed using SMART RHESINs.

I. Introduction

Magnetic particle imaging (MPI) is an emerging imaging modality based on magnetic nanoparticles (MNP) as a tracer with important features to further develop medical diagnostics and treatment [1]. One of them is the possibility of quantifying the iron content of the tracer due to its linearity with the particle signal [2]. However, for future human application quantification is challenging due to the interaction of the particles with their physiological surroundings. This change of their physiochemical properties can destroy the linearity of signal strength and iron content [3] and significantly change their relaxation [4]. An innovative approach to avoid this is to encapsulate MNP tracers in a polymer nanosphere enabling a superparamagnetic magnetite architecture made of phenolic resin hollow spheres (SMART RHESIN), which additionally can be coated with luminescent Eu(III) complex-containing silica nanoparticles [5]. Here, we show a comparison of conventional and encapsulated Perimag® (Micromod GmbH, Germany) for different viscosities of surrounding media. This is done using the novel method critical offset magnetic particle spectroscopy (COMPASS) that is highly sensitive towards changes of the particle mobility and thus their relaxation behavior, which makes the method excellently suited for distinguishing the behavior of MNP for varying viscosities of their environment [6].

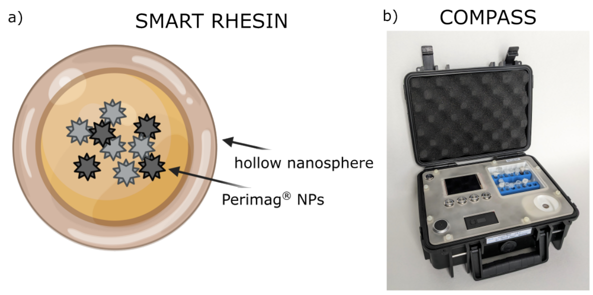

Figure 1: Structure of SMART RHESINs. b) portable COMPASS measurement device.

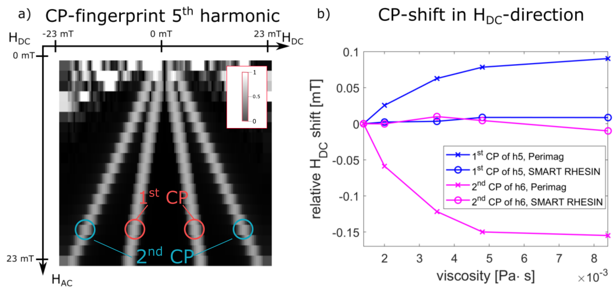

Figure 2: a) exemplified CP-fingerprint pattern of the 5^{th} harmonic of SMART RHESINs with 10% of glycerol. It depicts the derivative of the phase of the complex signal spectrum in H_{DC}-direction. b) Shift of two CPs (5^{th} and 6^{th} harmonic) in H_{DC}-direction relative to the sample containing 10% glycerol at H_{AC} = 18.4 mT for SMART RHESINs and Perimag®.

II. Materials and methods

To fabricate hollow nanospheres (SMART RHESIN) based on a soft-templating technique, 27 mg sodium oleate (SO), 17 mg Pluronic P123 ($(HO(CH_2CH_2O)_{20}$-$(CH_2CH(CH_3)O)_{70}(CH_2CH_2O)_20H)$) and 588 µL MNP solution (Perimag®) were blended and filled up with deionized H_2O to a final volume of 7 mL. The solution was mixed with 69 mg 2,4-dihydroxybenzoic acid (DHB) and 56 mg hexamethylenetetramine (HMT) dissolved in 22 mL deionized H_2O to produce an emulsion. In a microwave vessel and under hydrothermal condition (150 °C), HMT decomposed to formaldehyde and ammonium. Afterwards, the formaldehyde product polymerized with DHB on the surface of the emulsion droplets, yielding hollow polymer nanospheres containing MNPs, which is outlined in figure 1a).

The method of choice to demonstrate the shielding of MNP from the environment by SMART RHESINs is COMPASS. It extends conventional magnetic particle spectroscopy (MPS) by adding an offset field (H_{DC}) to the oscillating field (H_{AC}). This leads to the occurrence of critical points (CP) in the phase of the higher harmonics of the complex COMPASS spectrum at specific combinations of H_{AC} and H_{DC}. CPs are characterized by a steep change in phase. Especially the CP positions are very sensitive towards changes of the MNP mobility, which is significantly influenced by the viscosity of surrounding media. The COMPASS measurement device shown in figure 1b) is very small and thus, it even fits into a portable case.

III. Results and discussion

Here, the CP positions of Perimag® and Perimag® in hollow nanospheres from the same batch are compared. Two sample series with glycerol content varying from 10 to 50% in volume and constant iron content were prepared and COMPASS measurements over a range from 0 mT to 23 mT for H_{AC} and H_{DC} were performed.

By looking at selected CP of the 5^{th} and 6^{th} harmonic, it is visible that their positions change significantly with increasing glycerol content for Perimag®, while it only shows small variations for the encapsulated Perimag® particles. This qualitative comparison suggests that the relaxation and thus the mobility of the SMART RHESIN particles is less affected by viscosity changes than free Perimag® in suspension.

IV. Conclusion

Using the novel COMPASS measurement technique, it can be shown that shielding of MNP against influences of their environment can be achieved by surrounding MNP with a hollow nanosphere. This was demonstrated on the example of Perimag® based SMART RHESIN and by varying the viscosity of the medium with a glycerol water mixture. The results have shown that a significant change in the CP position, the characteristic measurement parameter of the COMPASS method with high sensitivity towards the particle mobility, only occurs for free Perimag® particles. In contrast, this parameter was less influenced for SMART RHESIN particles based on Perimag®.

Author's statement

Conflict of interest: Authors state no conflict of interest. Informed consent: Informed consent has been obtained from all individuals included in this study.

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