Comparison of Superparamagnetic Quantifier and Magnetic Particle Spectroscopy

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I. Introduction

In the design process of superparamagnetic iron oxide nanoparticles (SPIONs) it is inevitable to have a consistent characterization technique. Such a device enables you to check quickly what the effect is of a change in the process. For example, used chemicals and their precursor concentration, temperature, and alkalinity of the medium are factors that influence the produced particles and their magnetic properties [1].

In order to characterize SPIONs, many techniques can be used, including the Superparamagnetic Quantifier (SPaQ) and Magnetic Particle Spectroscopy (MPS). The SPaQ was developed at the University of Twente for the evolution of DiffMag. DiffMag is a procedure to selectively detect SPIONs [2]. In this research, the MPS system of the TU Braunschweig was used [3].

II. Materials and Methods

Both systems make use of Faraday detection, using copper excitation and detection coils. The detector has a gradiometer configuration to compensate for the large excitation signal. The advantages of induction coils are the ease of realization, fast measurements and high signal to noise ratio.

The derivative of the magnetization curve (*m(H)* curve) is measured in both systems, which is related to the point spread function in MPS [4]. In this contribution, two types of particles (Resovist™ (Bayer Schering Pharma GmbH) and SHP-25 (Ocean Nanotech)) were measured in both devices to evaluate differences in the measured magnetization curves. The differences, both in resulting curve and measurement method, are summarized in Table 1.

III. Results and Discussion

The resulting curves are shown in Fig. 1 and Fig. 2, for the SPaQ and MPS measurements, respectively. The MPS measurements show a clear hysteresis loop, whereas the SPaQ measurements show minor hysteresis. This can be explained by the fact that the entire curve is measured in every period of the sine in de MPS measurements, leading to large influence of particle dynamics. SPaQ measurements, on the other hand, can be considered as quasi-static, due to the small AC amplitude.

The sample influences the height and width of the measured curve. In MPS, the distance between the peaks (e.g. the width of the hysteresis loop) changes as well as a response to particle dynamics.

IV. Applications

Measuring the magnetization curve enables the characterization of SPIONs. Many parameters can be deduced from the curves, such as the core diameter, hydrodynamic diameter, and anisotropy [5]. Additionally, these measurements can provide information about the environment of the particles. As a result, SPIONs can be studied in biological systems, such as blood [6] and lymph nodes.

Characterization of SPIONs in lymph nodes provides information that is useful for the sentinel node biopsy (SNB). SNB is a tool to determine the lymph node status of cancer patients [7]. Consequently, it can be seen if the tumor has metastasized and the patient prognosis and treatment can be personalized. In SNB, a tracer material is injected in or close to the tumor. The tracer will follow the natural path through the lymph nodes and accumulate in the sentinel node. The sentinel node can be found using a dedicated detector, and examined for metastases after surgical removal.

As tracer material, SPIONs can be used in combination with a handheld DiffMag probe [2]. When the SPIONs accumulate in a lymph node, the particles will be (partially) immobilized and their magnetic behavior will change. To evaluate the resulting effect on the DiffMag signal, SPaQ measurements can be utilized. This application is superior in the SPaQ compared to MPS, because of the direct correlation to DiffMag.

A last application of the SPaQ is to use it for *ex-vivo* SNB [8]. In rectal cancer it is recommended to remove all regional lymph nodes, since it reduces the chance of local recurrence [9]. If the SPIONs are injected *in-vivo* during surgery, all lymph nodes can be dissected and measured in the SPaQ *ex-vivo*.

V. Conclusions

In conclusion, both systems are capable of measuring the magnetization curve, which results in invaluable information on particle properties for many applications.

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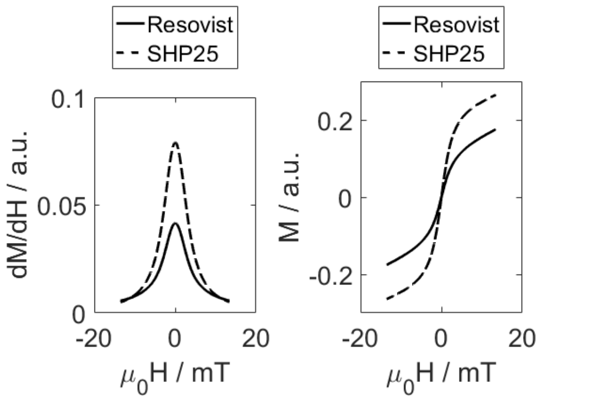

Figure 1: *SPaQ results, measured on Resovist^{TM} and SHP-25 samples containing 750 µg iron in a total volume of 150 µl.*

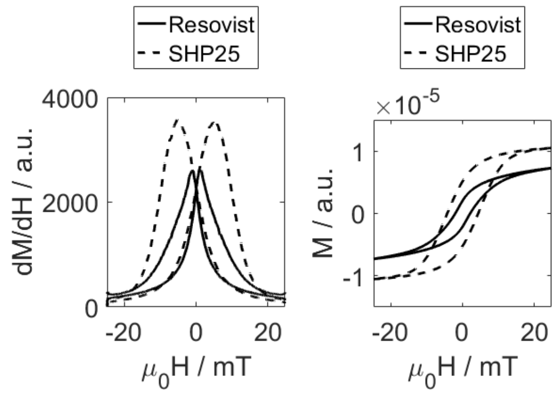

Figure 2: *MPS results, measured on Resovist^{TM} and SHP-25 samples containing 750 µg iron in a total volume of 150 µl.*

Table 1: *Differences between SPaQ and MPS*

	SPaQ	**MPS**
Excitation sequence	Small AC amplitude (1.3 mT)	Large AC amplitude (25 mT)
	DC offset (up to 13.3 mT)	No DC offset
Measurement time	5 seconds	0.5 seconds
Measurement	Quasi-static	Dynamic
Magnetization curve	Minor hysteresis	Hysteresis